MORPHOLOGICAL PROCESSING IN CHILDREN: AN EXPERIMENTAL STUDY OF GERMAN PAST PARTICIPLES

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November 2013

Doctoral Thesis submitted to the Faculty of Human Sciences
at the University of Potsdam
in partial fulfillment of the requirements for the degree
Doctor of Philosophy
in Allgemeine Sprachwissenschaft

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Thesis Defense:	Potsdam, 09 May 2014

Published online at the
Institutional Repository of the University of Potsdam:
URL http://opus.kobv.de/ubp/volltexte/2014/7058/
URN urn:nbn:de:kobv:517-opus-70581
http://nbn-resolving.de/urn:nbn:de:kobv:517-opus-70581

Acknowledgments

Ich danke ganz herzlich Harald Clahsen für seine intensive Betreuung während der gesamten Doktorarbeit, für seine maximal fördernde Begleitung, für viele gute Gespräche und für seine Liebe zum Detail. Ich durfte vier Jahre lang davon profitieren, dass Harald alles, was er tut, mit vollstem Engagement tut.

Ich danke den Teilnehmern meiner Studie. Besonderer Dank gebührt Frau Jackisch von der Clemensschule in Hornburg, Ulrike Bruschke und Gunter Meißner von der Katholischen Kindertagesstätte St. Bernward in Salzgitter-Steterburg und Dr. Christine Lehmann dafür, dass sie mir Türen geöffnet haben.

I thank Marion Owen for proof reading my work.

Ich danke Wegbegleitern, die Freunde geworden sind; den Mitgliedern der Psycholinguistic Research Group 2009-2011 an der University of Essex und den Mitgliedern des Potsdamer Instituts für Mehrsprachigkeit 2011-2013.

Ich danke dem Cusanuswerk für eine Förderung, die immer über finanzielle Aspekte hinausging; besonders danke ich Dr. Manuel Ganser für seine engagierte Beratung in vertrauensvoller Atmosphäre.

Ich danke meiner Familie und meinen Freunden.

Ich danke Sevgilim.

Abstract

An important strand of research has investigated the question how children *acquire* a morphological system using offline data from spontaneous or elicited child language. Most of these studies have found dissociations in how children apply regular and irregular inflection (Marcus et al. 1992, Weyerts & Clahsen 1994, Rothweiler & Clahsen 1993). These studies have considerably deepened our understanding of how linguistic knowledge is acquired and organised in the human mind. Their methodological procedures, however, do not involve measurements of how children process morphologically complex forms in real time. To date, little is known about how children process inflected word forms.

The aim of this study is to investigate children's processing of inflected words in a series of on-line reaction time experiments. We used a cross-modal priming experiment to test for decompositional effects on the central level. We used a speeded production task and a lexical decision task to test for frequency effects on access level in production and recognition. Children's behaviour was compared to adults' behaviour towards three participle types (*-t* participles, e.g. *getanzt* 'danced' vs. *-n* participles with stem change, e.g. *gebrochen* 'broken' vs. *-n* participles without stem change, e.g. *geschlafen* 'slept').

For the central level, results indicate that *-t* participles but not *-n* participles have decomposed representations. For the access level, results indicate that *-t* participles are represented according to their morphemes and additionally as full forms, at least from the age of nine years onwards (Pinker 1999 and Clahsen et al. 2004). Further evidence suggested that *-n* participles are represented as full-form entries on access level and that *-n* participles without stem change may encode morphological structure (cf. Clahsen et al. 2003). Out data also suggests that processing strategies for *-t* participles are differently applied in recognition and production.

These results provide evidence that children (within the age range tested) employ the same mechanisms for processing participles as adults. The child lexicon grows as children form additional full-form representations for *-t* participles on access level and elaborate their full-form lexical representations of *-n* participles on central level. These results are consistent with processing as explained in dual-system theories.

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1 Introduction

The architecture of language in the human mind has been of great interest to many disciplines, including theoretical linguistics, psycholinguistics, psychology and the cognitive sciences. One notable characteristic of language is its productive use. Speakers can understand and produce an infinite number of words and sentences that they have never encountered before, such as ‘I instagrammed a picture of you’ or ‘to reinstagram’ (provided they know that instagram is an online platform for pictures). Productive use of the language can also be observed in children (Chomsky 1957, 1965; Berko 1958). Recent decades have seen rapid advances on the question of whether mental mechanisms can explain the productive use of language. All researchers on language in the human mind agree that language relies on a memory system that stores the sounds and meanings of words and, possibly, grammatical information. However, researchers strongly disagree over whether the language system also contains grammatical rules which combine memorised forms to form complex expressions. For example, the word forms ‘talk’, ‘talked’, ‘talks’ and ‘talking’ could be stored in the mental lexicon as four different entries [talk], [talked], [talks] and [talking]. Alternatively, they could have a single entry [talk] in the mental lexicon, together with grammatical rules which add ‘-s’ to form the 3rd person singular present tense (‘talks’); ‘-ing’ to form the present progressive (‘talking’); or ‘*-ed*’ to form the past tense (‘talked’). The latter idea was proposed by traditional generative approaches (e.g. Chomsky & Halle 1968; Halle & Mohanan 1985) which claimed that the memory system only stores small components of words, known as morphemes (such as $[talk]_V$), and that grammatical rules combine them to form complex expressions.

Psycholinguists have tested these hypotheses empirically and asked whether grammatical rules affect how words are mentally represented and processed. They have tested the concepts of storage and computation on, for example, the phenomenon of inflected words. Many inflected words consist of two or more overt morphemes. Some can be transparently dissected into their morpheme components (e.g. walked → walk+ed, houses→ house+s, love+ly→ lovely), which suggests that these inflected words could easily be stored as their component parts and their surface forms computed by linguistic rules. Other inflected words are less transparent and may need to be stored as full forms. For example, the stem $[go]_V$ plus suffix *-ed* does not yield the correct past-tense form ‘went’. The question of how far words are stored as their morphological constituents and how far they are mentally (de)composed by linguistic rules has been the focus of major debate in psycholinguistics.

For many years, the scientific debate on the mental representation and processing of inflected forms focused on the English past-tense inflection. The past tense has been of theoretical interest because it involves two very different phenomena. Pinker (1997) argued that past-tense forms are easily classified into regular default forms, which can be formed by adding *-ed* (e.g. talk → talked, walk → walked), and irregular, non-default forms (e.g. brought, sang). In Pinker's understanding, the regular past-tense inflection is the English default past-tense inflection. It is productively applied to new words, as experiments on non-words have consistently reported for adults and children. Irregular past-tense inflection is applied unpredictably to around 180 base verbs. It is generalised to non-words only under specific phonological circumstances (e.g. Prasada & Pinker 1993; Weyerts & Clahsen 1994). Although the past tense has been one of the main empirical phenomena used in the study of dual and associative models of language (McClelland & Patterson 2002; Pinker & Ullman 2002: 457), it has become clear that the English past-tense inflection is confounded with a number of properties (e.g. Bybee 1999; Dabrowska 2001). One of these is the affixation process. Regular past-tense forms undergo suffixation 'add *-ed*' (e.g.walk + ed → walked) while irregular past tense forms do not. Instead, they require unpredictable changes to the verb stem (e.g. take → took) and unpredictable suffixation (e.g. bring → brought). Another confound is that there are subgroups of phonologically similar forms among irregular past-tense forms (e.g. bring, sing) but this is less true of the regular past-tense forms (Bybee & Moder 1983; Pinker & Prince 1988; but see Dabrowska 2001: 551). Furthermore, frequency is confounded with inflectional type: *-ed* past-tense forms have a higher type frequency and token frequency than irregular past-tense forms (e.g. Bybee 1995; Marchman 1997).

In response to these criticisms, Clahsen suggested that the German past participle formation[1] offers an alternative for the investigation of dissociations of inflected forms (e.g. Marcus et al. 1992: 166ff; Clahsen 1999). Clahsen (1999: 994) identified the *-t* participle without stem changes

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[1] The German past tense, unlike that of English, is not suitable for testing with adults or children. It is used mostly in written language but rarely in spoken language, and is mostly applied to auxiliaries (*hatte* 'had', *war* 'was'). It emerges late in child language production. Past participles, in contrast, are part of the frequently used present perfect, which emerges early in child language production, before the age of three.

as the German default participle inflection, like the English *-ed* past tense. In addition, 'regular' and 'irregular' forms of the German past participle system are very similar with respect to their frequency and their phonological and orthographical transparency. The frequency of *-n* and *-t* participles is about evenly distributed across German *-t* and *-n* past participles (see section 2.1.3 for discussion). German *-t* and *-n* past participles follow the same affixation process. As shown in (1), participles take a prefix *ge-* and the suffix *-t* or *-n*. Participles like *getanzt* 'danced' take the *-t* suffix and participles like *gegriffen* 'grabbed' take the *-n* suffix. Because of these convenient properties, German past participles have been used to test the relevance of linguistic rules in the mental representation and processing of inflected default and non-default forms.

(1)

tanzen [tantsn] 'to dance' → getanzt

greifen [graɪfn] 'to grab' → gegriffen

Language acquisition studies were the starting point for the debate on the mental representation of inflected words (Berko 1958). Researchers described the remarkable amount of productivity in children's language production. The productivity of children's language production was mainly revealed in production errors such as *gegeht 'goed' or *zwei Kinders 'two childs'. Children produce incorrect words such as *gescheint 'shined' instead of *geschienen* or *gegeht 'goed' instead of *gegangen*, applying the default *-t* suffix to forms that require the *-n* suffix, but the reverse is rarely observed (e.g. Chomsky 1959; Marcus et al. 1992; Clahsen & Rothweiler 1993; Weyerts 1997; Szagun 2011). Researchers endeavoured to explain these findings within different acquisition theories. Some suggested that default and non-default forms were represented differently in children's language systems (e.g. Marcus et al. 1992, 1995; Prasada & Pinker 1993; Clahsen 1999) while others explained the dissociative behaviour of default and non-default forms by differences in how often they occur in the language (e.g. *-ed* is more frequent than *sing – sang*), and if inflected forms of the same verb resemble each other orthographically and phonologically ('walks' is more similar to 'walked' than 'goes' is to 'went') (e.g. Rumelhart & McClelland 1986; MacWhinney & Leinbach 1991; Marchman 1997; Bybee 1999).

Studies on child language acquisition have relied on off-line methods to learn more about children's mental representation of morphologically complex forms. However, these methods do not give insights about the mental strategies involved in children's real-time processing. Meanwhile, new on-line methods have been developed to investigate mental strategies involved in real-time processing and they have mainly been used to investigate *adult* language processing: speeded production (e.g. Prasada et al. 1990, Clahsen, Hadler & Weyerts 2004), cross-modal priming and masked priming (Stanners, Neiser, Hernon & Hall 1979; Sonnenstuhl, Eisenbeiss & Clahsen 1999) and brain studies using event-related potentials (ERP) (e.g. Lück, Hahne & Clahsen 1997; Ullman 2001a, 2001b), showing a clear difference between the processing of default forms and non-default forms (Pinker 1999, Clahsen 1999, Pinker & Ullman 2002). Results for adults may not be transferrable to children because children and adults differ in important ways. Children's cognitive capacities, for example, are not fully developed; these may affect the production of inflected word forms in children. Also, the child's lexicon contains fewer entries than that of the adult and may be less elaborated in terms of phonological information, semantic information and associations between lexical entries. So far, only a few studies have applied psycholinguistic on-line methods to investigate the real-time processing of complex forms in children (Clahsen, Hadler & Weyerts 2004; Clahsen, Lück & Hahne 2007). The results have indicated differences in morphological processing between adults and children, even for children of school age (Clahsen, Hadler & Weyerts 2004; Clahsen & Felser 2006; Clahsen, Lück & Hahne 2007). However, we still know relatively little about the role of morphological structure in child language processing.

My own study, described in Chapter 5 and the subsequent chapters, tries to fill this gap and examines the role of morphological structure in primary-school-age children. The processing of German *-t* participles (*tanz – getanzt* 'danced'), *-n* participles without stem change (*schlaf – geschlafen* 'slept') and with stem change (*brech – gebrochen* 'broken') was investigated in three reaction time experiments. Speeded production was used to test for full-form frequency effects in the production of inflected words. Cross-modal priming was used to investigate decomposition on a central representation level. Lexical decisions were employed to look for full-form frequency effects in the recognition of inflected words. The behaviour of native German children (6–11 years) was investigated, as well as that of a control group of adult native speakers of German. German past participles were studied, as they allow for comparing the role of the suffix (comparing *-t* vs. *-n* without stem change) and the role of phonological/orthographic similarity (by comparing *-n* with stem change to *-n* without stem change). The results from children were compared to those from adults to find out whether children's mental mechanisms are similar to those in adult morphological processing. The results from younger children were compared to those from older children to detect potential developmental shifts in processing patterns depending on age.

The thesis is organised as follows. Chapter 2 discusses the treatment of inflected forms in linguistic theories. The representation of inflected forms is reviewed, in particular the question of whether they are represented according to their morphological structure. Chapter 3 deals with the acquisition of inflected forms. We will review common observations about children's production and, in particular, highlight production errors which reflect the productive use of inflectional affixes. We will discuss how approaches to language acquisition account for these observations. This discussion is followed by a review of previous acquisition studies, specifically focusing on results for the acquisition of English past-tense forms and German past participles. Chapter 4 provides background information for current theories of morphological processing. We will compare empirical studies on adults and children and discuss how current theories may be applicable to children. We will go on to compare empirical studies on comprehension and production and discuss whether they rely on the same or different mental strategies, at least in different experimental tasks. Chapter 5 serves as an introduction to the empirical Chapters 6, 7 and 8. It presents the research questions for the current study that tackle the issues presented in the three preceding chapters. It will then introduce the experimental methods used here to study morphological processing. Chapter 6 presents a study of speeded production to test for the effect of full-form frequency on an access level in the production of inflected words. Chapter 7 investigates morphological processing in a cross-modal priming experiment to assess the decomposition of inflected forms on a central representation level. Chapter 8 reports on a study of lexical decisions to test for the influence of full-form frequency on an access level in the recognition of inflected words. Chapter 9 discusses the results of these empirical investigations. In particular, we will identify differences and similarities in processing strategies between adults and children. These differences are then further investigated to see if they can be explained in terms of general processing capacities or whether they reflect fundamental differences between adult and child morphological processing. We also discuss what the results tell us about the representation of *-n* and *-t* participles and what our findings mean for current theories of morphological processing. We also compare the processing effects observed in the production task to those observed in the recognition task to identify modality-specific experimental effects. The chapter finally points out limitations of the present study and suggests directions for future research.

2 Linguistic Theories of Inflection

This chapter discusses the role of morphemes in linguistic theory. After brief introductory remarks on morphology, the first section describes German verb inflection in general and past participles in particular. The second section gives an overview of theories that explain the representation of inflected forms. It applies these theoretical assumptions to the representation of German past participles and provides, where available, empirical evidence for these specific assumptions.

The morpheme has long been an important entity in theories on word structure (e.g. Spencer 1991). Morphemes are involved in three morphological processes: compounding, derivation and inflection. Compounding combines stems to form new words (e.g. black + board → blackboard). Derivation typically adds derivational affixes to a word to create new lexemes (e.g. love, lovable, unloved, lovely). Inflection adds inflectional affixes to a word or lexeme to produce new word forms (e.g. walks, walked, walking). Morphologists have taken particular interest in the structure of inflected words. One reason for this is that inflection is at the interface of morphology, syntax and phonology. Inflection produces new word forms from a lexeme and therefore belongs to morphology. The affixes added to a word form carry information (e.g. person/number) which is related to other constituents in the sentence ('agreement') and thus affects syntax. An inflectional morpheme may take different phonological realisations and is therefore affected by phonology. This phenomenon is called 'allomorphy' and can be conditioned by the phonological environment (Nevins 2011; Wagner 2012: 3), the morpho-lexical environment (Stump 2001) or prosody (Anderson 2011: 7). The English past-tense affix *-ed*, for example, has three allomorphs depending on the phonological environment: it is phonologically realised as /əd/ after /t/ and /d/, as /t/ after other voiceless phonemes and as /d/ after voiced phonemes (cf. Spencer 1991).

Since what has been called the "cognitive revolution" (Kuhn 1962), linguists do not study language as an abstract system of regularities, detached from human mental reality (Fanselow & Felix 1987: 16). Instead, they use language as a window into human cognition (Chomsky 1957, 1980). They have developed ideas about how the constituents of inflected forms are represented in the mental lexicon, how inflected words are formed and how the constituents of words relate to each other. Psycholinguists draw on theoretical accounts to derive predictions. It is therefore important for us to understand the range of morphological theories and their predictions in order to evaluate current results in terms of them.

2.1 Describing German Verb Inflection

2.1.1 Inflected German Verbs

German inflected verb forms consist of stems and affixes. Stems carry semantic meaning. Affixes are combined with stems and carry morpho-syntactic information, such as tense, mood, person and number (Spencer 1991). Consider the German verb *sagst*. It consists of the stem *sag* ‘say’ and the inflectional affix ‘*-st*’ carrying the information 2nd person, singular, present, indicative.

Stems can take different phonological forms, depending on the grammatical categories of the verb. Each inflected verb is specified for five grammatical categories: number, person, tense, mode and voice (cf. Eisenberg 1998). The verb *riechen* ‘to smell’, for example, takes the stem vowel [i:] in the infinitive but [ɔ:] in the past-tense form *roch* ‘I smelled’. Table 1 below shows that German inflected verbs can be grouped according to the stem changes and suffixes which they show in their present-tense, past-tense and past-participle forms. Following the stem vowel changes in the present stem, past-tense stem and participle stem, verbs have traditionally been grouped into weak verbs and subgroups of strong verbs (Grimm 1919). Weak inflected forms always take the base stem (see Table 1, 1a and 1b). For example, all inflected forms of *sagen* ‘to say’ take the same base stem *sag-te*, *ge-sag-t*, *sagtest*, *sagest*. They contrast with strong verbs like *denken* ‘to think’ which take the base stem in present-tense forms (e.g. *denkst*, *denke*, *denken*) but a different stem form in past-tense forms and the past participle (e.g. *dach*, as in *dach-te ge-dach-t*, *dachtest*) (see Table 1: 2a, 2b, 3a, 3b, 4a and 4b). These contrast to strong verbs such as *lesen* ‘to read’ in 5a and *verlassen* ‘to leave’ in 5b. These take the base stem in their present-tense forms and the participle form but take an alternating stem in their past-tense form (e.g. verließ ‘(I) left’). Finally, forms like *gehen* ‘(to) go’, *ging* ‘went’, *gegangen* ‘gone’ take different stems in their present- and past-tense forms and the past participle. Affixes also take different phonological forms. Consider, for example, the 3rd person singular past-tense forms (see Table 1, past-tense column). This can be realised as *-te*, as in *machte* ‘(he) did’, or as the null morpheme as in *ging* '(he) went'[2]. Another example is the past participle ending, which in some verb forms is realised as *-(e)t* (*gemacht* 'done') and in others as *-(e)n* (*geschlafen* 'slept'). A *schwa* sound is added before the *-t* suffix if the stem-final phoneme is /t/ or /d/ (e.g. *red* 'talk' *geredet* 'talked', or *arbeit* 'work' *gearbeitet* 'worked') (Wiese 2000: 90).

The suffix cannot be reliably predicted from the stem. Infinitival stems always pair with the 3rd person past-tense suffix *-te* (*lebte* '(he) lived') but alternating stems combine with the null suffix *-Ø* (as in *gab* '(he) gave') or with the *-te* suffix (*brachte* '(he) brought'). Stem changes cannot be predicted from the suffix for past participles. The alternating stems pair with *-t* suffixes (*gebracht* 'brought') or *-n* suffixes (*geschrien* 'screamed'). Base stems also pair with *-t* suffixes (*gemacht* 'done') or *-n* suffixes (*geschlafen* 'slept').

Stem or affix changes of past-tense and past-participle forms cannot reliably be derived from the phonological base form[3]. *Leben* '(to) live' and *geben* '(to) give', are phonologically similar, but all inflected forms of *leben* take infinitival stems and take a *-t* participle ending *gelebt*, while some inflected forms of *geben* take an alternating stem as in *gab*, *gabst*, *gaben* and take an *-n* participle ending.

What we said about bare stems above is equally true for prefixed verb stems: they show the same stem changes and affix changes as bare stems. Prefixed verb stems are sometimes semantically related to their bare stems, as in *brennen* 'to burn', *verbrennen* 'to burn something', but not always, as in *legen* 'to lie' and *verlegen* 'to lose' or 'to edit'.

Another type of inflected variant, the suppletion forms, show semantic but no phonological relation to their base stems (*sein* '(to) be' – *war* 'was' – *gewesen* 'been', Table 1, 7). Suppletion forms correlate with high frequency in a language (Bybee 1995; Hippisley, Chumakina, Corbett & Brown 2001). It has been argued that high frequency keeps suppletion forms from being regularised and erased from the vocabulary (e.g. Hippisley 2001).

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[2] Another example of stem and suffix allomorphy is the German plural suffix, which is formed using five different endings (*-er –e, -s, -Ø, -n*), and can show vowel changes.
[3] Note that there are some morpheme-conditioned regularities for the German noun plural, e.g. words ending in *-keit*, *such* as *Fröhlichkeit* 'joy', always take the plural suffix *-en* (Spencer 1991; Wiese 1996: 136f).

	Infinitive	Present	Simple Past	Past Participle
1a	sag-en	sag-e	sag-te	ge-sag-t
	‘(to) say’	‘(I) say’	‘said’	‘said’
1b	beleidig-en	beleidg-e	beleidg-te	beleidig-t
	‘(to) insult’	‘(I) insult’	‘(I) insulted’	‘insulted’
2a	brenn-en	brenn-e	brann-te	ge-brann-t
	‘(to) burn’	‘(I) burn’	‘(I) burned’	‘burnt’
2b	verbrenn-en	verbrenn-e	verbrann-te	verbrann-t
	‘(to)burn sth.’	‘(I) burn’	‘(I) burned’	‘burnt’
3a	denk-en	denk-e	dach-te	ge-dach-t
	‘(to) think’	‘(I) think’	‘(I) thought’	‘thought’
3b	bedenk-en	bedenk-e	bedach-te	bedach-t
	‘(to) consider’	‘(I) consider’	‘(I) considered’	‘considered’
4a	bieg-en	bieg-e	bog	ge-bog-en
	‘(to) bend’	‘(I) bend’	‘(I) bent’	‘bent’
4b	verbieg-en	verbieg-e	verbog	verbog-en
	‘(to) distort	‘(I) distorted’	‘(I) distorted’	‘distorted’
5a	les-en	les-e	las	ge-les-en
	‘(to) read’	‘(I) read’	‘(I) read’	‘read’
5b	verlass-en	verlass-e	verließ	verlass-en
	‘(to) leave’	‘(I) leave’	‘(I) left’	‘left’
6a	geh-en	geh-e	ging	ge-gang-en
	‘(to) go’	‘(I) go’	‘(I) went’	‘gone’
6b	begeh-en	begeh-e	beging	begang-en
	‘(to) commit’	‘(I) commit’	‘(I) commited‘	‘commited’
7	sein	bin	war	ge-wes-en
	‘(to) be’	‘(I) am’	‘(I) was’	‘been’

Table 1: Classes of German Verbs (cf. Wunderlich & Fabri 1995)

Traditionally, weak verbs which take no stem changes in their inflected forms have been referred to as ‘regular’ verbs. Strong verbs which show stem changes in one or more of their inflected forms have been referred to as ‘irregular’ verbs (e.g. Hock 1968; Wurzel 1970; Augst 1975, 1977). As shown above, these labels are a way of describing the surface forms of verbs. Current linguistic and psycholinguistic theories, however, have moved beyond the description of verb forms, and are more interested in the cognitive representation of inflectional phenomena (Felix & Fanselow 1987). As mentioned in Chapter 1, a current research question is whether inflected forms are subject to linguistic rules or whether all inflected forms are represented in the same way. Proponents of linguistic rules in the human mind have developed criteria to decide which forms are subject to a linguistic (default) rule and which are not. Marcus et al. (1995: 197) have suggested that default inflection is preferred for non-rhyming novel words, low-frequency and unusual words, non-canonical roots, and derived words; it is overapplied in the speech errors of both children and adults. In many cases, the ‘default form’ thus produced is also the traditionally ‘regular’ form. There are, however, many cases in which the ‘default form’ is not a ‘regular’ form. The German plural inflection *-en* is regularly applied after nouns ending in *-keit* and *-heit.* But it is not the default plural inflection, because it does not meet the criteria established by Marcus et al. (1995).

In this study, we are not concerned with the effect of surface form on the processing of verb forms but primarily in the role of grammatical (default) rules in such processing. We therefore do not distinguish between regular and irregular verbs. Instead, we distinguish between inflection that has been identified as the default inflection – ‘default forms’ – and inflection which has not, i.e. ‘non-default forms’ (cf. Marcus et al. 1995: 196ff.; Pinker 1999; Sonnenstuhl & Huth 2002). Current linguistic and psycholinguistic theories have made fundamentally different assumptions about the existence of default and non-default forms and make different predictions about the relevance of these forms to representation and processing. Testing default and non-default forms allows us to test the different predictions made by current morphological theories. All other parameters being equal, different behaviour by default and non-default forms speaks in favour of a default rule. Similar behaviour by default and non-default forms supports the view that a default rule is not relevant in language representation and processing.

2.1.2 German Past Participles

The linguistic phenomenon under study is past participle formation in German. Three morphological processes are involved in participle formation of base verbs: *ge-* prefixation, +/- stem allomorphy and *-t*/*-n* suffixation. Table 2 ilustrates participle formation in German. Regular or default participles such as *getanzt* ‘danced’ take the *-t* suffix and undergo no stem change. Participles like *geschwommen* ‘swum’ take the *-n* suffix and undergo stem change. Participles like *geschlafen* ‘slept’ take the *-n* participles and, like the default regular *-t* participle, undergo no stem change. Finally, *-t* participles like *gebracht* ‘brought’ take the *-t* suffix and undergo stem change, like *-n* participles with stem change.

We will label past participles according to their suffix and stem changes. Past participles which take the *-t* suffix and unmarked stem are referred to as *-t* participles. Past participles which take an *-n* suffix and an infinitival stem are referred to as *-n/without* participles and past participles which take an *-n* suffix and an alternating stem are referred to as *-n/with* participles. Due to its small size, the group of 13 *-t* past participles which take an alternating stem cannot be experimentally investigated in the current study.

Suffix	**Stem Change**	**Example**
-t	without	*tanzen* ‘to dance’ – *ge-tanz-t* ‘danced’
-n	with	*schwimmen* ‘to swim’- *ge-schwomm-en* ‘swum’
-n	without	*schlafen* ‚to sleep’ – *ge-schlaf-en* ‘slept’
-t	with	*bringen* ‘to bring’ – *ge-brach-t* ‘brought’

Table 2: German Past Participles

The participles shown in Table 2 are similar in terms of morphological complexity. They take the *ge-* prefix and have segmentable endings (*-t* or -n) yielding the same form structure: [ge-] [stem] [suffix].

The *ge-* prefix is added to participles whose verbs stems are stressed on the first syllable (e.g. *machen – gemacht* ‘(to) do – done’) and not to verb stems which are stressed on another syllable, such as already prefixed verbs (e.g. *besuchen – besucht* ‘(to) visit – visited’, *verbrauchen – verbraucht* ‘(to) consume – consumed’, *empfehlen – empfohlen* ‘(to) recommend – recommended’). The *ge-* prefixation rule is thus prodosodically, not morphologically determined. It applies equally to *-t* and *-n* participles (Wunderlich 1996: 98; Wiese 2000: 89).

Participles differ in their phonological transparency, involving either stem change or no stem change (Schriefers 1999). The majority of *-t* suffixed participles are paired with base stems. Only thirteen *-t* participles undergo stem changes (e.g. *bringen-gebracht* ‘(to) bring – brought’, *denken-gedacht* ‘(to) think – thought’). The behaviour of *-n* participles is less phonologically transparent. Out of 160 base verbs (*Grundverben*) that form their participles with the *-n* suffix, 35 carry the base stem (e.g. *schlaf – geschlafen* ‘slept’) and 125 carry an alternating stem (e.g. *biegen – gebogen* ‘bent’). Hence, we see that the addition of the *-t* participle suffix to a stem changes the phonological form of the stem only in a small number of *-t* participles, while the addition of the *-n* suffix to a stem alters the phonological form of the stem in the majority of *-n* participles.

Participles also differ in their productivity. Anshen & Aronoff (1988: 643) have defined productivity as the likelihood that a particular affix will be used in the production of new words in a language. The *-t* suffix is highly productive and, like the English past-tense suffix *-ed*, generalizes to new words and non-words (Clahsen 1997). It is mostly used for low-frequency verbs. According to the CELEX data base, 976 out of 997 *ge-* participles with a word form frequency of 0 take the *-t* ending (cf. CELEX Baayen, Piepenbrock & Gulikers 1995; Bybee 1995). The *-t* suffix is not bound to particular phonological environments (Marcus et al. 1995). Studies on spontaneous and elicited child language production, which will be reviewed in detail in section 3.3, have shown that the *-t* ending is overapplied in children's production (e.g. Clahsen & Rothweiler 1993; Szagun 2011). In contrast, *-n* suffixation only generalises to new words which are similar to existing non-default word forms (Weyerts & Clahsen 1994, Weyerts 1997) and is rarely overapplied by young children. Consequently, *-t* suffixation with no stem changes has been identified as the default participle formation process in German (cf. Marcus et al. 1995). Therefore, we will consider *-t* participles without stem change as *default* participles and *-n* participles with and without stem change as *non-default* participles.

The literature has discussed the categorical status of participles: are they part of inflection? This debate was based on the observation that participles are not inflected for person, number, tense, mode or voice, in contrast to other inflected verb forms. Participles cannot establish a congruence relationship with a subject in a sentence by themselves and hence must occur with an inflected auxiliary verb or a modal verb (cf. Engel 1988). In line with Heidolph, Flämig & Motsch (1981) and Wunderlich & Fabri (1995), we argue that participles are inflected forms. These linguists have argued that the participle is not fully 'non-inflected' either because it is more marked than the infinitive. Heidolph et al. (1981) suggest that the infinitive is the unmarked form among the non-finite forms and the participle is the marked form. Wunderlich (1996) similarly distinguishes between infinitive forms as [-part] and participles as [+part]. Even though they are not inflected for person, number, tense, mode or voice, they must be distinguished from infinitive forms. We therefore consider participles as inflected forms.

The literature has further discussed whether the participle has a verbal or an adjectival status. Heidolph, Flämig & Motsch (1981) argue that participles, for example *getanzt* in sentences like *Er hat getanzt* 'He has danced', describe a limited or completed action and thus have a verbal status. Wunderlich & Fabri (1995) agree that the participle is a verbal form. Lenz (1993), by contrast, argues that the participle contains both adjectival and verbal properties. She suggests that participles which can be prefixed with *un-* 'un-' should be assigned adjectival status and those which cannot be prefixed with *un-* 'un-' should be assigned verbal status. Following this line of argument, the participle *geöffnet* 'opened' in the sentence *Das Tor ist geöffnet* 'The gate is opened' should have adjectival status because it can take the prefix *un*-, as in the sentence *Das Tor ist ungeöffnet* 'The gate is unopened (=closed)'. The participle *geöffnet* 'opened' in the sentence *Er hat das Tor geöffnet* 'He opened the gate' should have a verbal status because it cannot be prefix with *un*-. Lenz (1993) does not assume that the adjectival and verbal forms have two different lexical entries. Instead, she assumes that the participle has a verbal status and is only converted into an adjectival participle through a conversion rule (cf. Weyerts 1997).

We follow Heidolph et al.'s, Wunderlich & Fabri's perspective and assume that participles are verbal forms. This seems particularly appropriate because in our study participles are presented in isolation, so – in Lenz's terms – there is no necessity for speakers to convert the verbal representation of participles into adjectival forms.

2.1.3 Issues in Frequency Counts of German Past-Participle Forms

We have described differences in the surface form of past participles (*-t vs. -n/with vs. -n/without*). We have further argued that the *-t* form is the default participle inflection and *-n* participles with or without stem change are non-default participle forms. Proponents of a dual theory of language have argued that the default status of inflected forms determines how they are represented and processed. Other acquisition theories, which will be explained in greater detail in section 3.2.2, have argued that inflected forms' frequency of occurrence is the key determinant of how such forms are acquired and processed. In their view, *-t* participles behave differently from *-n* participles in children's language production and in adult language processing simply because the former are more common in the language than the latter (e.g. Bybee 1999; Szagun 2011). It is agreed that frequency is one of the most important factors in lexical organisation (e.g. Morton 1969; Balota 1994). This section describes different frequency types and investigates whether participle forms differ by frequency types.

Two sorts of frequency are relevant for our study: type frequency is the number of word forms in a corpus. For example, 1,980 different participles are listed in the CELEX corpus. Token frequency, also referred to as word-form frequency, measures the occurrence of a given word form within a corpus. The participle *gesagt* 'said', for example, occurs 1,667 times in the CELEX corpus. In this study, we control our materials for word-form frequency and lemma frequency and rely on CELEX, one of the richest frequency databases for the German language (Baayen et al. 1995), which gives frequency counts for 5.4 million German tokens from written text corpora derived from the corpora *Bonnlex* (Institute for Communication Research and Phonetics, Bonn), *Molex* (Institute for German Language, Mannheim) and *Noetic Circle Services* (MIT). CELEX also provides morpho-semantic, orthographic, phonological and grammatical information. According to CELEX, German has 5,692 past participles (including 1,985 *ge-* participles), 1,513 *-n* participles with a mean token frequency of 4.5 per million (= 6808 instances) and 4,179 *-t* participles with a mean token frequency of 1.76 per million (= 7355 instances). That means that 48% (6,808/14,163) of all participles in the corpus are *-n* suffixed and 52% (7,355/14,163) are *-t* suffixed. This finding indicates that German speakers produce and listen to *-n* participles about as often as they produce and listen to *-t* participles. Clahsen & Rothweiler (1993: 9) used Ruoff's corpus of spoken German (1981) and Meier's corpus of written German (1964) to determine participle distribution in adult German. Clahsen & Rothweiler analysed the 1,000 most frequent participle types from the spoken corpus, which accounted for 96% of all verb tokens in the corpus, and reported 498 *-t* participles (49.8%) and 502 *-n* forms (50.2%). Meier (1964) counted the most frequent word forms in German written texts. He reported the 1,200 most frequent word forms, among them 23 participle forms, and found 23 *-n* participles and only eight *-t* participles.

The CELEX corpus, like Meier's (1964) and Ruoff's (1981) corpora, is based on adult language. However, the number of *-t* and *-n* participle forms in child language input and output might be different: child language might contain more high-frequency word forms (e.g. *gemalt* 'painted', *gesagt* 'said', *gegessen* 'eaten', *geschlafen* 'slept') than low-frequency word forms (*getrachtet* 'aimed at', *gesandt* 'sent') (cf. Cameron-Faulkner, Lieven & Tomasello 2003). As *-t* participles constitute a smaller proportion of high-frequency items than *-n* participles, this would imply that the proportion of *-t* participles is at least as high in child language as in adult language.

The frequency of *-t* and *-n* participles has been assessed in a number of longitudinal child language corpus studies, which have determined the frequency of *-t* and *-n* participles in a number of ways. They have studied children's input *or* output and used different criteria for what counts as a participle form. Consequently, the corpus studies have produced a range of different results (see Clahsen 2007: 104 for discussion), but we can identify some general trends. Most analyses of child corpora agree that *-t* and *-n* participles have a similar token frequency in children's input and output. Clahsen & Rothweiler (1993), for example, studied the production of participles in three typically-developing children in the age range 1;6–3;9 and analysed 843 participle tokens. They then studied 19 children with specific language impairment (SLI) in the age range 3;1–7;11 and analysed 1,004 participle tokens. Both groups behaved alike in that *-t* and *-n* participles occur early in development, at a mean length utterance (MLU) of 1.75–2.75 words, and seemed to emerge simultaneously (totals of eight *-t* participles and nine *-n* participles in all unimpaired children in the first stage; Clahsen & Rothweiler 1993: 11). Weyerts (1997) studied nine children in the age range 1;4–3;8 and analysed 1,462 participle tokens. Like Clahsen & Rothweiler (1993), she found that *-n* and *-t* participles emerged in parallel and that 51.09% of the produced participle tokens were *-n* suffixed at the age range tested (Weyerts 1997: 94).

Child language corpus studies report various results for the type frequency of *-t* compared to *-n* participles. Weyerts & Clahsen (1994) and Sterner (2013) found that *-t* participles had a similar type frequency to *-n* participles in child language corpora. Weyerts & Clahsen (1994) determined type (and token) frequencies in seven corpora of child-directed speech (Miller 1976; Wagner 1981) with a total of around 45,000 words, covering the age range 1;5–8;7. All participle forms produced by the caretakers were analysed in terms of their type and token frequency. The authors reported similar type frequencies for *-t* and *-n* participle forms: 49.1% for the former and 50.9% for the latter (Weyerts & Clahsen 1994: 439). Sterner (2013) investigated past participle production in four Turkish-German successive bilingual children and analysed a total of 191 different participle forms. She found that the overall proportion of *-t* and *-n* participles was similar (*-t* participles 52.4%, *-n* participles 44.0%[4]). More specifically, *-t* and *-n* participles occurred with similar frequency in two children (Faruk *-t* 48.0%, *-n* 50.0%; Eser *-t* 50.0%, *-n* 48.9%). Gül produced considerably more *-n* participles (*-t* 39.1%, *-n* 54.3%) and *-t* participles were considerably more frequent in the child Zeren (*-t* 58.8%, *-n* 38.0%). Statistical tests showed that the difference between *-t* and *-n* participles was not significant in any of the four children, including Zeren (Wilcoxon, n.s., p.213). Results from these studies show that type frequencies for *-t* and *-n* participles are similar in German child language. These results are consistent with

[4] Percentages reported from Sterner (2013) do not add up to 100 because we are not including her results for *-t* participles with stem change ('mixed class'). This group will not be tested in the current study as they constitute a small proportion of participles.

findings from Clahsen, Aveledo & Roca (2002), who found similar type frequencies for regular and irregular forms in a corpus of Spanish child language production.

Bybee (1995) reanalysed Clahsen & Rothweiler's (1993) data and proposed a different interpretation. Clahsen & Rothweiler had counted prefixed forms as individual types, but Bybee considered all prefixed forms (e.g. *schreiben* 'to write', *aufschreiben* '(to) write down', *abschreiben* '(to) copy', *vorschreiben* '(to) enjoin', *verschreiben* 'to prescribe') as one type. She found that *-t* participles had a considerably higher type frequency than *-n* participles in German (*-t* 88% *vs.* *-n* 12%, p. 437), and concluded that *-t* participles outnumber *-n* participles and that the relative distribution of *-t* and *-n* participles in German is similar to the distribution of English regular and irregular past tense.

Szagun (2011) comes to a similar conclusion as Bybee (1995). She studied, among other things, the frequency of correct production of past participles in six children in the age range 1;4–3;8, considering 1,938 participle tokens, and child-directed speech from 22 adults with a total of 1,035 participle tokens. Like Clahsen & Rothweiler (1993), she counted prefixed forms as individual types. Her results showed that type frequencies and token frequencies were similar in adults and children (p. 742): the type frequency of *-t* participles was considerably higher in adults (ca. 58%) and children (ca. 56%) than that of *-n* participles (adults: ca. 40%, children: ca. 42%, Wilcoxon: adults $p<.001$, children $p=.043$, p.743).

The discrepancies between Szagun's (2011) results and those of Clahsen, Weyerts & Rothweiler can be ascribed to differences in what is included in the participle count. Clahsen, Weyerts & Rothweiler included correct and erroneous participle forms in their frequency count while Szagun (2011) included only correctly produced forms. She argues conclusively that the researcher cannot decide whether incorrectly produced forms, such as *gefallt* or *gefall*, belonged to the group of *-t* participles or to the group of *-n* participles for a child, and therefore cannot be assigned to one participle class in the frequency count (p. 740). However, this way of counting introduces a significant problem: it confounds the frequency count with error frequency per participle type. Szagun's data shows that *-n* participles are much more often subject to overregularisation errors than *-t* participles (Figure 3, p. 745). The number of *-n* participles, but not that of *-t* participles, is thus considerably reduced by the exclusion of incorrectly produced forms. Further, Szagun (2011) does not present the individual type frequencies per child and adult. It might be, as was the case in Sterner (2013), that one child or adult produces considerably more *-t* participles than *-n* participles, while the rest of the group shows a balanced output of *-t* and *-n* participles. Such unusual behaviour by one participant would have a disproportionate effect on the overall frequency counts and distort the results.

The discrepancy between Bybee's (1995) analysis and results from the Weyerts (1997), Weyerts & Clahsen (1994) and Clahsen & Rothweiler (1993) child language corpus studies presented above could also be due to methodological issues. For example, the studies differed in what was considered a 'type', i.e. an individual lexeme. German has many base verbs (e.g. *kommen* 'to come') which share the same root with large families of particle and prefix verbs, such as *kommen* (*ankommen* 'arrive', *bekommen* 'receive', *aufkommen* 'support, pay'). Naturally, the type frequency of *-n* participles is much higher if prefixed verbs are counted as individual lexemes than if they are counted as variants of one lexeme. Bybee (1995: 436) argued that verbs which share a root should be counted as variants of one lexeme and, accordingly, found the type frequency of *-n* participles to be much lower than that of *-t* participles. However, there are important arguments which support the view that base verbs, prefixed verbs and particle verbs should be considered as individual lexemes. Prefixed and particle verbs behave like separate words. First, they have non-compositional meanings, i.e. (the meaning of *aufkommen* 'pay' or 'support' is not composed from the meaning of the root *komm* 'to come' and the meaning of the prefix *auf-* 'up'. Secondly, they behave orthographically and phonologically like single verbs. Thirdly, they always appear as single verbs in their participle form. Consequently, and in our view correctly, Clahsen and his collaborators decided to count base verbs, particle verbs and prefix verbs as separate lexemes and produced the result that *-n* and *-t* participles have about the same (type and token) frequency.

Bybee (1995: 436) also critically remarks that the Ruoff database only includes the 1,000 most frequent participle types, excluding many low-frequency *-t* participles but no *-n* participles. We think, however, that it is a sensible decision to exclude participles of very low frequency when estimating type frequencies applicable for children. Type frequency counts based on the entire adult German verb lexicon contain many low-frequency words which are unlikely to be familiar to children. The CELEX corpus, for example, contains forms such as *abandonniert*, an archaic form for 'abandoned' and *gedarbt* 'suffered from privation'.

Bybee (1999) also noted that participles should be compared on the basis of their ending (*-t vs. -n*) and also on the basis of their stem (with *vs.* without stem change), to capture subregularities in irregular forms such as *-n* participle forms. In this case, *-n* participles would be split into a number of subgroups, each with a lower type frequency than *-t* participles. It is true for English that many irregular past-tense forms can be reliably predicted from their verb stem. Albright & Hayes (2003), for example, reported that six out of seven stems ending in *-eed* have past-tense allomorphs that rhyme with *bled.* Similarly, subregularities can be observed in German *-n* participles; these can substantially influence acquisition and processing of *-n* participles if they allow reliable predictions from the stem to the participle form. In this case, one could argue that subregularities among *-n* participles enable children to form *-n* participles by rule application and exempt children and adults from one-by-one storage.

However, rule application is only possible if there is a consistent relationship between base form and participle form. To investigate this, we now assess the consistency between German base forms and participle forms. First, we examine whether vowel change can be predicted in *-n* participles on the basis of their stem vowels. Second, we examine whether the suffix (*-t vs. -n*) can be predicted on the basis of the verb stem. Table 3 presents an overview of vowel change patterns in German *-n* participles. Column 1, ‘Subgroup’, assigns labels a–m to each subgroup. Column 2, ‘Vowel change’, summarises all vowel change patterns observed for *-n* participles in German, followed by an ‘Example’ in Column 3. Column 4, ‘Number of *-n*’, shows the number of *-n* participles with this specific vowel change pattern and Column 5 shows the number of *-t* participles which have the same vowel in the stem. We see from Table 3 that the majority of German *-n* participles, 143/160 *-n* participles (89%), fall into one of five subregular groups (a–e). Thirty-five verbs take the same vowel as the base stem, 36 *-n* participles show the vowel change /ei/ → /ie/ (e.g. *scheinen* → *geschienen*, ‘shine → shone’), 28 show the vowel change /e/ → /o/ (e.g. *schmelzen* → *geschmolzen*, ‘melt → melted’), 25 show the vowel change /i/ → /o/ (e.g. *fliegen* → *geflogen*, ‘fly → flown’) and 19 show the vowel change /i/ → /u/. We also see within the group of *-n* participles that the majority of forms can be fairly reliably predicted on the basis of their stem vowels. Specifically, /ei/ predicts /i/ by 100%, /e/ predicts /o/ by 93%, /i/ predicts /o/ by 53% and /u/ by 40%. We conclude from step 1 that the vowel change from base form to participle form within the group of *-n* participles might be predicted on the basis of the base form and therefore does not necessarily have to be memorised. However, in step 2 of our analysis, we look at Column 5 and find that there is always a higher number of *-t* suffixed participles than *-n* suffixed participles for every stem vowel (a)-(m), which means that children cannot predict the *-n* suffix on the basis of the verb stem, or at least, must memorise one-by-one which verb takes the the *-n* suffix. Putting these observations together, we see that the speaker may not need to memorise vowel change patterns but will need to memorise *-n* suffixation. This result might be taken to indicate that *-n* suffixation is more difficult to acquire than vowel change patterns, as the latter but not the former could technically also be derived by fairly reliable rules. This analysis therefore strengthens the assumption that participle forms should be compared on the basis of their endings (*-t vs. -n*) but not on the basis of their stem changes (with *vs.* without stem change). Further support for this argumentation comes from a study by Clahsen, Aveledo & Roca (2002) on the development of regular and irregular verb inflection in 15 Spanish-speaking children in the age range 1;7–4;7 years. Spanish inflected verbs consist of stems and inflectional affixes. Stems are combinations of roots and theme vowels. The authors compared the production of regular Spanish verb forms with non-alternating stems to that of irregular Spanish verb forms with stem changes. The error analysis showed, among other things, that Spanish children combined irregular stems with regular inflectional suffixes (p. 26). The authors take this to indicate that Spanish children manipulated stems and suffixes separately. This result is a further indication that stem change and suffixation in a verb should not be considered as one entity but as two separate processes within one inflected form. For German, our analysis has shown that stem formation and suffixation processes differ in their predictability. Therefore, we conclude that Bybee's suggestion of splitting verb forms by suffixation *and* stem change is not persuasive for German.

Subgroup	Vowel change	Example	Number of *-n* participles	Number of *-t* participles with same stem vowel
a)	/x/ → /x/[5]	geben → gegeben 'give → gave'	35	all
b)	/ei/ → /ie/	scheinen → geschienen 'shine → shone'	36	91
c)	/e/ → /o/	schmelzen → geschmolzen 'melt → melted'	28	227
d)	/i/ → /o/	fliegen → geflogen 'fly → flown'	25	271
e)	/i/ → /u/	stinken → gestunken 'smell → smelled'	19	271
f)	/au/ → /o/	saugen → gesogen suck → 'sucked'	3	74
g)	/i/ → /e/	sitzen → gesessen 'sit → sat'	3	271
h)	/ü/ → /o/	lügen → gelogen 'lie → lied'	3	88
i)	/e/ → /a/	stehen → gestanden 'stand → stood'	2	227
j)	/ä/ → /o/	erwägen → erwogen 'consider → considered'	2	151
k)	/ö/ → /o/	schwören → geschworen 'swear → sworn'	2	68
l)	/ä/ → /a/	hängen → gehangen 'hang → hung'	1	151
m)	/u/ → /a/	tun → getan 'do → done'	1	199

Table 3: Subregularities in German stem – (*-n*) participle pairs

We think that frequency counts that put *-t* participles in the majority are less reflective of children's production and input of participle forms. Instead, we believe that studies indicate that the token frequency and type frequency of *-n* participles is about as high as that of *-t* participles in German adult language and German child language.

2.2 Linguistic Accounts of Word Structure

This section considers a selection of linguistic models that explain how the word structure of inflected forms is represented in the human mind, particularly with regard to the word structure of German default *-t* past participles and non-default *-n* past participles. There are a number of

[5] The variable /x/ representes any vowel. '/x/ → /x/' means that the base stem contains the same vowel as the participle.

ways to categorise the broad range of theories on word structure. One is to group models according to the entity which they see as 'smallest meaningful unit'. For a long time, linguists identified this as the morpheme (Bloomfield 1933; Spencer 1991: 5). 'Meaningful', here, does not refer only to a morpheme's semantic meaning but also to its grammatical function (e.g. 'houses': noun, -s suffix indicates plural of house) (Booij 2007: 34).[6] However, this classic definition has proven problematic (e.g. Stump 1993: 449) and alternative approaches have emerged which do not make use of the notion 'morpheme' but instead use 'lexeme' or 'word form'. We will differentiate between morpheme-based models, lexeme-based models and word-form-based models. A lexeme is an abstract unit (e.g. BAUM 'tree'), represented in the lexicon, which belongs to a particular syntactic category. A word form is a variant of a lexeme (e.g. *Baum* 'tree', *Baumes* 'tree'$_{[genitive]}$, *Bäume* 'tree'$_{[plural]}$, *Bäumen* 'tree'$_{[accusative]}$). It is built from morphemes and systematically varies from the lexeme according to its syntactic context (Stump 1998: 13). Morphemes are components of word forms (e.g. Baum+Ø, Bäum-e, Bäum-en). Naturally, these three theoretical appraoches take different views on whether the morphological structure of inflected forms affects representation.[7] Traditional generative approaches assume that the mental lexicon only contains morphemes, which are joined together by linguistic rules to form morphologically complex forms (Chomsky & Halle 1968; Halle & Mohanan 1985). Current morpheme-based approaches propose that non-default forms are directly represented in an associative lexicon and morphemes of default forms are represented in the lexicon to be joined together by grammatical rules. (e.g. Wunderlich & Fabri 1995; Wunderlich 1996; cf. Spencer 1991; Durrell 2001). In contrast, lexeme-based accounts[8] have suggested that all inflected forms can be realised from an abstract representation by a set of, for example, phonological rules (e.g. Barbour 1982; Beedham 1994, 1995/1996) or functions which are organised in paradigms

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[6] Morphemes can be either isolated (free morphemes = words, e.g. walk, jump, carry) or require to be attached to another morpheme (bound morphemes = e.g. inflectional affixes such as present-tense singular -s). A word which is made up of one morpheme is a monomorphemic word (e.g. agree), while a word which is made up of more than one morpheme is a polymorphemic word (e.g. agrees) (Spencer 1991).

[7] Among morphlogical models, we can also distinguish between Item-and-arrangement models and Item-and-process models (cf. Hockett 1954). Item-and-arrangement models investigate the internal structure of individual words, for example the morphemes which constitute inflected forms ('word syntax'). They can easily explain how morphemes are concatenated to form the default form of past participles: *gemacht* 'made' – *ge+mach+t.*Item-and-process models investigate the relation between two word forms and describe the processes that turn one word form into another. They can explain word-internal modifications between two forms of the same lexeme, for example stem and an inflected form: *ablaut brechen – gebrochen* 'break – broken' or *umlaut Vater – Väter* 'father – fathers' (cf. Köpcke 1998: 47ff.)

[8] Lexeme-based approaches are also referred to as realisation-based approaches, a term that highlights the fact that the surface form is realised (spelled out) via rules or functions from an underlying abstract representation.

('word-and-paradigm model', e.g. Stump 1998, 2001; Blevins 2003, 2006). Alternatively, word-form models have suggested that all inflected forms are individually represented in the lexicon and linked to their stem (e.g. Feldman & Fowler 1987) or associated with each other through phonological, orthographic or semantic properties (e.g. Bybee 1995).

2.2.1 Morpheme-Based Models

Early morpheme-based models of inflection (item-and-arrangement theories, Hockett 1958; cf. Spencer 1991: 49) claimed that all morphological processes are purely agglutinating, simply adding together the meanings of morphemes. In this view, one morpheme carries one meaning or function and adds it to the stem. Morphemes, including affixes, have independent representations in the lexicon. However, the simple one-to-one relationship of morpheme and information does not hold for inflectional morphology. Inflectional morphemes often add more than one type of morpho-syntactic information to the stem (e.g. German verb *-st*: 2nd person singular, present tense, indicative). Cases of homonymy, in which several meanings are associated with a single form (e.g. *-t* = 3rd singular *geht* or participle suffix) and synonymy, in which several forms have the same meaning (e.g. 3rd singular past = *-te* or null morpheme) also contradict a purely agglutinating account. German past participles present another difficult case. Their morphological properties are expressed by phonological stem changes in some inflected forms (e.g. *gebracht*, *gebrochen*), and these are difficult to explain within a purely agglutinating approach. Hockett's attempts to solve these issues within the item-and-arrangement approach remain unsatisfactory (see Spencer 1991: 50, for discussion).

The distributed morphology model has abandoned the idea of purely agglutinating morphological rules and puts forward a range of additive and modifying rules. 'Additive' means that morphemes can add more than one piece of information to a form; 'modifying' means that a rule can not only add phonological material but also alter the stem. Distributed morphology is rooted in the theories of generative phonology of Chomsky & Halle (1968) and Halle & Mohanan (1985).The distributed morphology model is also a morpheme-based model (Halle & Marantz 1993, 1994; Embick & Halle 2005; Embick & Marantz 2005) but rejects the idea that morphemes are represented on a separate level. Morphemes are not allocated in the lexicon, as in other morpheme-based theories (Chomsky 1970; Selkirk 1982; DiSciullo & Williams 1987; cf. Harley & Noyer 1999: 3). Instead, morphemes are allocated to syntax and later spelled out by phonology. On the morpho-syntactic level, we see two sorts of elements, a root [walk] and an abstract morpheme [past]. On this level these have no phonological content and are combined into one abstract syntactic object. It is only on the morpho-phonological level that phonological expressions (called Vocabulary Insertion) are added to the root and morpheme in a process called spell-out. In this process, rules (called Vocabulary Items) pair the morpho-syntactic context with the phonological string /walked/. These are also called phonological exponents (Halle & Marantz 1993, 1994). The meaning of a stem is represented separately from its phonological expression as an entry in the 'encyclopaedia'. The sound–meaning correspondence, in lexicalist hypotheses collected in the lexicon, is realised at a conceptual interface between the morpho-phonological component and the encyclopaedia. In this view, an inflected word such as 'walked' has a morpho-syntactic description of [root+[past]] and a morpho-phonological description [wɔ:k+ t]. If multiple morpho-syntactic features are realised in one phonological exponent, abstract morpho-syntactic morphemes are merged with the syntactic tree by a fusion rule, before the vocabulary item is inserted. In cases when morpho-syntactic features are expressed by vowel change instead of an additional morpheme, a zero suffix is inserted, before readjustment rules perform the necessary item-specific phonological operations (cf. Embick & Halle 2005).

For the English past tense, Embick, Halle and Marantz suggest that verb stems of inflected forms are grouped in lists according to the affixes of their inflected forms. For example, verb stems which add '*-t*' to form the past tense form the list (2a) (e.g. 'buy – bought', 'bring – brought'). Verb stems which add a null morpheme '-ø' to form the past tense appear in list (2b) (e.g. 'hit – hit', 'put – put'). Verb stems which undergo an ablaut process constitute another list (e.g. 'sing – sang', 'take – took'). As Wunderlich & Fabri (1995) suggest, the main characteristic of the default rule '*-ed*' is that it is not specified for particular contexts: see (2c). Affixes are specified for a list of verb stems which they inflect. The specificity criterion requires that affixes with more specific conditions on insertion block less-specified affixes, thus keeping the default rule from overregularising word forms (cf. Embick & Halle 2005; Embick & Marantz 2005: 244).

(2)

a. T[past] ↔ -t/{LEAVE, BEND, BUY…}+ ______ (List x)
b. T[past] ↔ -Ø/{HIT, SING, SIT…}+ ______(List y)
c. T[past] ↔ -ed/{}+ ______ (List x)

In the example (2), the phonological exponent *-ed* is added to the form. This process is not to be mistaken for morpheme concatenation by a default rule that combines stems and affixes. Affixes, represented as a lexical entry with meaning and form, do not exist in this approach. The function of affixes is represented on the syntactic level as 'abstract morpheme', e.g. [past] or [plural]. The phonological form of abstract morphemes is 'spelled out' during Vocabulary Insertion by a 'phonological exponent' (Embick & Halle 2005).

Yang (2002, 2004, 2005) presents the Rules and Competition theory within the framework of distributed morphology (Halle & Marantz 1993). This theory describes a set of phonological rules to explain the English past-tense inflection and linguistic productivity in general (Yang 2005: 266). Especially relevant for the current study is Yang's theoretical approach to language acquisition. We will therefore come back to Yang's work in section 3.2 when we discuss language acquisition theories.

Within the theoretical framework of distributed morphology, default and non-default forms are represented in the same way on the morpho-syntactic level. On the morpho-phonological level, by contrast, they show subtle differences. Non-default forms are computed by a *restricted* rule ('add *-n*', *schlaf* → *geschlafen*, 'add *-n*' and ablaut process *brech* → *gebrochen* 'break – broken') and default forms are computed by the *default* rule ('add *-(e)t*', *mach* → *gemacht*, 'do – done').This means, for non-default, but not for default forms, the speaker needs to memorise which verbs are on the lists that take restricted rules. In that sense, default forms require computation while non-default verb forms require two distinct components: computation and memory (Embick & Marantz 2005: 244). The information that the suffix -Ø is added to, for example, 'hit' is stored on the list, but the form 'hit' is not represented as a full form in a mental lexicon. In fact – and this is an important difference from lexicalist theories – there is no lexicon in distributed morphology, so the 'lexical entry' has no significance in the theory (cf. Harley & Noyer 1999: 3). Thus, frequency effects do not originate from an individual form frequency level (as suggested by Ullman, Clahsen, Pinker and collaborators) but arise when inflected forms involve *memorised connections* between the elements of a rule. For example, exposure to the construction 'sang' activates the memorised connection between 'sing', list (2)-Ø and the form 'sang+-Ø'. Accordingly, exposure to 'sang' raises the frequency level of 'sing', list (2) -Ø and the form 'sang+-Ø' (Embick & Marantz 2005: 245). Frequency counts, on this interpretation of relevant frequency, do not exist, but may be calculated on the basis of individual construction frequencies. The frequency of a construction such as 'sang+ -Ø' is equal to the word-form frequency, because the construction is activated when the specific stem and rule is activated. The frequency of stems such as 'sing' would be equal to the lemma frequency because activating a stem in the mental dictionary should activate all the stems and the lists on which this stem appears (Embick & Marantz 2005: 244). The frequency of the rule arises from the total frequency of all constructions on the list, because the rule is always activated when a form from the list is activated. With regard to German past participles, all are subject to a rule mechanism and non-default forms additionally involve a memory component. Distributional morphology therefore predicts that default forms and non-default forms will show different behaviour. Experimental results for default forms such as *-t* participles should reflect default rule computation, but results for non-default forms such as *-n* participles with and without stem change should reflect a memory component: specifically, the frequency of memorised lists and elements connected to those lists.

In contrast to distributed morphology, other morpheme-based approaches regard the lexicon as a central component of language representation. In their view, the lexicon contains lexical entries for stems and affixes which are specified for phonological form and compatibility with other morphological constituents, and can carry – possibly multiple – morpho-syntactic features. In contrast to distributed morphology, which predicts only subtle differences between the representation of default and non-default forms, these morpheme-based theories assume fundamentally different representations for inflected default and inflected non-default forms. They are therefore also called hybrid or dual models. In this view, the stems and affixes of default forms are joined together by *default* affixation rules to form morphologically complex forms (Wunderlich & Fabri 1995). Non-default forms require a full-form lexical entry because they are not fully systematic and productive. However, full-form lexical entries are not arbitrary lists. Common patterns of lexical entries are captured by, for example, lexical redundancy rules (Jackendoff 1975; Aronoff 1976; Lieber 1980), subnodes of structured lexical entries (Wunderlich & Fabri 1995; Wunderlich 1996, cf. Spencer 1991; Durrell 2001) or schemata (e.g. Köpcke 1998).

Stump (1993) and Corbett & Fraser (1993) have criticised the *default* affixation process in morpheme-based approaches in which affixes are *subsequently* added to the stem. They argue that many languages with a richer inflectional system than German do not show a single default process (e.g. Polish and Russian) but a variety of more or less productive inflectional types (cf. Spencer 1999: 1040). Also, they argue that the notion of 'morpheme' (with its grammatical function, semantic meaning and phonological form) creates problems in languages such as Swahili. In Swahili, affixes are added before or after a stem and take different phonological forms depending on affixes which are added later. It is hard to see how affixes can (phonologically) adapt to affixes which are inserted at a later point (cf. Anderson 1992: 48ff.). Therefore, like the proponents of distributed morphology, Stump and others suggest that inflection is a two-level process: in the first step, an inflected word is associated with its morpho-syntactic features on an abstract level, and in the second, those features are phonologically realised.

One of these hybrid morpheme-based linguistic models is summarised in the framework of minimalist morphology (Wunderlich & Fabri 1995; Wunderlich 1996). The theory is 'minimal' because it makes use only of a few general principles and relies on maximal underspecification of categorical and phonological information (Wunderlich 1996: 93). Minimalist morphology holds that inflected default and non-default forms differ fundamentally in their representation. Default forms are represented according to their morphemes and are subject to (default) combinatorial affixation rules. Morphemes are lexical items which combine phonological and categorical information, so that phonological information is inserted along with categorical information (Wunderlich 1996: 93, 102). This principle of 'early insertion' of phonological content in minimalist morphology contrasts with the principle of 'late insertion' in distributed morphology. The combinatorial inflectional rules capture productive aspects of the language. They apply in contexts in which memory patterns are not accessed and the default inflection is applied, as specified by Marcus et al. (1995: 197). They are applied to, for example, novel words which do not show phonological similarity to existing non-default word forms. They operate on the output of morphological processes such as derivation or compounding, and are overapplied in adults' and children's speech errors. An affixation rule concatenates a lexical entry with an inflectional affix and generates a pair of <phonological string, morphological feature values> (Wunderlich 1996: 94). As illustrated in (3), the inflectional affix thus adds morpho-syntactic properties to the word form.

(3) $[\text{walk}]_{V} \rightarrow [\text{walk}]_{V}+[\text{ed}]_{[\text{past}]}$

The morpho-syntactic feature content of the target word form is built up bit by bit from the content of its inflectional morphemes[9] (e.g. Selkirk 1982; Lieber 1992). In this process, the inflectional morphemes are added to the stem in a defined order. Affixes adjacent to the stem are added first. Siegel (1979) grouped affixes into Classes I and II for English. Class I affixes are added to the stem before Class II affixes. Consider the regular German past verb form $mach_{[\text{stem}]} + t_{[\text{past}]} + e_{[\text{1st Sg}]}$ '(I) did'. The past suffix is added to the stem before the person/number suffix. The reverse order – **machste* – yields an ungrammatical form. In addition, the person/number suffix is selected according to the preceding affix. Irregular past-tense forms such as *ging* '(I) went' take a person/number Ø-suffix: *ging*+ Ø.

Non-default forms are directly represented in structured lexical entries that allow default inheritance (Wunderlich & Fabri 1995: 253ff). The listed stem changes in the structured lexical entries cannot be reliably derived from their stem through the default rule: such a derivation fails in cases of fully idiosyncratic forms (e.g. go – went) or subregular forms (e.g. think – thought, bring – brought). Wunderlich & Fabri (1995) proposed default inheritance of phonological and categorical properties from higher nodes to low nodes in the structured lexical entries to account for subregularities among non-default forms[10]. Figure 1 displays an inheritance hierarchy tree for the non-default forms of the verb *sterben* '(to) die' in German (Wunderlich 1996: 96). Each node represents a combination of a phonological string and morphological feature values (Wunderlich 1996: 95). The base node [stɛrb] represents the base form of the lexical item as it appears in infinitival forms. Inflected forms of the base stem are represented in subnodes and related to the base stem by subpaths. They inherit all features from the base stem, except phonological information (e.g. […a…] […y…]) and morphological features (e.g. [+PART], [+SUBJ]). In this sense, the subnode […a…] inherits the onset *st-*, the coda *-rb* and the categorical feature [+V] from its mother node. Through this maximally underspecified representation, redundancies are avoided and lexical templates are shared by groups of inflected verbs which exhibit similarities between base form and stem variants (cf. Clahsen, Prüfert & Eisenbeiss 2002: 94).

[9] The features are transmitted through a process called *percolation*: any feature marked on the head of a construction will be inherited by that construction (Spencer 1991: 186).
[10] Jackendoff (1975) and Lieber (1980) explained subregularities by lexical redundancy rules, which do not freely generate new forms as does the default rule, but merely capture patterns of redundancy in the lexicon.

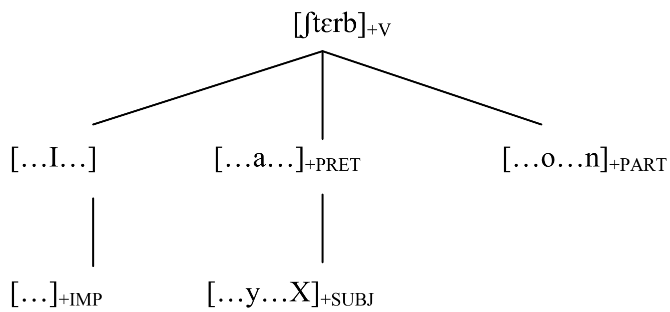

Figure 1: Inheritance hierarchy tree for the verb *sterben* 'to die'

Structured lexical entries can be traced back to Chomsky's (1970) notion of lexical redundancy rules, lexical rules (Jackendoff 1975) or default inheritance hierarchies (Corbett & Fraser 1993; Wunderlich 1996). The common purpose of this mechanism is to capture relationships between inflectional variants of the same lexeme. Furthermore, such a mechanism helps to avoid redundant information in the lexicon and hence concurs with the general principle of economy.

The affixation rule, joining lexical entries of stem and affixes, and the unproductive fixed stem entries, might produce different phonological forms for the same categorical information. That means that the past-tense form of 'to bring' is realised by an affixation rule as $[\text{bring}]_{V}[\text{ed}]_{past}$ and by an unproductive stem entry as $[\text{brought}]_{V,past}$. Paradigm structures work at the interface of syntax and morphology and function as a checking device. They are affix-driven, which means that they are defined by the combinatory options of the inflectional affixes. The affixed forms in the paradigm are specified for their categorical properties, just as *warf-t* '$(\text{you})_{pl}$ threw' is specified for [+2, +pl] (Wunderlich 1996: 97). Thus they represent the categorical distribution of inflection forms and allow only those syntactic forms that are licensed by the paradigm specifications. Paradigms are subject to the general completeness principle, meaning that every cell of a paradigm must be occupied, and the uniqueness principles, meaning that every cell of a paradigm is uniquely occupied (Wunderlich 1996: 99).

The minimalist morphology model clearly describes the mechanisms involved in the representation of morphologically complex forms, including which word forms are subject to each mechanism: non-default forms are represented as full forms, default forms are subject to an affixation rule. The nature of these two mechanisms involved in inflected word forms should also be reflected in the way they are processed and stored. Thus the model predicts that default forms should reflect signs of (de)composed representation while non-default forms should reflect full-form representation.

There is ample empirical evidence for the hypothesis that non-default forms are represented differently from default forms and that default forms are subject to a combinatorial process. It comes, for example, from language acquisition studies (e.g. Marcus et al. 1992; Weyerts & Clahsen 1994; Marcus et al. 1995; Clahsen & Rothweiler 1993), language processing studies (Sonnenstuhl, Eisenbeiss & Clahsen 1999; Clahsen & Felser 2006; Neubauer & Clahsen 2009) and brain studies (e.g. Ullman 2001a; Penke et al. 1997). We will present these studies in Chapter 3 on language acquisition theories and Chapter 4 on language processing theories, after introducing the relevant theoretical background. More interesting for now are two empirical studies which tested the specific predictions derived from the minimalist morphology model. Evidence for structured lexical entries of verb stem alternates in inheritance hierarchy trees, as proposed by Wunderlich & Fabri (1995), comes from Clahsen, Eisenbeiss, Hadler & Sonnenstuhl (2001), who conducted a cross-modal priming experiment to examine the relationship between stem variants of structured lexical entries. The participants were presented with visual targets preceded by an auditory prime and asked to make a lexical decision on the visual target. To test predictions of the inheritance hierarchy model, the hierarchical relation of primes and targets was varied. In the morphological test condition 3, primes were higher than targets in the inheritance hierarchy tree (helft → halft). In the morphological test condition 2, primes were lower in the inheritance hierarchy tree than targets. If activation spreads along the branches of the tree, starting at the base stem, activation of an item should cause activation of higher items in the branch. Conversely, activation of an item should not cause activation of lower items in the branch (helft → half). Reaction times were compared to the maximum amount of facilitation obtained in an identity condition for both 2nd plural present-tense and 2nd plural past-tense forms. The results showed that the priming effects of unmarked stems on marked stems were significantly different from those of marked stems on unmarked stems. Marked stems facilitated response to unmarked stems much more effectively than unmarked stems facilitated response to marked stems (Clahsen et al. 2001: 532). These results support the idea that inflected non-default forms are represented in a hierarchy tree and that this hierarchy is relevant in word processing.

More evidence in favour of hierarchical tree representation comes from Clahsen, Prüfert, Eisenbeiss & Cholin (2002), who ran a study on the production of inflected nonwords. These were designed by analogy to existing irregular forms, such as *helfen* 'to help', *sterben* 'to die' or *werfen* 'to throw', which take an -e- stem in the infinitive (*werfen* 'to throw') and an -i- stem in the imperative (*wirf* 'throw$_{[imp]}$'), in the 3rd singular present tense (*wirft* 'throws$_{[3rd\ Sg.]}$') and in the 2nd singular present tense (*wirfst* 'throw$_{[2nd\ Sg.]}$'). In line with the inheritance hierarchy tree outlined in Figure 1 above, the authors explained that the -e- vowel is unmarked and is located higher in the tree, while the present tense -i- stem is marked and is located lower in the tree. They investigated differences in the generalisability between the unmarked -e- stem and the marked present tense -i- stems in nonwords. Participants read infinitive form and 2nd/3rd singular present-tense forms of a nonword in a sentence context. The infinitive always took the -e- stem (e.g. *quelmen*). The 2nd/3rd singular present-tense forms took either the -e- stem (e.g. *quelmt*) or the -i- stem (e.g. *quilmt*). Participants repeated the nonwords and produced another inflectional form, the imperative form or the 2nd/3rd singular present-tense form, which they had not encountered before. The results showed an asymmetry between the generalisation properties of -e- and -i- stems in the subjects' responses. The participants frequently used -e- to form the imperative and 2nd/3rd singular present-tense forms, even when the nonverbs had been introduced with an -i- stem. In contrast, -i- stems were almost never generalised to nonce verbs that were introduced with -e- stems (Clahsen et al. 2002: 105). Again, these results corroborate Wunderlich's suggestion of structured lexical entries in inheritance hierarchy trees for verb stem alternates: the unmarked -e- base stem is represented as the highest node and is thus used as the default, in cases when it is not blocked by a more specific stem located lower in the tree.

Another morpheme-based model was suggested by Köpcke (1998) who agrees with the distinction between decomposed representation of fully transparent forms and direct representation of non-transparent forms. In contrast to Wunderlich & Fabri's (1995) minimalist morphology theory, Köpcke does not see these representations as two categories but rather as two poles of one continuum (Köpcke 1998: 50). At one extreme, we see morphologically and semantically fully predictable default forms whose morphemes are represented in the lexicon and combined by rule (e.g. *mach – ge-mach-t* 'done'). At the other extreme, we see idiosyncratic forms (suppletive forms such as *sein – ge-wesen*) which have item-specific representations (Köpcke 1998: 50). In between, non-default forms are represented in schemata according to their shared semantic or formal properties. The schemata capture typical phonological past-tense forms and the typical phonological properties of the verbs with which these past-tense forms are associated. Verbs which are represented in one scheme are subject to similar morphological processes. The schemata are lined up between two poles according to their transparency and form variation. Of verbs belonging to the scheme [#__aj+b/p] (e.g. *bleiben* '(to) stay', *reiben* '(to) rub'), 67% take an non-transparent inflection, but only 32% of [#__aj+t/d] do so, and even fewer (22%) for verbs in the scheme [#__aj+k/g]. Thus, the scheme [#__aj+b/p] has a stronger item-specific representation than schemes [#__aj+t/d] and [#__aj+k/g] (Köpcke 1998: 55). Like the minimalist morphologists, Köpcke states clearly that inflected forms can be subject to decomposition or full-form storage. He specifies these mechanisms for the extremes of the continuum: fully transparent, regular forms are subject to decomposition and suppletive forms are subject to full-form storage. However, Köpcke does not explain which mechanism applies to which scheme. For example, it is not clear whether rules apply only to fully transparent forms or also to partially transparent forms, or whether 'partially transparent forms' are subject to full-form representation. The question also remains whether a default rule, as specified by Wunderlich & Fabri (1995), or relatively discrete rules like 'add *-ed* to the verb to form the past tense' operate on fully transparent forms (cf. Pinker & Ullman 2002: 458). Nor are we informed about the nature of stored representations. For example, it remains unclear how item-specific representation can 'increase' with decreasing transparency. In addition, we do not know how Köpcke envisions the item-specific representations in a mental lexicon: is the lexicon just a list of words or is the lexical architecture affected by parameters such as frequency and transparency, as in an associative lexicon? Finally, Köpcke does not provide clear guidelines for assigning inflected word forms to specific schemata. One may only suppose that *-t* participles, as fully transparent forms in the continuum, may be subject to rule-like operations. Similarly, *-n* participles without stem change are phonologically and semantically fully transparent but the *-n* suffix must be stored (as we argued in section 2.1.3 above) and may therefore not be subject to rule-like operations but require at least some item-specific representation. Participles with *-n* suffix and stem change are less transparent than *-n* participles without stem change. They therefore might have 'more' item-specific representations than *-t* and *-n* participles without stem change and therefore may be located to the right of *-n* participles without stem change. Participles with *-n* suffix and stem change are also far from suppletive forms and therefore might be located left of the suppletive pole. The main problem with the model is that it does not spell out the mental mechanisms underlying the representation of inflected forms. It therefore produces less clear empirical predictions for German past participles than the minimalist morphology theory.

Morpheme-based models predict different processes for *-t* participles and *-n* participles. According to the morpheme-based approaches presented above, default forms such as the *-t* participle are subject to a default rule. Non-default forms such as *-n* participles with and without stem change involve some sort of memory component. In minimalist morphology, non-default forms are memorised and stored in structured lexical entries. In distributed morphology, the non-default forms are assigned to specific lists of phonological rules which the speaker needs to recall when producing or recognising a word form. In Köpcke's schema approach, non-default forms are supposedly more towards the right side (i.e. they show more variation and are less transparent) than default forms.

The reviewed morpheme-based approaches also differ in some aspects. Classical theories of generative phonology (Chomsky & Halle 1968; Halle & Mohanan 1985) and more recent theories of distributed morphology generate non-default forms by affixing an abstract morpheme to the stem and applying phonological rules that alter the stem's phonological form. These theories convincingly account for the observation that non-default forms are not fully arbitrary but form subgroups of similar phonological patterns, e.g. for English bleed – bled, sleep – slept, feel – felt or for German *trinken – getrunken* 'drink – drunk', *sinken – gesunken* 'sink – sunk' (cf. Pinker & Ullman 2002). One theoretical problem which arises in 'late insertion' theories such as distributed morphology is that such theories specify category combinations independently of the affix resources and may allow categories that are not realised in a given language. Also, they may allow category combinations that have collapsed through syncretism. 'Early insertion' theories such as the minimalist morphology theory avoid this problem because the lexical inventory determines which categories are possible and which category combinations project into syntax (Wunderlich 1996: 102).

The proposal of a dual language system has also received much attention from psycholinguists (Pinker & Prince 1988; Pinker 1991, 1997, Clahsen 1999), and has found strong empirical support. However, linguists have controversially discussed the basic assumption of two strictly separated mechanisms for rule-generated and stored inflected forms. For example, Wunderlich (1999) added that one default rule might not be able to account for predictable language phenomena which show more than one fully regular inflectional process. Spencer (1999) and Dabrowska (2001) argue that it is hard to identify the default rule cross-linguistically, especially in inflectional phenomena which show more than one fully productive inflectional type or none.

Wiese (1999) addressed the representation of non-default forms and argued that subregularities among non-default forms needed to be captured more explicitly in the mode. In accordance with their approach, Yang (2002) and Embick & Marantz (2005) argued that such subregularities should be captured by phonological rules. Even though the basic assumptions of the dual view of language representation have attracted criticism, it remains one of the most discussed, successively refined, and influential theoretical approaches in linguistic theory and of great relevance to psycholinguistic research.

2.2.2 Lexeme-Based Approaches

Alternative approaches to inflection have suggested that word forms are realised from an abstract representation (lexeme/stem/root) (Aronoff 1976, 1994; Anderson 1982, 1992; Stump 1993, 2001) and are organised in inflectional paradigms. Most people are familiar with inflectional paradigms from language class text books as lists or tables of inflected forms. Paradigms also play an important role in minimalist morphology theory where they function as the interface between morphology and syntax (Wunderlich 1996), but they are an epiphenomenon of inflection for distributed morphology, without significance in linguistic theory (e.g. Halle & Marantz 1993). From the perspective of word-and-paradigm models, the paradigm is an important theoretical construct which is reflected in the way morphology is formalised. The cells of the paradigm are specified for morpho-syntactic features and must be filled with word forms of the lexeme. Paradigms are only constrained by universal principles: if two rules are applicable to one paradigm cell, the more specific one is preferred (Specificity and Blocking, Kiparsky 1982, 1998; also Elsewhere condition or Panini's principle). Every cell of the paradigm is filled (Completeness: Pinker 1984; Wunderlich 1996) with only one form (Uniqueness: Pinker 1984; Wunderlich 1996).

Word forms of the lexeme are created by rules and fill the cells in the paradigm (Anderson 1992; Aronoff 1994; Stump 2001). In contrast to the rules of morpheme-based approaches (see example 4a), realisation rules do not add morpho-syntactic properties to the word form but only 'realise' a word form's already existing morpho-syntactic properties, which have been pre-specified in the paradigm cells (see example 4b). The rules do not differentiate between affixation and readjustment, as suggested in distributed morphology models, but rewrite the stem for any morphological change (Anderson 1992; Embick & Halle 2005).

(4)

a. $[walk]_V \rightarrow [walk]_V+[ed]_{[past]}$
b. $[walk]_{V[past]} \rightarrow [walked]$

One example of a word-and-paradigm model is the Paradigm Function theory of Stump (1993, 1998, 2001). This theory starts out with a lexeme, a paradigm of its feature specifications (e.g. 1st singular present, 2nd singular present) and a set of functions that realise these feature specifications. The inflectional functions operate on lexemes and construct the inflected word form of the lexemes. Consider the examples in (5). The abstract function in (5a) specifies that the past tense of lexeme x is formed from X and *ed.* If the lexeme is 'walk', the past tense function yields the form 'walked', (5b). Similarly for the 3rd person singular present-tense form shown in (5c), x yields x*s*, i.e. walk yields 'walks'. Grammatical specifications which are not specified in a function are subject to a default rule, which is illustrated in (5d). The Elsewhere Condition that 'the most specific rule applies' ensures that (5c) is preferred to the default rule (5d).

(5)

a. [TENSE: Past](x) = X*ed*
b. [TENSE: Past](walk) = walk*ed*
c. [TENSE: Pres] [PERS: 3] [NUMB: Sg] (x) = X*s*
d. x = x

In morpheme-based approaches, additive morphological operations are realised as affixes and modifying operations as, for example, vowel change. These morphological operations are realised in lexeme-based approaches as 'exponents' (e.g. Anderson 1992). Exponents are simply phonological material that is added to realise morpho-syntactic features. While the early item-and-arrangement tradition holds that affixes are additive in nature, Spencer (1991) and Wurzel (1970) argue that an affix can also be modifying or subtractive. Evidence for this understanding of affixes comes from inflectional affixes which change (umlaut *Mutter* → *Mütter* 'mother – mothers', ablaut *singe – sang* '(I) sing – (I) sang', *schlafe* '(I) sleep'→ *schliefe* '(I) slept'$_{[subj]}$) or delete the stem's phonological form (elision). Stump (1998, 2001) argues that it is difficult to explain additive and non-additive morphological phenomena within one theoretical framework. Therefore, he argues, affixation should be regarded as the application of realisation rules (or morpho-lexical rules, Anderson 1982, 1992), which are intrinsically open for additive and subtractive or modifying operations. Realisation rules indicate how specific morpho-syntactic features are spelled out. This means that all inflected default and non-default forms are subject to morphological operations; the first to additive processes, the latter to additive or modifying processes. This means that all German participle types are subject to realisation rules: *-t* participles are subject to additive processes (*-t* suffixation), as are *-n* participles without stem change (*-n* suffixation); *-n* participles with stem change are subject to modifying processes (stem change) as well as additive processes (*-n* suffixation).

The theoretical problem of ‘late insertion’ in morpheme-based theories discussed in the preceding section is often related to theories adopting ‘rules of referral’. Rules of referral allow, for example, the overwriting of one cell of a paradigm by the content of another. Zwicky (1985: 433) and Stump (1993: 452) claimed that rules of referral were necessary to explain syncretism. However, there have not been any substantial restrictions to rules of referral in the literature. Any cell could be overwritten, meaning that paradigm construction would eventually fail. Wunderlich (1996: 108) therefore argues that rules of referral could only be assumed if they were seriously restricted. Wunderlich, and many others with him, therefore rejects the idea of rules of referral in paradigms.

2.2.3 Full-Form Models of Inflection

Full-form models of inflection suggest that all inflected variants (e.g. *gemacht*, *machst*, *machen*) of one lexeme (*mach*- ‘do’) are represented as fully-specified entities which are associated with other inflected variants of the same lexeme. These theories state that morphological structure and rules are not relevant to the representation of inflected forms. They see morphological structure as an epiphenomenon of connections between individual word representations (e.g. Rumelhart et al. 1986: 217; Feldman & Fowler 1987). One of the earliest full-form associative models is the Satellite Model (Lukatela et al. 1980, 1987; Feldman & Fowler 1987). In this model, individual representations of inflected forms are arranged as satellites around a nucleus which represents the unmarked stem. Inflected variants have strong connections to their base stem but are not necessarily connected to each other. Early empirical evidence has supported the model, especially the prominent status of the stem (Lukatela et al. 1980; Günther 1988). More recent evidence, however, has not corroborated this specific organisation of lexical entries. Results from lexical decision experiments, for example, indicate affix stripping, which is not predicted in the model for any inflected word form (Marslen-Wilson, Tyler, Waksler & Older 1994; Clahsen et al.

2001). For example, Clahsen, Prüfert, Eisenbeiss & Cholin (2001), in a visual lexical decision task, analysed reaction times to German past-tense forms, consisting of strong stems that were regularly suffixed for person and number (e.g. *singen – sangen* '(to) sing – (we) sang'). Preterit forms were divided by stem frequencies into a high-frequency group and a low-frequency group, while full-form frequencies were held constant across both groups. The results showed a clear stem frequency effect. This was taken as evidence that strong stems are lexically represented and that are represented separately from regular affixes, so these are not represented together as full forms. In a second experiment the authors investigated preterit stem frequency in verbs such as *lügen – log – gelogen*, 'lie', which exhibit the same stem form *log* in both participle form and preterit form, to investigate whether forms that have the same stem but different functions share the stem or have separate stem representations. Again, groups were formed of high stem frequency and low stem frequency forms, while verb frequencies and word-form frequencies were held constant across both groups. The results showed a stem frequency effect for both groups, which was taken as evidence that the preterit stem frequencies affected reaction times, indicating that preterit stem forms were stored separately from participle stems, even though they are phonologically identical.

Current approaches in the associative tradition (MacWhinney et al. 1989; Bybee 1991, 1995; Bybee & Newman 1995; Elman 1999) hold that associations exist between all inflected forms based on phonological and orthographic form overlap and semantic similarity. The associative network model is also shaped by usage of word forms. High-frequency representations have greater lexical strength than low-frequency representations. Lexical strength allows easier access and offers greater resistance to diachronic change (Bybee 1995: 428). This approach is adopted by current models involving associative representation of inflection, such as schema-based models (Bybee 1995) and connectionist models (Seidenberg & McClelland 1989).

On this basis, Bybee (1995) explains the concepts of verbal paradigms (Anderson 1992; Aronoff 1994; Stump 2001) in terms of associative network representations. In her view, verbal paradigms are collections of highly connected verb forms that share, for example, phonological and orthographic characteristics. Forms with the same stems (*ge-sag-t*, *sag-st*, *sag-test* '(to) say') or affixes (e.g. *ge-schlaf-en* 'slept', ge-ruf-en 'called', *ge-lad-en* 'loaded') are associated in the network by their common sets of phonological, orthographic and semantic associations, not through shared morphological constituents. Accordingly, associative links depend on form overlap only and may be just as strong between members of a paradigm as with representations outside the paradigm. For example, the verb form *warten* '(to) wait' is as strongly connected to *warfen* '(they) threw' as it is to *wartet* '(he) waits'.

According to an associative full-form approach, *-n* participles and *-t* participles are represented alike because, without stem changes, they have the same amount of phonological, orthographic, and semantic overlap with their base forms. Participles with *-n* suffix and stem changes which deviate from the stem form in the vowel share less information with their base form. The assumption that strength of associations and phonological similarity between representations are correlated predicts that associative connections between *-t* participles and *-n* participles without stem change and their base stem (*tanz* 'to dance' – *getanzt*, *schlaf* 'to sleep' *geschlafen*) are equally strong and stronger than connections of *-n* participles with stem change and their base stem (*brech* 'to break' – *gebrochen*).

The results of empirical studies have corroborated the predictions made by the associative full-form model. They come, for example, from language acquisition studies (e.g. Szagun 2011) and language processing studies (e.g. Smolka, Zwitserlood & Rösler 2007) and will be presented in more detail in the later chapters devoted to these areas of research.

We have seen that there is a wide range of theories about the word structure of inflected forms, which can be grouped into two categories: theories which assume that default forms and non-default forms differ fundamentally in their representation (morpheme-based theories) and theories which assume that they do not (lexeme-based theories and full-form models).

Empirical evidence from adults has consistently shown differences between default and non-default forms. As we will see in the next chapters, these differences are observed in language acquisition and language processing and have produced double dissociations[11]. At least for now it seems difficult to reconcile these results with theories that only admit item-level differences between default and non-default forms. The current study will examine inflected words in three experimental studies, presenting results from adults and children at different age ranges. An

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[11] Double dissociation in this context refers to the observation that default forms have produced effect x in study 1 but not in study 2, whereas non-default forms have produced effects y in study 2 but not in study 1.

adequate theory must explain the full set of results, so we will come back to these theories when we discuss our results.

3 The Acquisition of Inflection: Theoretical Approaches

The debate on a dual versus a unitary language system in the human mind has long been fuelled by data from children's language production. In language production, children use inflectional morphemes productively. Evidence for the productive use of inflectional morphemes comes from children's application of inflectional morphemes to novel verbs (e.g. *lanen* → [lan]+[st]) (Bybee & Moder 1983; Pinker 1984; Rumelhart & McClelland 1986; Clark 1995; Bybee 1995) and their incorrect application of inflectional morphemes to existing verbs (**gegehst* 'goed' instead of *gegangen* 'went', Plunkett & Marchman 1991, 1993; Marcus et al. 1992, Marcus et al. 1995; Marchman, Plunkett & Goodman 1997). As both these processes yield forms that do not occur in the language input, the observations have been taken to give insight into the mechanisms involved in children's developing language system. Children's productive use of morphemes supported the idea that children not only memorise inflected forms from their input (as assumed in behaviourism, Skinner 1957) but also analyse their morphemic structures and apply them to new forms (Chomsky 1959).

The debate extends to more general questions, such as whether the language representation relies on grammatical rules, as claimed by linguistic theories (see section 2.2.1). The rule-like application of inflectional suffixes to new forms suggests that grammatical rules are indeed active in children's language system. It also raises the question of to what extent storage and grammatical rules interact. For example, one might suggest that children rely on memory to know which forms take regular or irregular inflection. These questions relate to the fundamental architecture of the cognitive language system not only in language acquisition but also in language processing in children and adults. An established range of methods, such as corpus studies, acting-out tasks and grammaticality judgments, has enabled the investigation of productivity in child language development (cf. Sekerina, Fernandez & Clahsen 2008). Most researchers agree that children often overapply regular inflection in English (e.g. *holded, *breaked, *feeled) and German (*geschlaft 'sleeped', *gebrecht 'breaked'), but only rarely overapply irregular inflection to forms that require regular inflection. But until now, researchers have fundamentally disagreed about why children apply these processes differently. Cross-linguistic research on the acquisition of inflection has revealed general acquisition patterns and language-specific characteristics (e.g. Clark 2003; Bittner, Dressler & Kilani-Schoch 2003; Eisenbeiss 2005; Stephany & Voeikova 2003; Stavrakaki & Clahsen 2009). This chapter focuses on German children's acquisition of inflection, specifically focusing on past participles. The first section describes how inflected verbs emerge in child utterances and the second reviews how current linguistic theories explain these observations.

3.1 The Emergence of Inflected Utterances in Children's Production

In contrast to many other language domains, children show not a steadily increasing but a u-shaped learning curve in the production of inflected forms: following a period of almost error-free production of inflected words, children's accuracy rates in inflected word production decline. Errors only gradually disappear until children show adult-like accuracy rates (Bowerman 1982; Marcus et al. 1992, Marcus et al. 1995). The three stages are not incremental but coexist: transition from one stage to the other may extend over a period of several months with the child showing the characteristics of more than one stage at a time (e.g. Kuczaj 1977, 1978: 325). Eisenbeiss (2005) noted that the u-shaped learning curve is a typical developmental pattern in the acquisition of inflectional markers across a range of languages including French, Swedish and Spanish (Eisenbeiss 2005: 222).

Children as young as 18 months show sensitivity to inflectional morphemes in their language input (e.g. Luther 2003). The first inflected verbal forms can be found as early as in the one-word stage in languages with rich inflectional systems (e.g. Niemi & Niemi 1987 for Finish; Pizzuto & Caselli 1994 for Italian) and around the two-word stage in languages with less rich inflectional systems. Bittner (2003b) described inflected forms in German child language production and reported present-tense indicative forms and a few past-participle forms around the age of 1;8 (Bittner 2003b: 59). Similarly, longitudinal studies show that children produce the first past participles very early, around the age of 1;10 (Weyerts 1997; Szagun 2011) or at an MLU less than 1.75 (Clahsen & Rothweiler 1993). Clahsen & Rothweiler (1993) further report that *-t* and *-n* suffixed participles emerge simultaneously and show a similar developmental pattern (p. 10). These first inflected word forms show a high degree of accuracy with respect to the target language (Bowerman 1982: 321; Marcus et al. 1992: 41; Bittner 2003b: 59).

Anecdotal evidence from the CHILDES corpus (MacWhinney 2000) corroborates this finding. At the age of 2;0, Simone produces the word *buddemacht* (= *kaputtgemacht*, example 6a) 'destroyed' which is correctly *-t* suffixed. Deviations from the adult target form are due to typical phonological processes at that age: elision of unstressed syllables (ka → ø), reduction of unstressed syllables (ge → e) and voicing (p→ b, t→d). Similarly, at the age of 26 months, Simone uses the form *puttgegang* (example 6b) in which she correctly produces the unstressed *ge-* suffix and the past participle stem. It is not possible to tell if she intended to correctly *-n* suffix the verb stem. The *-n* suffix has not been transcribed, but it is also phonetically reduced in adult German. Elision of unstressed syllables is a phonological process in typically developing children until the age of 3;5 years (Fox 2003) and cannot be counted as inflectional error. In these examples, Simone uses correct affixes.

(6)

a. *buddemacht* [kaputt gemacht]
'destroyed'
(Simone, 2;0.01, Childes Corpus)

b. *puttgegang* [kaputt gegangen] '
'broken'
(Simone, 2;2.21, Childes Corpus)

Most researchers agree that the correctly inflected forms in this first stage, also referred to as the pre-morphological phase, do not reflect morphological awareness but are rote-learned and reproduced entities (Ingram & Thompson 1996; Bittner 2003a; Penke 2006). Bittner (2003b: 60) supports this claim with findings from a corpus study on two children (age range 18–24 months). She reports that most verbs occurred with only one inflected form (e.g. *-en*, *-Ø or -t*) and that these forms were used in inadequate person number contexts (extended infinitive, e.g. *er gehen* '(he) go'), violating subject–verb agreement. These results indicate that inflectional forms do not yet represent an inflectional function (Bittner 2003b: 72).

Even though children do not yet correctly apply inflectional morphemes, they are already sensitive to correct co-occurrence patterns of inflectional markers at the age of 18 months, as Nazzi et al. (2011) have shown in experimental research on French subject–verb agreement. The context-adequate production of inflectional markers in German (Cazden 1968; MacWhinney 1978) also starts around 18 months with the beginning of first word combinations (Bittner et al. 2003b; Kannengieser 2012). Several factors influence the order and speed of children's acquisition of inflectional markers. Dressler (2010) found that frequency affects this process in German: frequent inflectional markers (e.g. 3rd Sg. German: -t, *geht* '(he) walks', cf. Peters &

Menn 1993; Penke 2006) are segmented before less frequent inflectional markers. Cross-linguistic evidence has shown that child speakers of inflectionally rich languages, such as Turkish, acquire inflectional markers earlier than those speaking inflectionally poorer languages. One reason for this might be that inflection in these languages fulfils more functions and is more informative (Wijnen et al. 2001; cf. Dressler 2010: 117).

In the next stage, children's production seems to take a step backwards: "…children do get systematically worse as they get older" (Marcus et al. 1995: 43). They incorrectly apply the regular inflection to words with irregular inflection, which they had formerly produced correctly. Overregularisation errors on irregularly inflected words are affected by frequency and phonological form. Marcus et al. (1992) described a relation between input token frequency and overregularisation rates for specific English verbs: the more often a child hears a given irregular form, the less likely he or she is to overregularise it (cf. Bybee 1995). The authors also noticed that the more frequent phonologically similar irregular forms ('phonological neighbourhood' or 'cluster': sing–sang, ring–rang etc.), the less likely a form is to be overregularised (cf. Bybee & Slobin 1982). Even though overregularisation errors constituted, overall, a small part of the production of inflected words (4.2% of past-tense forms in 24 child corpora, Marcus et al. 1992: 35), they are a phenomenon of child language which has been consistently reported in the literature (Bowerman 1982: 321; Clahsen & Rothweiler 1993; Elsen 1998; Lindner 1998; Clahsen et al. 2002; Szagun 2011). Production errors have also been reported in longitudinal studies of German past participles. These have differentiated between omission errors (suffix omission, prefix omission) and overapplication errors (of *-n*, *-t* or unmarked stems). The proportion of prefix omission was similar in the three studies and ranged between 10% and 16%, affecting both *-n* participles and *-t* participles to the same degree. The proportion of suffix omission differed across studies. Clahsen & Rothweiler (1993) and Weyerts (1997) reported a proportion of suffix omission around 14%, whereas Szagun (2011) reported a much lower proportion of suffix omission: around 3% for the older child group and 6% for the younger child group. While prefix omission seems neutral with respect to *-n* and *-t* participles, all the studies report a clear asymmetry with regard to suffix errors. The *-t* suffix was much more often overapplied to participle forms that require an *-n* suffix than vice versa. Clahsen & Rothweiler (1993: 13) report 44 *-t* overapplications and only one *-n* overapplication. Weyerts (1997) reported that 18.1% of *-n* participle productions were erroneously *-t* suffixed but only 1.2% of *-t* participle productions were erroneously *-n* suffixed. Szagun (2011) reported *-t* overapplications of the *-n* participles at the rate of 10% in the older group and 27% in the younger group, while the reverse was observed in only 1% of the *-t* participles in both groups.

In fact, these incorrect patterns prove an important step forward in children's inflectional acquisition, segmentation and – not always correct – application of inflectional markers. The contrastive application of inflection to mark inflectional variants of one lexeme appropriately in obligatory contexts is the key criterion determining children's productivity (Clahsen & Penke 1992; Pizzuto & Caselli 1994). These instances of overregularisation can also be found in Simone's production. As shown in example (7a), she produces the participle *geesst* 'eaten' with a *-t* suffix although it requires an *-n* suffix. Likewise, in example (7b), she produces the *-t* suffixed form *umgefallt* 'fallen over', which requires an *-n* suffix in its past participle. The reverse case is rare but can also be found, as Simone shows in example (7c). She produces the word form *geschlachten* 'slaughtered' which exemplifies an over*irr*egularisation error, in that she attaches the non-default *-n* suffix to the verb stem *schlacht* which requires the default *-t* suffix in its past-participle form.

(7)

a. *Ich hab g(e)rade geeßt.*
'I have just *eated.'
(Simone, 3;07.08, Childes Corpus)

b. *[Er] hat alleine umgefallt.*
'[He] has *falled over by himself.'
(Simone, 2;07.23, Childes Corpus)

c. *Mhm die wird geschlachten.*
'Mmh, she is slaughtered.'
(Simone, 2;10.11)

Once the child has identified the form and function of inflectional markers, they apply them to all forms, sometimes yielding overregularisation errors. But children also compare their output forms with input forms. If they mismatch, children realise there is an exception to the rule and replace their forms with the adult forms. For inflectional forms, children become aware that some verbs are exceptions to the inflectional rules, such as the irregular English past tense form 'went', which is an exception to the rule application yielding 'goed'. Children produce fewer and fewer inflectional errors, until they reach a correctness level of 90% or above. Simone's example utterances in examples (8) show that overregularisation errors and correctly inflected non-default forms can co-occur: at around the same time, Simone produces the incorrect form **geesst* 'eated' (3;07.08, (7)) and the correct forms *gefunden* 'found' (3;05.21), *gebrochen* 'broken (3;07.08) and *weggenommen* 'taken away' (4;00.06).

(8)
... mit meiner Creme die ich gefunden hab.
... with my creme, which I have found.
(Simone, 3;05.21, Childes corpus)

...er hatte noch sein [Sparschwein] gebrochen.
... he had broken his piggy bank
(Simone, 3;07.08, Childes corpus)

...und der große Junge kommt wieder und hat ihm das weggenommen.
...the older boy comes back and has taken it away from him
(Simone 4;00.06 Childes corpus)

3.2 Different Accounts of Children's Production of Inflected Word Forms

Acquisition theories generally agree that children first simply reproduce inflected forms from language input as unanalysed strings of phonemes with a semantic meaning. When they produce overregularisations, it is apparent that their linguistic output is more than just the reproduction of the linguistic input. Overregularisations such as *geschlaft* 'sleeped' are a systematic deviance from the language system and cannot be reproduced from the input. Overregularisations therefore reflect children's generative competence to combine linguistic entities to form new utterances (e.g. Marcus et al. 1992). Pinker (1984), following Chomsky (1965, 1975), has shown that language acquisition is far more complex than other learning processes. He pointed out that language input and generative competence are two very different things. Language input, on the one hand, is nothing but an acoustic signal. Language competence, on the other, involves abstract knowledge about the language, for example linguistic categories such as nouns and verbs, and how these categories can be combined to yield larger expressions. Furthermore, the lack of negative evidence from the language input makes the language acquisition process even more challenging. ‘Lack of negative evidence’ refers to the observation that caregivers do not give systematic feedback to the child on what is *wrong* in the child’s language output. Thus, children cannot (and probably would not) systematically revise their utterances on the basis of meta-linguistic knowledge provided by caretakers. Also, it has often been shown that the language input *under*determines the underlying operations involved in the target language (‘poverty-of-the-stimulus argument’, e.g. Chomsky 1980: 30; Marcus 1999, but see Pullum & Scholz 2002; in response Legate & Yang 2002; Fodor & Crowther 2002; Reali & Christiansen 2005). In other words, the input does not provide sufficient evidence to enable the child to directly build and test hypotheses about underlying language operations. One example concerns the structure dependency in English interrogative questions and children’s knowledge of it in the absence of learning experience (Chomsky 1975; Crain & Nakayama 1987; cf. Yang 2002). Forming an interrogative question in English involves inversion of the auxiliary verb and the subject:

(9)

a. Is Ben *e* buying a car?
b. Has Ben *e* bought a car?

There are many hypotheses compatible with the language input in (9). For example, the child could hypothesise that the first auxiliary verb in the sentence should be fronted, or the auxiliary verb that most closely follows a noun, or the last auxiliary verb, and so on. How does the child reach the structure-dependent hypothesis that sentences consist of phrases and it is the auxiliary that follows the first arbitrarily long noun phrase should be fronted? In language acquisition, the child somehow solves this dilemma: she or he identifies the correct operation very early. Chomsky (1975: 33) argued that the principle of structure-dependence is not learned from the input but forms part of the inborn conditions for language learning. Therefore, the child does not draw this specific linguistic knowledge from the language input but is equipped with these language principles in a grammatical component. In this view, what the child does is to test hypotheses about the language against input, in accordance with his or her inborn language principles (Pinker 1984; Fodor 1998a,b; Valian 1990).

Acquisition researchers agree that linguistic input and general cognitive mechanisms are essential in language acquisition. Current development research has shown that children use domain-general techniques such as statistical learning to extract information from the input (see Höhle 2009). Children are continuously extracting information from the language input to learn about the target language (Hirsh-Pasek et al. 2000). For example, they make use of the correlation between prosodic and syntactic boundaries to detect phrase boundaries (Höhle & Weissenborn 1999; Höhle & Weissenborn 2003; Wellmann, Holzgrefe, Truckenbrodt, Wartenburger & Höhle 2012). They make use of syntactic structure in verb learning (e.g. Fisher, Gertner, Scott & Yuan 2010). Children use word frequency and syllable frequency to detect word boundaries (Saffran, Aslin & Newport 1996; Brent & Siskind 2001; Goodman, Dale & Li 2008; Singh, Nestor & Bortfeld 2008) and are influenced by subsyllable frequencies to facilitate noun and verb learning (Ott et al. 2012). In addition, they detect phoneme frequency to enhance word learning (Storkel 2009; Storkel & Rogers 2000), which also plays a role in word- and non-word-repetition (Mainela-Arnold, Evans & Coady 2009; Coady, Evans & Kluender 2010). Even though these results indicate the relevance of domain-general abilities in language acquisition, the question remains of whether child language system involves a language-specific grammatical component. Two main types of acquisition theory can be distinguished and will be discussed below.

3.2.1 Dual System Approaches

Building on dual approaches to word representation (Wunderlich & Fabri 1995), dual-system views on language acquisition assume that inflected words are acquired in a fundamentally different way. In their view, children must acquire grammatical rules in order to combine morphemes from the lexicon into default forms (e.g. trees → [tree][s], houses → [house][s], walked → [walk][ed]). Non-default forms must be stored in the mental lexicon as whole forms ([brought], [children], [sang]). They assume that two mental devices are required to underlie these functions: the mental lexicon and the grammar. The mental lexicon is a subdivision of memory. It stores morphemes and simple words as arbitrary sound-meaning pairs. The mental grammar is a system of combinatorial, productive processes concatenating simple words and morphemes into complex words (Pinker & Ullman 2002: 456; Penke 2006). The mental grammar operates on the level of words and sentences. As shown in example (10a), grammatical rules join the suffix [-able], the verb stem [digest] and the prefix by [un-] to form [undigestable]. The mental grammar specifies how words (e.g. determiner, noun) are combined to form phrases. Example (10b) shows that a determiner phrase like [the girl] can be combined with a prepositional phrase [with red hair] to yield the complex determiner phrase [the girl with red hair]. Phrases are combined to form sentences. Example (10c) shows how determiner phrases [the girl with red hair], [ice cream] can be combined with a verb [likes] to form an inflectional phrase.

(10)

a. [[un]$_{prefix[}$[digest]$_{verb}$[able]$_{suffix}$]$_{adjective}$

b. [[The girl]$_{DP}$ [with red hair]$_{PP}$]$_{DP}$

c. [[[The girl]$_{DP}$ [with red hair]$_{PP}$]$_{DP}$ [[likes]$_{V}$[ice cream]$_{N\ VP}$]]$_{IP}$.

This account suggests that the acquisition of inflected default forms requires the child to develop grammatical aspects of the language: in this case, inflectional rules. In case of German -*t* participle forms like *gemacht* 'done', an inflectional rule unifies the affix -*t*$_{[PART]}$ with the stem *mach*$_{[V]}$ stored in the mental lexicon. More generally, the inflectional rule concatenates inflectional morphemes with the symbol 'V' (verb) and can thus join any lexical entry categorised as 'V' with an inflectional morpheme to produce default inflected forms. The acquisition of non-default forms requires the child to store arbitrary forms and to elaborate his or her lexicon (e.g. Pinker 1999; Clahsen 1999). Inflected non-default forms like *gebrochen* 'broken' are stored in the mental lexicon like simple words but with the grammatical feature 'participle'.

According to this theory, the acquisition task for the child is to identify the inflectional rules of the target language and memorise the non-default inflected forms which deviate from regular inflection. So far, the dual acquisition theory makes refers to linguistic concepts already introduced by Wunderlich and his colleagues. Prasada & Pinker (1993) and Pinker (1999) further elaborate this theory and suggest an interesting interplay between rule and memory. They suggest that the rule is constantly active and ready to produce a default form. In cases where the default inflection is not appropriate, the stored non-default form of a verb form needs to block the application of the default rule. The stored non-default form is only activated if it carries the desired grammatical information of the target form. For example, the lexical entry for [*gebrochen*]$_{[PARTICPLE]}$ 'broken' blocks the production of the default inflected form [*gebrecht*] 'breaked'. We see that, as well as learning inflectional rules, the child has to memorise the non-default inflected forms of a verb (e.g. Weyerts & Clahsen 1994). If a target non-default form has not yet been stored, the child applies the default rule, yielding an overregularisation error. Also, if the stored inflected form of a verb is not sufficiently strong, it is not able to block the default rule

(Pinker 1999: 219), with the result that children, and occasionally adults too, produce overregularised forms of non-default verb forms which they have already learned. An overregularisation error like '*goed' instead of 'went' or, for German, **gebringt* 'bringed' instead of *gebracht* 'brought' is therefore called a "blocking-and-retrieval-failure" (Marcus et al. 1992; Marcus 1995). Pinker (1999) suggests that stored inflected forms block the rule through an inhibitory link. That means the rule is not immediately turned off by the lexical entry but massively slowed down, so that the stored inflected form is retrieved before the rule produces the default form. On this understanding, overregularisation (e.g. *goed) occurs because the mental grammar and the mental lexicon overlap in their expressive power; both a stored inflected form and a rule-generated form can satisfy the syntactic and semantic features that must be overtly expressed (Pinker & Ullman 2002: 456).

This theory yields specific predictions about the acquisition of German past participles. First, the acquisition of the rule is sudden, so the occurrence of overregularised non-default forms is also sudden (Pinker 1999: 225). Second, default and non-default inflection behave differently. Since the inflectional rule applies to any lexical entry carrying the index 'V' for verb, overregularisation errors affect non-default forms. Since non-default inflection is not applied by rule, overirregularisation should not affect default *-t* participles (Pinker & Prince 1988; Marcus et al. 1992; Marcus et al. 1995; Clahsen 1999). The production of non-default forms shows characteristics of retrieval from memory. Since memory, but not grammar, is organised according to frequency, phonological and semantic properties, non-default forms are sensitive to full-form frequency, phonological form similarity and semantic associations among non-default verb forms. That means that high-frequency *-n* participles should be overregularised less often than low-frequency *-n* participles. Those *-n* participles which are phonologically similar to a large number of *-n* participles should show higher accuracy than *-n* participles which are phonologically similar to a smaller number of *-n* participles. Error patterns in *-t* participles should not be affected by item-level properties such as frequency and form similarity to other verb forms.

3.2.2 Single System Approaches

Yang's (2002) Rules and Competition theory is rooted in distributed morphology (Halle & Marantz 1993) and establishes a fully rule-based account for the acquisition of inflected forms. In line with the dual-system approach based on minimalist morphology by Wunderlich and his collaborators, Yang assumes that default forms are subject to a default rule. In contrast to the dual-system approach, Yang (2002) suggests that non-default forms are also subject to systematic rules (p. 61). In the tradition of distributed morphology, Yang suggests that the critical distinction is between being subject to a 'more general' rule or a 'less general' rule. The default rule is the most general rule (p. 65). Thus, the only distinction between default and non-default forms is that the default rule is not restricted to specific contexts and, hence, the most general rule. Non-default forms are subject to rules which are restricted to specific, in cases of suppletive forms, even *item*-specific, contexts.

The learning task for the child is to discover the default inflectional rules of the language (p. 65) and memorise which forms are subject to specific rules. In this view, errors such as *-t* overapplications to past participles are not blocking errors but failures to apply appropriate phonological rules over the default rule. Yang further argues that inflectional rules emerge in the child as co-existing and competing hypotheses. The learner has to decide for each non-default verb whether the default rule or a specific rule applies and, if the latter, which of the specified rules applies (Yang 2002: 61).

Overregularisation errors are explained through probabilistic strategies. During the process of language acquisition, the child uses the probabilistically most advantageous rule, leading to overapplication of the regular default rule to forms that require specific, non-default rules. Yang argues that overapplication errors are thus not "memory lapses" (Yang 2002: 11), as suggested by the word-and-rules theory of Pinker (1999), but misapplied phonological rules. However, Embick & Marantz (2005: 245) and other proponents of distributed morphology suggest that consulting a rule requires the speaker to rely on their memory. The speaker must remember which stem form is located on which list. For *sang*, for example, a speaker needs to know that there is a *-Ø* realisation of past tense, and that *sing* is on the specific list of verbs that appears with *-Ø*. One could argue that the failure to apply the appropriate phonological rules involves a memory lapse: either the verb has not been stored on the appropriate list or the stored verb has not been correctly retrieved from its list.

Applied to German past participles, the theory assumes that all forms are subject to phonological rules. The default rule applies to *-t* participles and specific rules apply to *-n* participles. None of the participle types are represented as whole forms in the lexicon (cf. Wunderlich & Fabri 1995) or associative network (cf. McClelland & Patterson 2002). The acquisition of inflected verbs should therefore not be influenced by word-level properties. On the other hand, participle types could show the influence of rule-level properties. Restricted rules can be applied to forms that should be subject to the default rule and the default rule can be applied to forms that should be subject to restricted rules. As a consequence, errors can occur in both directions.

A third option, rejecting the involvement of grammatical rules, comes from the family of constructivist approaches. It is rooted in theoretical models of full-form representation as suggested by Bybee (1991, 1995), Bybee & Newman (1995) and Elman et al. (1999). In this view, the child relies entirely on input information to construct the language system. Thus, input information and learning strategies, not a language-specific grammatical rule system, constitute the driving force behind language acquisition (e.g. Rumelhart & McClelland et al. 1986; McClelland & Patterson 2002; Tomasello 2000, 2009).

In a constructivist approach, language acquisition is item-based: individual words, phrases or sentences are stored as mappings of form and meaning without consideration of any syntactic category or inflectional type. With regard to inflected forms, all their regular and exceptional aspects are similarly extracted from the input and stored in a single, integrated mechanism in the same way (McClelland & Patterson 2002: 2). No inflected words are morphologically decomposable. Items in the network are associated based on phonological, semantic or functional overlap: the more overlap, the stronger the association between two forms. General cognitive mechanisms operate on the stored mappings of forms and meanings, identify common patterns and form analogies to similar cases (Rumelhart & McClelland 1986; Plunkett & Marchman 1991, 1993; Bybee 1995; McClelland & Patterson 2002; Cameron-Faulkner et al. 2003; Tomasello 2003, 2009). While grammar and lexicon are strictly distinct components in such a dual-system theory, on a connectionist understanding they are not separable components but merge into a single mechanism (cf. Goodman & Bates 1997: 560). The learning mechanism is not language-specific but children form analogies about almost any part of their world. The child assumes that rules established for a known situation also apply to a new situation (Gentner & Toupin 1988; Lu, Chen & Holyoak 2012): 'A is to B as C is to D' (see 11a, Hock 1991: 173). In language acquisition, analogy enables children to guess forms by inferring from inflectional patterns.

'House is to houses as fork is to forks' illustrates the analogical derivation of plural inflection (see 11b). 'Walk is to walked as talk is to talked' illustrates the past-tense rule, as in (11c).

(11)

a.	A	:	B	::	C	:	D
b.	house	:	houses	::	fork	:	forks
c.	walk	:	walked	::	talk	:	talked

There is a crucial difference between an analogy and the default rule application as described in a dual-system model. The inflectional rule contains the abstract linguistic variable 'V' and can apply to all lexical entries carrying the variable 'V'. Analogies in a connectionist network are based on form–meaning associations between discrete lexical entries. These can therefore not apply freely to any kind of verb but can only be generalised to those that share form or meaning. Hence, in contrast to default rules which apply to any example of a given linguistic category, analogy-building in the constructivist approach is restricted to, for example, specific phonological or semantic contexts. It is difficult to imagine how children learn the mappings between semantics and linguistic categories, or how they could identify verbs if they do not refer to the linguistic category 'V'. It may be that syntactic categories differ on a conceptual level. A verb might be intuitively understood as an 'action', such as 'play' or 'run', and a noun might be understood as an object. Young children, however, already produce and comprehend verbs that do not refer to actions, such as 'believe', 'be' and 'love' and they produce and comprehend nouns that do not refer to objects.

In the family of constructivist approaches, connectionist models have put forward specific assumptions about the associative network and learning mechanisms. Using computer simulations, connectionists modelled language acquisition in a single unitary network, parallel to a neural or computer network. They tried to replicate the dissociation between regular and irregular English past-tense forms in language acquisition to prove that these could be side-effects of the parameters of a unitary system. One of the pioneers in this field of work was Rumelhart and the PDP research group, who created a parallel distributed processing (PDP) model. The model was based on the controversial assumption (cf. Marcus et al. 1992) that the stage of overregularisation correlated with stronger lexical growth in regular than in irregular verb forms (Rumelhart et al. 1986: 219). The model consists of two parts. The core of the model is a simple pattern associative network which receives and analyses the relationship between the phonological structure of stem forms and their past-tense forms. The second part is a decoding network which translates an initial phonetic featural representation of the past-tense form into a permanent phonological representation based on '*Wickel*-features' (cf. Wickelgren 1969). These *Wickel*-features code phonological features of the preceding, central and subsequent phonological segment in one triple. The pattern associator contains two elements: a pool of input units representing the verb base form, and a pool of output units representing the past-tense forms that will be generated by the pattern associator in analogy to its previously analysed stem–past-tense form relationships. Each input unit is connected to each output unit. All connections initially have the same strength. In the course of the learning process, the network compares the output, which it would create on the basis of the input, to the target form in the input. If the forms are identical (hits or correct rejections), the weights stay the same. If they are not identical (misses or false alarms), the weights are increased (in the case of misses) or decreased (in the case of false alarms, Rumelhart et al. 1986: 226).

As outlined above, constructivist approaches reject the notion of grammatical rule, as do Rumelhart, McClelland & the PDP research group (1986). The same connections and units which produce default forms also produce non-default forms. For regular English past tense, *walk–walked*, the network copies the features of the stem to the past-tense form and adds /d/, /t/ or /^d/. For non-default forms, such as *keep–kept*, the network uses the same connection-based knowledge that produces default forms and additionally taps into specific connections activated by the particular properties of *keep* to produce the vowel adjustment (McClelland & Patterson 2002: 464). Differences between productive '*-ed*' and non-productive inflection are explained through the architectural parameters of the unitary network, namely frequency, semantic, phonological and orthographical similarity. The network tries to find the maximum commonality between stored forms and a new form to predict the past tense of the new form from that of the stored forms.

From the perspective of constructivist learning, the child stores increasing numbers of form–meaning pairs in the associative network, where they are associated according to overlapping features (Croft 2005; Goldberg 2006, 2009; Lieven 2009). The child exploits the overlapping semantic and form features of inflected items and establishes common patterns in the network (Plunkett & Marchman 1991, 1993; Bybee & McClelland 2005: 391). For example, the child realises that words like 'walked', 'danced' and 'looked' share the ending '*-ed*' and express past tense. The forms are associated in the network based on their common '*-ed* past' in the associative network and the child realises that the schema 'X-*ed*' expresses the past tense of X (cf. Goldberg 2009: 94, 98). It is unclear how the child discovers that the schema only refers to verbs if it does not know the linguistic category 'verb'. It is also unclear how the child can extract the schema *-ed* from the input in the presence of many other words which also contain *-ed* but do not express past tense, such as nouns like 'bed' or 'hatred'.

Implementations of German inflection in connectionist networks have been proposed by, for example, Westermann & Goebel (1995). Even though the authors assume a dual structure with a connectionist short-term memory allowing for the processing of symbolic rules and an associative memory storing forms, the model deviates from the Words and Rules model in crucial ways. For example, the rule and the memory work are not separate but work in parallel to produce *-t* and *-n* participles. 'Micro rules' (p. 240) produce a number of default vowel changes, also applying to *-t* participles. The associative memory stores the *-n* suffix and stem forms for both *-t* and *-n* participles where the default stem change does not apply. German past participles which share phonological properties are clustered: for example, rhyming verbs such as *heißen – reißen – beißen – schmeißen* (p. 238). Accordingly, participle forms which share the same suffix (*-t* or *-n*) are more strongly associated than participle forms which do not. Also, participle forms are more strongly connected to inflected forms if they share the same stem (e.g. *gesagt* '(have) said' – *sage* '(I) say', *geschlafen* '(have) slept' – *schlafe* '(I) sleep', than to inflected forms which take an alternated stem (e.g. *gebrochen* '(have) broken' – *breche* '(I) break'). To explain productivity, the connectionist approach would assume that the child extracts the schema '*ge+X+t'* or '*ge+X+n*' from the input and applies it to new forms. The child applies the schema based on form similarity, so *-n* and *-t* should be applied alike. The child also applies the schema based on frequency, and since frequency of *-t* participles and *-n* participles types is about equal, the inflectional *-n* and *-t* schema should be generalised with similar frequency to new forms (cf. Lindner 1998; Bybee & McClelland 2005).

To explain the period of overregularisation in children, connectionists assume a drastic increase in the proportion of default forms in the associative memory. Rumelhart & McClelland (1986) state that the higher proportion of default forms than non-default forms considerably strengthens the *Wickel*-features of the inflectional past tense *-ed*, which makes it more likely to be applied to all verb forms, including those which require a non-default form. Following a period of overregularisation, the proportion of correctly inflected forms gradually increases. The child compares its output against its input and realises the discrepancy between his output, e.g. *geschlaft* 'slept', and input, e.g. *geschlafen*. The child adapts the weights of input–output pairs, thus further elaborating its associative network.

The connectionist theory yields predictions about the acquisition of German past participles. First, overregularisations occur gradually because the inflectional rule is gradually acquired. This is because a steady increase in *-t* participles in the child's associative network causes the network to be gradually reorganised and leads the child to apply the *-t* participle inflection to other forms. Second, default and non-default forms behave similarly and any differences in their behaviour can be explained by parameters of the associative network. Third, all forms are sensitive to full-form frequency and phonological-form similarity and semantic associations among verb forms, because these are the parameters of the associative network. The influence of these item-level properties can be observed in language acquisition in the following way. The suffix *-t* is overregularised to *-n* suffixed participles and the suffix *-n* can be overapplied to *-t* suffixed participles. The rate *-t* suffix overapplication is higher because of a supposedly higher number of *-t* participles than *-n* participles. High-frequency forms have a stronger representation than low-frequency forms, so high-frequency *-n* participles and *-t* participles should be less often over(ir)regularised than their low-frequency counterparts. Participles which are phonologically similar to a large number of participles within their participle type have stronger connections to their phonologically similar forms than participles which are phonologically similar to a smaller number of participles within their participle type. Therefore, *-n* and *-t* participles which are phonologically similar to a large number of participles should be less subject to over(ir)regularisation than *-n* and *-t* participles which are phonologically similar to a smaller number of participles (McClelland & Patterson 2002: 2).

3.2.3 Discussion

The fundamental differences between theories of language acquisition become apparent in their explanation of overregularisation errors. According to a constructivist model, the child learns everything about the target language from the input. The input's characteristic frequency, distribution, phonological and semantic word properties are the prime parameters in child language acquisition and are reflected in how the child produces and comprehends language. The single-system constructivist approach explains overregularisation by a massive surplus of default inflected forms in the mental lexicon. However, there is a fundamental problem with this assumption. Empirical evidence from acquisition studies, which will be discussed in more detail below, has shown that there is no surplus of inflected default forms in real production data (Marcus et al. 1992).

One general problem with connectionist approaches is the limited scope of their theory. The first connectionist models tried to explain the English past tense (Rumelhart & McClelland 1986). Very few recent connectionist models have tried to explain other linguistic phenomena, let alone more than one. None has ever tried to go a step further and model the development of syntax, that is, sentence structure, and its interaction with inflection. The dual-system approach is clearly stronger in this regard. It clearly states, and studies have empirically confirmed, that inflectional operations are observed not only for German participles, but also for German plurals, and they are observed cross-linguistically (e.g. Swedish: Lundin & Platzack 1988; Spanish: Clahsen, Aveledo & Roca 2002; Portuguese: Veríssimo & Clahsen 2009; Italian: Say & Clahsen 2002). Furthermore, connectionists want to explain linguistic concepts with non-linguistic, domain-general parameters of the network. As indicated earlier, this undertaking does not ultimately succeed. Consider the task of describing the linguistic concept ‘noun’ in non-linguistic terms. Gleitman, Cassidy, Nappa, Papafragou & Trueswell (2005) and Kako (2004) have suggested that children initially categorise nouns as concrete objects. This is one explanation for the observation that verbs are produced later in children’s production than nouns, at least in English (Gentner 2006). Later, the concept of a noun could be transferred to a less concrete understanding of a noun. For example, children might understand that the noun ‘school’ does not only refer to the concrete building but also refers to older siblings’ daily occupation. Eventually, children might realise that nouns can also refer to abstract concepts such as ‘freedom’, ‘fun’ and ‘sleep’. If this is the case, however, it remains unclear how children are then able to draw the line between abstract nouns (‘sleep’) and abstract verbs (‘to sleep’). This explanation is even more puzzling when we consider that children use nouns correctly in syntactic structures from an early age and do not show inappropriate use of nouns depending on their level of abstractness. If such an explanation raises problems in even the most basic principles of language, innate knowledge of word categories seems more plausible as an explanation of the error-free use of word categories from the earliest utterances.

In addition, like rule-based accounts, connectionist models are not sufficiently specific in their predictions. Pinker & Prince (1988) explained that the representation of verb forms through *Wickel*-features allows for the generation of word forms that do not exist in any natural language. As these features take into account only phonological similarity, not morphological structure, phonologically similar but otherwise unrelated forms could be taken as a possible pair of present- and past-tense forms as, for example, in mirrored forms (*brag – grab*) or other phonologically similar forms such as *mail – membled*, *tour – toureder* (cf. Weyerts & Clahsen 1994: 434). However, these kinds of forms do not exist in adult or child language.

Even more importantly, Pinker & Prince (1988) and Marcus et al. (1992) investigated one of the model's main assumptions: that a sudden massive growth of default verb forms in the mental lexicon causes overgeneralisation. Using a child corpus, they tested the assumption that the onset of overgeneralisations coincides with rapid growth of default verb forms. Both studies showed that this phenomenon is not observed in the data, although the proportion of regular default participle types increases in the course of vocabulary growth. In fact, the proportion of regularly inflected verb tokens in language input and in the adult lexicon was almost constant (Marcus et al. 1992: 72, 81). These findings raise serious questions about the connectionist model. The authors noted that Rumelhart & McClelland (1986) achieved the u-shaped learning curve by first feeding the model irregular forms only, inducing a period of error-free production, and then feeding it a large number of regularly inflected forms, which resulted in a period of overregularisation. As these input scenarios did not simulate reality, many researchers have since criticised the model (Pinker & Prince 1988, MacWhinney & Leinbach 1991). New models have since been developed which run more successfully (Maslen, Theakston, Lieven & Tomasello 2004; Ruh & Westermann 2008), but none of these has been able to model all aspects of language acquisition. MacWhinney & Leinbach (1991) and Plunkett & Marchman (1991), for example, were not able to simulate the u-shaped learning curve. Marcus (1999: 277) acknowledged that Plunkett & Marchman (1993) used a more realistic phonological coding scheme, and explored a broader range of parameters than Rumelhart and McClelland's model, but he remarks that the model still does not match what we observe in children's input and output. Most importantly, Plunkett & Marchman's (1993) model shows an unrealistically high proportion of overirregularisation errors. The authors reported an overregularisation rate of 0.9% and an overirregularisation rate of 1.01%. Xu & Pinker (1995) investigated overirregularisation rates in children's production of English past-tense forms and found an error rate of 0.10%, one tenth of Plunkett & Marchman's estimated error rate. As long as unrealistic exogenous changes in the training or input are necessary to explain consistent observations in children's production, the connectionist model cannot be seen as an alternative to a model relying on a symbolic rule.

It is true that a one-system model with few assumptions that can explain the same amount of data as a two-system model should be preferred (Occam's Razor, Clahsen 1999), and the small number of core assumptions in connectionist approaches has impressed the scientific community. However, our review has shown that the connectionist model cannot explain the same range of data as the dual-system model. Also, it might be questioned if this one system with its numerous parameters, layers, nodes and highly complex inflection system is indeed simpler than a fairly straightforward dual-system model (cf. Marcus 1998).

In any case, after a long period of domination by generative theories, the connectionist approach has provided an alternative understanding of children's language. It has given new fuel to the debates on morphological acquisition and the mental representation of language in general (Fodor & Pylyshyn 1988; Lachter & Bever 1988; Pinker & Mehler 1988; Pinker & Prince 1988). Connectionist approaches challenged the foundations of the dual-system theory, such as that language was inborn, demanded two separate systems, and required language-specific abstract rules, and generativist researchers were forced to defend and explain their basic assumptions (e.g. Pinker & Ullman 2002). In particular, the assumption that inborn universal grammar knowledge is an undefined language black box is no longer accepted; instead, researchers were encouraged to spell out what is inborn and what can be learned from input (Naigles & Hoff-Ginsberg 1995; Morgan & Demuth 1996; Fisher & Tokura 1996; Höhle 2002; Höhle & Weissenborn 2003). Although the astonishing amount of information in the input does not invalidate the assumption that the language system involves a language-specific grammatical rule system, it forces both sides to delineate the boundaries between innate versus input-driven mechanisms more strictly and thus push forward the debate on language acquisition.

3.3 Previous Research on Inflectional Acquisition

Most empirical evidence in the debate on the child language system has come from data from children's production at different ages, in spontaneous settings or in elicitation tasks (cf. Brandt-Köbele & Höhle 2010: 1911). Studies of spontaneous production analyse children's *natural* language production. In these settings, the child is left with a caregiver in a natural environment and their spoken communication is recorded. As spontaneous production studies do not involve prearrangements to elicit specific linguistic structures, this method is best suited to the investigation of frequent rather than infrequent linguistic structures (Eisenbeiss 2009; Ambridge & Lieven 2011: 7). Elicited production tasks confront the child with a pre-structured communicative situation. The child is asked to, for example, describe a picture (e.g. "The horse eats grass") or to fill in a sentence gap (e.g. "The horse always eats grass. Yesterday the horse …"). Elicited production tasks allow a high degree of control over the linguistic structures produced (cf. Eisenbeiss 2005), and also offer the possibility of introducing novel verbs in a sentence context to be inflected by the child. Empirical findings from child language production studies have contributed substantially to the debate about whether the observed differences originate from qualitatively different representations of default and non-default inflection or whether they can be explained by general item-level factors.

Errors in the spontaneous or elicited production of inflected forms at different ages have been particularly informative. The analysis of errors is based on the assumption that errors follow the principles of the language system (cf. Shattuck-Hufnagel 1979; Penke 2006: 25). Different types of errors have been distinguished in the error analysis of inflected words. Affix omission, stem substitution and affix substitution (cf. Clahsen & Rothweiler 1993: 13; Szagun 2011: 738, 744) can be found in all inflected forms. The overview (12) below spells out these errors for the linguistic phenomenon under study here, German past participles. Affix omission can refer to the prefix *ge-* being omitted, as shown in (a1) *brochen* instead of *gebrochen* 'broken', or the suffix -t/-*n* being omitted as shown in (a2) *gemach* instead of *gemacht* 'done'. Stem substitution or stem application errors can surface as the unmarked stem in forms that require a marked stem, illustrated in (b1) *gebrechen* instead of *gebrochen* 'broken', or as the marked stem in forms that require an unmarked stem, as in (b2) *geblunkt* instead of *geblinkt* 'blinked'. Finally, a suffixation error can surface as the substitution of the *-t* suffix in forms that take the *-n* suffix, shown in (c1) *geschlaft* instead of *geschlafen* 'slept', or as the *-n* suffix in forms that require a *-t* suffix, exemplified in (c2) *gesagen* instead of *gesagt* 'said'. Production studies have shown that the main error type in children's production of inflected forms across all linguistic phenomena, languages tested and experimental settings is overregularisation, illustrated in (d), a combination of stem substitution error and suffix substitution error. In this error type, inflectional markers of the default form are overapplied to verb forms which require non-default inflectional markers. In overregularisation errors of German participle forms, the unmarked stem and the *-t* ending are overapplied to forms which require the *-n* ending and, in some cases, stem changes. For *-n* participles without stem change, overregularisation is identical to suffix substitution error, yielding forms like **geschlaft* 'sleeped' instead of *geschlafen* 'slept'. For *-n* participles with stem change, overregularisation yields forms like **gebrecht* 'breaked' instead of *gebrochen* 'broken'.

(12)

a. Affix omission
   1. Prefix: *_brochen (=*gebrochen*) 'broken'
   2. Suffix: **gemach_*(=*gemacht*), 'done'

b. Stem substitution
   1. **gebr**e**chen* (=*gebrochen*) 'broken'
   2. **gebl**u**nkt* (=*geblinkt*) 'blinked'

c. Suffix substitution
   1. **geschlaft* (=*geschlafen*) 'slept'
   2. **gesagen* (=*gesagt*) 'said'

d. Overregularisation error
   1. **geschlaf**t*** (=*geschlafen*) 'slept'
   2. **gebr**e**ch**t*** (=*gebrochen*) 'broken'

This section reviews studies investigating predictions from the theoretical approaches introduced above about the representation of default and non-default forms in children's spontaneous and elicited production. We will focus on studies of the English past tense, German past participle and German plural. All these inflectional phenomena show a clear distinction between default and non-default inflection. Even though we now know that regular and irregular English past-tense forms are confounded with a number of factors, they have, for decades, provided the empirical basis for language acquisition research. It is important to understand the arguments derived from the empirical findings from the English past tense to compare them with findings from German past participles and German noun plurals. We can then consider whether arguments derived from the regular and irregular English past tense also hold for German past participles. We will also review studies on German plural production. This is a rather unusual inflectional phenomenon in that the frequency distribution of the five German plural endings is very similar and cannot be captured by standard rules. Clahsen, Rothweiler, Woest & Marcus (1992) identified the *-s* plural as the default form and other plural endings as non-default. We will compare results for the *-s* plural with results for English past tense and German past participles to find out whether the results for default forms depend on their high frequency or whether the results are similar whatever their frequency.

Acquisition Studies of the English Past Tense

Studies of the English past tense have produced strong support for the dual-system view of language. One of the most comprehensive studies of children's production of English past-tense forms comes from Marcus, Pinker, Ullman, Hollander, Rosen & Xu (1992). The authors focused on overregularisation errors in irregular past-tense forms in a corpus of more than 10,000 utterances from 83 English children in the age range 1;3–6;6. The results showed overregularisation errors in the unmarked stem and the suffix. For example, the ending *-ed* was overapplied to irregular past-tense forms yielding forms like **buyed* instead of 'bought' (cf. (12) above, error type c1). Also, the unmarked stem and *-ed* were overapplied, yielding forms like **boughted* (error type 3a). Omission error analyses were drawn from previous work on four children in the age range 1;6–5;2 by Kuczaj (1976) and in an unpublished analysis by Cazden (1966, 1968) and Brown (1973, Brown et al. 1971, Marcus et al. 1992: 31f) and showed the u-shaped learning curve, i.e. children produced overregularisation errors after an initial period of error-free production (Marcus et al. 1992: 38, 40). The overregularisation rate was stable at a low rate (p. 129). The accuracy of irregular past-tense forms was affected by the item-level properties of phonological similarity and frequency. Correlation of overregularisation rates with the number of phonologically similar irregular past-tense forms showed that irregular forms (e.g. $\text{stung}_{\text{[irreg]}}$: $\text{swung}_{\text{[irreg]}}$ – $\text{clung}_{\text{[irreg]}}$ – $\text{flung}_{\text{[irreg]}}$, p. 125) were less likely to be overregularised if they were phonologically similar to existing irregular forms. In contrast, irregular verbs phonologically similar to existing regular verbs were not *more* likely to be overregularised ($\text{stink}_{\text{[irreg]}}$: $\text{wink}_{\text{[reg]}}$ – $\text{blink}_{\text{[reg]}}$, p. 127). A correlation of overregularisation rates with full-form frequency showed that high-frequency irregular forms, such as 'bought', were less likely to be overregularised than low-frequency irregular forms, such as 'arise' (p. 117f.).

We now evaluate these findings against the predictions of the three types of language acquisition theory. The u-shaped learning curve in Marcus et al.'s data is predicted by all current language acquisition theories. On a methodological note, the authors mention that it is not obvious how to measure a u-shaped developmental sequence, as there is no standard way of doing this. U-shaped sequences have been defined in a variety of ways and different measures of children's performance yield different shapes. In addition, the overall overregularisation rate is very low (2.5%, p. 35) and some transcripts in Marcus et al.'s sample start at a time when overregularisations have already occurred (cf. Marcus et al. 1992: 40).

The beginning of overregularisation errors, i.e. the acquisition of the rule, seems rather sudden, with a period of error-free production followed by a period of overregularisation (e.g. Adam, Eve and Sarah, p. 38–39) and is thus consistent only with a dual-system view. However, according to the dual-system view, one would have expected the highest overregularisation rates at the beginning of overregularisation, slowly decreasing when irregular items are memorised and block the rule. In fact, the overregularisation rate seems to increase over time. Eve, for example, shows the highest overregularisation rates at the age of 2;2 and Sarah at 4;6, well after their first overregularisations. The gradually increasing rate of overregularisation seems quite consistent with the idea that the inflectional rule is gradually acquired and gets stronger with increasing language experience.

Also theoretically interesting is the dissociation of regulars and irregulars in terms of item-level factors. Specifically, item-level factors affected only irregular forms and the phonological similarity of regular forms did not affect accuracy in irregular forms. These results are consistent with findings from Bybee & Slobin (1982) and suggest that irregular forms, but not regular forms, have a full-form representation in an associative lexicon. The dissociation between regular forms and irregular forms would have been considerably strengthened by an additional correlation of over*ir*regularisation errors with form frequency and phonological similarity for regular past-tense forms, parallel to that for irregular forms. After all, the effect of form property on irregular forms but not of regular forms is not compatible with predictions made by strictly rule-based approaches because they do not expect any influence at all from form property. Nor is the finding compatible with connectionist approaches because they expect to find an influence of form property for regular and irregular forms. The different influence of form-level properties regarding regular and irregular forms is only compatible with the predictions of the dual-system model.

An additional analysis of errors in regularly inflected forms would also be useful, to examine dissociations between regular and irregular forms in terms of overall error rate. Later studies by, for example, Weyerts & Clahsen (1994) and Szagun (2011) on German past participles compared error rates in *-t* and *-n* participles and have shown that over*ir*regularisation of *-t* participles was extremely rare. Xu & Pinker (1995) analysed overirregularisation errors in 20,000 regular past tense and past participles from nine children and reported an error rate of 0.10%. The low error rate in regulars, at least in these studies, could not possibly have provided enough data points to allow for statistical analyses of item-level influence on accuracy rates in regulars. The findings of Xu & Pinker (1995), Weyerts & Clahsen (1994) and Szagun (2011) indicate that errors occurred mostly uni-directionally, in that regular inflection was overapplied to irregular forms but not the other way round. A higher rate of overregularisation compared to irregularisation is in conflict with predictions by single-system approaches, predicting bidirectional overapplication errors.

A study by Marchman, Wulfeck & Weismer (1999) reported different results than Marcus et al. (1992). They investigated speech errors in 31 typically developing children and 31 Specific Language Impairment (SLI) children in an elicitation task of English past-tense forms. In this task, the experimenter presented verbs in a sentence context, e.g. "This boy is walking. He walks every day. Yesterday, he…", to elicit past tense forms, e.g. "…walked". Irregular and regular *-ed* past tense target forms were grouped into high-frequency and low-frequency groups based on the "adult white middle-class samples" (Hall, Nagy & Linn 1984). Items were further coded for stem-final phonemes (alveolar *vs.* non-alveolar) and similarity relationships across items (i.e. neighbourhood structure). The results for both irregular and regular groups showed that low-frequency items were more likely to be incorrectly produced than high-frequency items. Analyses on neighbourhood structure and frequency showed that low-frequency irregular forms which were phonologically similar to regular forms were most likely to be subject to erroneous *-ed* suffixation. The authors concluded that error patterns could not be accounted for by inflectional type alone but required additional factors such as frequency, neighbourhood and phonological structure. In their view, this finding does not support the fundamental distinction between regular and irregular past-tense forms, as advocated by the dual-systems account. Indeed, Marchman, Wulfeck & Weismer (1999) argued that their data supported a single-system approach: because it showed a clear effect of item-level factors such as frequency, phonological similarity and neighbourhood structure in both regular and irregular verbs, it is taken to support the assumption that both regular and irregular forms are represented in similar ways, as advocated by a single-system model.

The two studies indicate full-form representation for irregular past-tense forms, but produce contradictory results about the representation of regular past-tense forms. The conclusions by Marcus et al. (1992) and by Machman, Wulfeck & Weismer (1999) about the inflectional system are based solely on evidence from the English past tense. Further evidence from other inflectional phenomena as German past participles is needed to see whether they align with the predictions from a dual-system perspective or those from a single-system perspective (cf. Bybee 1995: 86f).

Acquisition Studies on German Past Participles

Errors in children's spontaneous production of German past participles have been studied in three longitudinal studies by Clahsen & Rothweiler (1993), Weyerts (1997) and Szagun (2011)[12]. Clahsen & Rothweiler (1993) analysed German past participle production errors in spontaneous speech samples from 19 language-impaired children (age range 3;1–7;11) in 71 recordings containing a total of 1,004 participle tokens and in three MLU-matched typically developing children (age range 1;6–3;9) in 91 recordings containing a total of 843 participle tokens. Weyerts (1997) investigated the production of past participles in nine children in the age range 1;4–3;9, analysing 185 recordings with a total of 1,462 participle tokens. She differentiated between *-t* participles and *-n* participles but not between subgroups of *-n* participles with and without stem change (p. 92). Szagun (2011) investigated past participle production errors in the spontaneous speech in two age groups of children (younger age group 1;4–2;10, older age group: 1;4–3;8 years) in 50 recordings containing 434 participle tokens.

All the studies report prefix omission error rates between 10% and 16%, with 12.81% in Clahsen & Rothweiler (1992) and 15.8% in Weyerts' (1997) data, and 16% in Szagun's younger age group and 10% in her older age group (Szagun 2011). The suffix omission rate is reported as different in the three studies: it was 13.52% in Clahsen & Rothweiler's (1993) data with a similar result of 14.4% in Weyerts (1997), but Szagun (2011) observed a suffix omission rate of only 3% in the older age group and 6% in the younger age group. It is not entirely clear whether the

[12] Elsen (1998) and Lindner (1998) also investigate German past participle acquisition in a single case study of children in the age range 0;8–2;5. However, they analyse the data qualitatively and not quantitatively. The data can therefore not be directly compared to the quantitative corpus analyses reviewed in this section.

discrepancy in suffix omission errors reflects an actual lower omission rate in Szagun's data or whether it can, at least in part, be explained by methodological differences. Some reasons speak for the latter explanation. Clahsen & Rothweiler (1993), for example, apparently counted suffixes which may have been reduced in natural phonetic coarticulation processes such as suffix omission, which can be seen from the examples on **buddegang* (=*kaputtgegangen*) 'broken', **rausgegang* (=*rausgegangen*), 'gone out' (p. 18). Also, suffixes are phonetically small entities and are generally difficult to perceive, so the recording quality might have had an effect. Some suffixes might vanish on non-digital recordings as used by Clahsen & Rothweiler (1993) and Weyerts (1997) but might be perceptible on digital recordings of better quality (Szagun 2011; cf. Sterner 2013: 201). This concern applies especially to participles with stem-final alveolar sounds such as /d/ and /n/ which are phonetically similar to the suffix *-n* and therefore difficult to differentiate (**fund* (=*gefunden*) 'found', Clahsen & Rothweiler 1993: 18). Further results show that suffix omission was higher for *-n* than for *-t* suffixes. Szagun (2011: 748) reported a rate of about 4% suffix omission for *-t* participles and 7% for *-n* participles and Clahsen & Rothweiler (1993: 18f) reported higher omission rates for *-n* participles than for others, ranging from 21% (at stage 1, 1;6–2;5 years) up to 67% (at stage 3, 2;6–3;3 years). Weyerts (1997: 98) reported 8.6% *-t* suffix omission compared to 20.2% *-n* suffix omission.

We now discuss these findings with respect to theoretical predictions. Stem errors and suffixation errors show a clear asymmetry in all longitudinal studies: the default inflection – unmarked stem and the *-t* suffix – is frequently applied to forms that require non-default endings, i.e. unmarked or marked stem and *-n* suffix (e.g. **gebrecht*, error types (b1), (c1) and (d) in (12) above). Meanwhile, overapplication of the non-default *-n* participle endings and stem changes to forms that require default inflection are rare (error types (b2) and (c2) in (12)). First consider the stem substitution errors. Overapplication of unmarked stems to participles requiring stem vowel change (e.g. **gebrechen* 'broken') is considerably more frequent than overapplication of marked stems. Weyerts (1997) observed only 0.3% stem errors for *-t* participles but 12.7% stem errors for *-n* participles with and without stem change. Szagun (2011: 749) found that marked stems were not overapplied at all to unmarked stems but that unmarked stems were overapplied in 12% of all incorrect participle forms. Similarly, Clahsen & Rothweiler (1993: 14, 20) found no substitution of a marked stem in place of an unmarked stem but observed 40 stem overregularisation errors. Consider now the suffix substitution errors. We find a similar picture as for the stem substitution errors, with the *-n* suffix rarely overapplied but the default *-t* suffix frequently overapplied. Clahsen & Rothweiler (1993) reported 44 *-t* overapplications and only one *-n* overapplication. Weyerts (1997) found that only 1.2% of *-t* participles were incorrectly *-n* suffixed and 18.1% of *-n* participles were incorrectly *-t* suffixed. Similarly, Szagun (2011) reported that *-n* overapplication (e.g. **getanzen* 'danced') in the two groups (each around 1%) was significantly less frequent than *-t* overapplication (e.g. **geschlaft* 'slept') in the younger child group (27%) and the older child group (10%, Szagun 2011: 745f). The error rates are clearly asymmetrical for both stem errors and suffixation errors. Overregularisation is frequent but overirregularisation very rare. The analyses and results are an important extension to the results reported by Marcus et al. (1992). The analysis is parallel for irregular and regular forms and the results also confirm the dissociations between irregular forms and regular forms regarding overall error rates, again confirming predictions made by the dual-system view and providing evidence against the assumptions that regular and irregular forms could be qualitatively similar in their acquisition.

In addition to Clahsen & Rothweiler (1993) and Weyerts (1997), Szagun (2011) also investigated the token and type frequency of past participles in children's utterances and language input. In her analysis, these frequencies were significantly higher for *-t* participles than for *-n* participle groups (Szagun 2011: 742f). Szagun (2011) proposes that the input offered reliable frequency as well as distributional information for the child to determine the most frequent 'default' inflection. On this understanding, children might detect the frequent co-occurrence of prefixation *ge-* and suffixation *-t* in the input. The frequency and distributional information might lead the child to apply frequently co-occurring inflectional markers to new forms. However, Szagun (2011: 742) compared *-t* participles to subgroups of *-n* participles with and without stem change. We argued in Chapter 2 that frequency analyses split by suffix seem more convincing than frequency analyses split by suffix and stem change (as proposed by Bybee 1995, 1999). Comparing *-t* participles to *-n* participles shows that the two suffixes occur about equally in Szagun's data. Following this line of argument, we remain unconvinced that the child can reliably detect whether the *-n* suffix or the *-t* suffix is the 'default' form of the language from the input.

The longitudinal studies by Clahsen & Rothweiler (1993), Weyerts (1997) and Szagun (2011) assessed the production of default *-t* participles and *-n* participles and extend findings of Marcus et al. (1992) in several respects. First, it confirms a strong dissociation between the overapplication properties of *-t* and *-n* participles. According to connectionist and rule-based models, however, overapplication should occur in both directions. The results also disconfirm a strong connectionist assumption that the overregularisation rate should have at least mirrored the frequency distribution of participles in German (about half-and-half). Second, German past participles constitute an inflectional system which, unlike the English past tense, is not confounded by frequency and structural differences. Hence, the results tell us that frequency and structural differences between default and non-default forms in English are not the (only) determinants of how inflectional markers are applied. We can conclude from the data that even young children are aware of a distinction between the default inflectional patterns and their exceptions (cf. Clahsen & Rothweiler 1993). The results regarding the influence of item-level properties further indicated dissociations between *-t* and *-n* participles and, hence, supported a dual-system view on language acquisition. Specifically, *-t* participles seemed unaffected by item-level factors, which is consistent with the assumption that they are produced by rule. The *-n* participles were affected by full-form frequency and phonological form, which is consistent with the assumption that they are represented in an associative lexicon and affected by its parameters. Another interesting finding from longitudinal studies on German past-participle production is that *-n* and *-t* suffixes were omitted equally often in the data (Clahsen & Rothweiler 1993: 13). It is difficult to accommodate this finding with the assumption that *-n* participles are represented as whole forms in the lexicon. We will also see in the next chapter that behavioural and brain studies on adults (see Clahsen 1999) did not find convincing evidence for the relevance of morphological structure to the representation of *-n* participles. However, these studies have been mainly on adult participants and it is quite possible that children's representations show qualitative differences to those of adults. The suffix omission results for *-n* participles from the longitudinal studies might be a first indication that morphological structure could also be encoded in non-default inflected forms. We will discuss later whether the coding of morphological structure in non-default forms might help to explain the findings from inflected forms, at least in young participants, and should be appealed to when seeking an explanation for the results of the behavioural studies of inflected forms in children discussed here.

We have seen strong evidence from children's spontaneous production of inflected forms for the dual-system approach. We now consider if a new set of data from an elicitation task using past participles by Weyerts & Clahsen (1994) similarly supports our interpretation. Elicitation tasks encourage children to produce the target structure frequently and provide a large number of data points which tell us whether the error types in longitudinal data, including suffix omission errors, are also observed in an elicitation task.

The authors investigated the acquisition of past participles in typically developing German children in two elicitation tasks. In the first experiment, 70 children (age range 3;0–9;0) answered questions about 21 short stories. The target answer required *haben* '(to) have' + participle (present perfect) of previously presented verb forms (nine *-t* participles, nine *-n* participles with stem change, one *-n* participle without stem change and two *-t* participles with stem change). The verbs were controlled for token frequency. The error analysis showed that suffix omission occurred in only five out of 1,171 participles (0.4%, p. 449); in other words, errors were extremely rare in the data. The results further showed that about 90% of the suffix errors were *-t* overapplications while only about 10% were *-n* overapplications. A similar proportion was found when comparing error rates in *-n* participles without stem change to error rates in *-t* participles (*-t* overapplication to *-n* participles 8.3% *vs.* *-n* overapplication to *-t* participles 1.7%). Frequency affected overregularisation in *-n* participles but not in *-t* participles: low-frequency *-n* participles were significantly more often incorrect than high-frequency *-n* participles, while no such difference was found for high- and low-frequency *-t* participles. The high rate of overapplication of the *-t* suffix and the rare occurrence of unmarked stem errors in experiment 1 led the authors to argue for a decomposed representation of *-t* participles. These results, together with the low rate of suffix omission, are consistent with Clahsen & Rothweiler (1993), who argued that overregularisation rises with the child's awareness of obligatory suffixation. In the second experiment, Weyerts & Clahsen investigated whether phonological similarity was the trigger for associatively formed *-n* past participles, as had previously been proposed for English past tense forms (e.g. Prasada & Pinker 1993: 36). Forty-one children (age range 3;10–8;10) were asked to form participles from 14 non-words which had previously been introduced in a sentence context. Half of the non-words were phonologically similar to existing *-t* past participles and half were similar to existing *-n* past participles. The results revealed a predominant pattern of *-t* inflection in all groups of non-words. Inflection was not affected by similarity to default or non-default inflection (cf. Marcus et al. 1992). Non-words which were phonologically similar to default past participles were *-t* suffixed in 79.6% and *-n* suffixed in 11.1% of the cases. Also, non-words which were phonologically similar to non-default past participles were mostly *-t* suffixed (86.1% of the cases) and only rarely *-n* suffixed (6.5% of the cases) (Weyerts & Clahsen 1994: 452). The authors take the results from experiment 2, in accordance with the results from experiment 1, to indicate that *-t* is established as the default inflection in children as young as three and used as a default inflection form which is not affected by frequency or phonological similarity. The results of the error analysis are in accordance with previous findings from spontaneous production of *-t* participle inflection (e.g. Clahsen & Rothweiler 1993). However, experiment 2 produced unexpected results. Previous studies had consistently showed an influence of phonological similarity on non-default inflection (cf. Marcus et al. 1992). From an associative perspective, this finding is even more surprising, as the authors had predicted an influence of phonological similarity on both *-n* inflection and *-t* inflection. They argue that children want to be correct language users, especially in an experimental setting, and thus conservatively use the *-t* inflection. Also, it should be remembered that experimental non-word tasks encourages rule application because the task can be successfully completed if the rule is always applied. It is also clear from the task that it is not necessary to check the lexicon for inhibiting entries because, by definition, they do not exist for non-words. Hence, it might be that the influence of full-form properties does not appear because the task primarily encourages rule application and does not test full-form representations in the mental lexicon.

On this understanding, in contrast to Marcus et al. (1992), this study says more about *-t* inflection than about *-n* inflection. It produces evidence for a strong default *-t* inflection, which seems unaffected by frequency or phonological similarity (Weyerts & Clahsen 1994: 455). In sum, the studies confirm the asymmetry between default and non-default, or regular and irregular forms, and also confirm the nature of the asymmetry predicted by the dual-system view. By contrast, the results were not fully in line with predictions from fully rule-based or connectionist approaches.

One of the main assumptions of connectionist approaches is that overapplication is explained by frequency of inflectional types. An interesting case in this debate is the German plural. The regular German plural has both a low type-frequency and a low token-frequency but shows many properties of a default rule (cf. Marcus et al. 1995; Clahsen 1999: 994f.; but see Plunkett & Nakisa 1997; Hahn & Nakisa 2000). The results from Clahsen et al. (1992), presented below, show that default rules are necessary to explain acquisition of the *-s* plural, even in the absence of one predominantly high-frequent inflectional type.

Acquisition Studies on the German -s Plural

In order to provide stronger evidence in the debate on frequency versus rules, Clahsen, Rothweiler, Woest & Marcus (1992) studied the inflectional system of German noun plurals. The German noun plural is realised with five different suffixes (*-e*, *-en*, *-ø*, *-er*, *-s*) and non-default vowel change, with none of the plural suffixes being statistically most prominent and the *-s* plural the least frequent (Clahsen 1999: 995f; cf. Marcus et al. 1995). Linguists have argued that the *-s* plural (*Kinos* 'cinemas') is the 'default' plural because it is used productively and exhibits the obligatory properties of a default inflection: it easily generalises to new words, it is indifferent to gender and phonological environment, and it is applied irrespective of stress pattern, syllabic structure, word-final sounds etc. (Wiese 1994; see Marcus et al. 1995: 226; Köpcke 1988). Also particular to German plural inflection is that more than one plural suffix can be used productively. Schaner-Wolles (1988) and Veit (1986) observed that *-n* is the plural suffix most often used in overregularisation. Clahsen et al. (1992) studied longitudinal data in German children to learn how plural forms are overregularised and how they are used in compounds. The latter question is relevant here, as Kiparsky (1982, 1985) described a morphological constraint that default forms must not occur within compounds. A correlation between overregularisation errors and avoidance in compounds indicates rule-based inflection, whereas non-productive use and occurrence in compounds indicates full-form processing. The authors analysed longitudinal spontaneous production data from a group of typically developing children in the age range 1;7–3;9 and a group of language-impaired children. They found a negative correlation between overregularisation patterns and plural forms in compounds. The language-impaired children used *-s* and the *-n* plural in overapplications and errors such as **Lamps* instead of *Lampen* 'lamps' and said **Auton* instead of *Autos* 'cars'. At the same time, SLI children did not use *-n* or *-s* plurals within compounds. In the typically developing child Simone (CHILDES corpus, MacWhinney 2000), the authors reported the same correlation of overapplication and avoidance in compounds, but only for the *-s* plural suffix. Referring to Kiparsky (1982, 1985), the authors take these finding to indicate that all the children in the study differentiate between default and non-default plural suffixes and apply them consistently in inflection and within Kiparsky's level-ordering system. This correlation indicates that children, like adults, distinguish between default and non-default inflection. The overregularisation patterns are in line with previous results found for the

English past tense and German past participles in that rule-based inflection was observed in spontaneous production and also affects another level of morphology, compounding.

We can conclude that the longitudinal studies and the elicited production study on German past-participle production and on the *-s* plural have convincingly shown that the dissociation between default and non-default forms by Marcus et al. (1992) is replicable in other inflectional phenomena. The study of German *-s* plurals, in particular, has confirmed that child language investigated in spontaneous and elicited production can only be explained with the help of linguistic rules. We have seen dissociative behaviour for default and non-default forms and supportive evidence for the assumption that default forms are subject to rule-based operations, whereas non-default forms must be represented as full-form lexical representations in an associative lexicon. We have further seen that the predictions of connectionist theories and fully rule-based theories were confirmed only selectively, in those parts where they made similar predictions to the dual-system theory.

The observation that all inflected forms were affected by suffix omission is less easily reconciled with the dual-system assumption that only default forms have separable morphological constituents. Szagun (2011), Weyerts (1997) and Rothweiler & Clahsen (1993: 176) report that *-n* suffixes were omitted as often as *-t* suffixes in the youngest age range, that is, when omission errors are detected at all. Contrary to the assumptions of a dual-system approach, *-t* participles had even lower suffix omission rates than *-n* participles. As the omission of suffixes is thought to be indicative of the analysis of verbs into their morphological components (Clahsen & Rothweiler 1993: 19, 21), this finding is difficult to bring into line with full-form processing of *-n* past participles. As discussed above, this result gives rise to an interesting suggestion about alternative ways to represent non-default forms in the mental lexicon outlined above. Clahsen & Rothweiler (1993) themselves raised the question of whether this finding indicates rule-based processing (e.g. Wunderlich 1992) or whether it can be accounted for by *-n* being represented as a sublevel regularity within a lexical entry (Marcus et al. 1992). We further suggested that full-form representations of non-default forms might be structured according to their morphological constituents and therefore allow for separate omission.

This chapter has considered the acquisition of inflected forms. Indications about the strategies involved in the mental access and retrieval of these forms come from theories and studies of language processing. These will be reviewed in the next chapter.

4 The Processing of Inflection: Theoretical Approaches

This chapter reviews the scientific debate on the question of whether children decompose complex words (e.g. *walked*) into their morphological constituents (e.g. *walk* + *ed*) in *real time* during recognition and production. Recent research has mostly focused on word recognition in adult speakers and has led to a number of morphological processing models. These models are in the tradition of previously presented dual-system models and single-system models. The first part of this chapter focuses on morphological processing theories based on adults, the second on morphological processing in children. For both adults and children, we first review theories explaining what information in inflected words is relevant in word recognition; specifically, whether the morphological constituents of inflected forms are accessed and retrieved in this process. We will then consider what information is relevant in the production of morphologically complex forms, according to current processing theories. Finally we will consider how the recognition and production of morphologically complex words might vary.

4.1 Word Recognition in Adults

Processing theories differentiate four steps in word recognition: pre-lexical access, lexical access, selection and lexical integration. On the prelexical access level, psycholinguists have investigated how the first contact with the lexicon is established for spoken word recognition. Few researchers believe that the incoming signal is directly mapped onto a lexical entry, as Goldinger (1998) suggests in his episodic lexicon theory. Most believe that the signal is mapped onto an intermediate representation between the signal and the lexicon: the prelexical representation. In this prelexical processing step, abstract units are extracted from the incoming signal, which then form the input for the lexical search. The lexical search benefits from the prelexical representation because it reduces the individual variability of the speech signal and enables a quicker and more accurate lexical search (cf. Pisoni & Remez 2005). Researchers have made different proposals about the units of the prelexical representation. Davis et al. (2002) have suggested that they consist of phonemes, others that they consist of phonetic spectral information or distinctive features (Lahiri & Marslen-Wilson 1991; Lahiri & Reetz 2002, 2010) or syllables (Mehler et al. 1981). In the next recognition step, lexical access, lexical entries are activated which match the incoming signal – or, rather, the prelexical representation. Usually, only a single entry is activated in lexical access. Then, the lexical entry is selected: this indicates that a lexical entry matches the incoming signal but information about the lexical entry is not yet available. It is in the final step of lexical integration that the lexical entry is activated.

In word recognition, theories of morphological processing have discussed two processes through which the lexical activation of morphologically complex forms could take place. In one, words could be processed through the properties of their whole form: this is referred to as 'full-form processing'. Alternatively, words could be processed through the properties of their morphological constituents: this is referred to as 'decompositional processing'. Processing theories put forward hypotheses about which of these routes are active in morphological processing and how they interact. Most approaches agree that full-form processing is applied to at least the restricted set of monomorphemic words. One of the central questions in the current debate is to what extent decomposition is involved in the processing and the representation of morphologically complex words.

Full-form models

Full-form models, as proposed by Manelis & Tharp (1977) and Butterworth (1983), suggest that all existing words of a language are listed as full forms in the mental lexicon. Their internal morphological structure (e.g. 'walked', 'walk', 'walks') is extraneous to the way words are processed and is not encoded in the lexical entry. Individual morphemes are irrelevant to how words are stored and accessed. Building on this idea, Rumelhart & McClelland (1986), among others, have implemented the full-listing model in computer-based associative networks. This model was initially intended to explain the acquisition of inflection and we encountered it in the preceding chapter (section 3.2.2). Like earlier full-listing models, these network models assume that all word forms, including morphological variants, are represented and accessed as a whole within one system. On this understanding, representation of the morphological structure of words is dispensable and does not require abstract rules, variables or structured representations – not even lexical entries. However, representations in the associative network are not only organised according to frequency (cf. Butterworth 1983) but are interlinked on the basis of phonological, orthographic and semantic overlap (e.g. Seidenberg & McClelland 1989; Bybee 1995; Sereno & Jongman 1997; Seidenberg & McDonald 1999; Plaut & Gonnerman 2000; McClelland & Patterson 2002). Words cannot be stored as form–meaning mappings in a lexicon, as in a dual-system approach (see below), but are represented as '*Wickel*-feature representations' and 'phonological representations' in an associative network. These representations are related to other *Wickel*-feature/phonological representations through weighted connections (McClelland & Rumelhart 1986: 222). The strength of the connection between two words increases with their semantic, phonological and orthographic similarity. The language system applies the characteristics of a known form to new forms to which it is similar. This is how full-listing models account for a large part of the current empirical evidence. Proponents of full-form models argue that different processing of inflectional default and non-default forms, as has been described by Pinker (1999) and Clahsen (1999), can be explained by genuine differences in frequency and phonological, orthographic and semantic overlaps between default and non-default forms. Predictions about the processing of default *-t* participles and non-default *-n* participles are based on the assumption that all inflected forms are represented alike and are represented as full forms in memory in terms of phonological and semantic codes. Full-form models predict that default and non-default forms should show similar processing patterns, namely indications of full-form processing and no indications of decomposition. Differences between default and non-default forms are explained through differences in the strength of connections between representations of words.

Rule-based single-system models

In contrast to associative full-form models, decompositional approaches to word recognition (e.g. Taft & Forster 1975; Halle & Mohanan 1985; Yang 2002; Rastle & Davis 2008) assume that all complex word forms are subject to parsing operations during processing. In this view, an automatic parsing process decomposes all word forms into stems (e.g. [mach]) and affixes (e.g. [te]) based on their formal surface properties, neglecting any semantic information. For example, the English past-tense form 'danced' would be decomposed into the stem 'dance' and the ending *-ed*; the German past participle form *getanzt* 'danced' would be decomposed into prefix *ge-*, stem *tanz* and ending *-t*. Next, the lexical representation of the stem (e.g. mach) is accessed and "provides an address" (Taft 1979: 270) for the full-form representation in a 'master file', which contains all the information about the full forms in a speaker's vocabulary, which are clustered and accessed via their stems. Taft and his colleagues (Taft 2004; Taft & Nguyen-Hoan 2010) have developed the model further. The revised decompositional model retains the obligatory pre-lexical decomposition on a form level and introduces another morpheme-based representation on an abstract level of representation which mediates between the form level and the semantic-syntactic level. The assumption of two stages in morphological decomposition, early form-level access and later morpho-semantic analysis, is consistent with recent findings from masked priming studies (Meunier & Longtin 2007; Rastle & Davis 2008; Silva & Clahsen 2008; Clahsen, Felser, Neubauer & Sato 2010).

As Taft and his co-authors argue that decomposition applies on a form level, regular and irregular past tenses are differently affected by decomposition. Regular past-tense forms carry strippable affixes and can be decomposed into stems and affixes. For example, 'talked'-*ed* is decomposed into 'talked' and *getanzt* 'danced' would be decomposed into the affixes *ge-*, and *-t* and the stem *tanz*. Not all irregularly inflected forms have strippable affixes. To take the English past tense, for example, it is hard to imagine how 'sang' could be decomposed into a stem 'sing' and an affix referring to vowel change. In German, however, irregular past participle forms do have strippable affixes. A word form like the non-default form *geschlafen* 'slept' could be decomposed into the stem *schlaf* and the affixes *ge-* and *-en*.

Rule-based single-system models predict that all past participles are decomposed into stems and affixes and should show similar processing patterns, which should always indicate root activation and not indicate full-form representation.

A decompositional approach has recently been proposed by Stockall & Marantz (2006). In their view, both types of form are clustered by lexical roots and functional morphemes. For example, the word form 'taught' is recognised as the output of the rule "/ti:tʃ/ + past → /tɔ:t/", thus activating the root 'teach' and a functional morpheme 'past'. In this view, early visual word recognition is not only sensitive to overt, regular word-form patterns, as proposed by Taft and his colleagues, but also to allomorphy patterns which do not conform to the regular word forms (Stockall & Marantz 2006: 90). This model considers morphological relatedness as an identity relation between the shared lexical root which cannot be reduced to semantic and phonological relatedness. The authors present evidence from two magnetoencephalography (MEG) visual priming experiments. Participants made lexical decisions about stem forms after processing one of the following primes: an identical stem (walk – walk), regular past-tense forms (talk – talked), irregular past-tense forms with high overlap in their stems (give – gave), irregular past-tense forms with low overlap in their stems (teach – taught) or a form with high orthographic overlap in a control condition (stiff – staff). The authors tested for the MEG component M350, indicating initial root activation, prior to lexical decision. They report dissociations between the MEG measure and the behavioural measure: early root morphological priming, as indicated by M350, was found for all morphologically related forms, but reaction times were slower for irregular forms with high overlap than for irregular forms with low overlap. Reaction times were shortest for regular forms. The authors interpret these results to indicate that, in very early stages, all inflected forms activate their root, but similar forms enter the competition at later stages, leading to longer reaction times. The results are also consistent with a different interpretation. Dual models with decomposed processing of regular forms and associative representation of irregular forms would predict similar results. These models suggest that root activation is not the only source of priming (Sonnenstuhl et al. 1999; Veríssimo & Clahsen 2009), but that full-form representations may prime each other via phonological and orthographic form overlap encoded in their associative representation. In this view, regular forms produce the strongest priming effect because regularly inflected forms activate the same lexical representation as the stem itself (walked – walked). Irregular forms with full-form representations produce partial priming driven by mediated activation of full-form representations. As associations between full-form representations are stronger with form overlap, irregular forms with a high orthographic overlap (give – gave) produce stronger priming than forms with a low orthographic overlap (teach – taught).

Dual-system models

A third family of theories, dual-route accounts, arises from the generative tradition and suggests that morphologically complex words can be recognised through whole-word access of associatively stored entries or through morphological parsing which decomposes visual or auditory input into its constituents (e.g. Marslen-Wilson et al. 1994; Chialant & Caramazza 1995; Schreuder & Baayen 1995; Clahsen 1999; Pinker 1999; Marslen-Wilson 2007).

Within the group of dual-system approaches, various factors have been examined that may determine the interaction of these two distinct core mental mechanisms in real time. No consensus has been reached so far about which of these factors is ultimately decisive. Proponents of the Augmented Addressed Morphology model (Caramazza, Laudanna & Romani 1998; Chialant & Caramazza 1995) assume that both processing routes are active in parallel, but that the full-form route is faster than the decompositional route. Chialant & Caramazza (1995) suggest that familiarity determines which route is used. Known inflected forms are always accessed by the full-form route and only newly-encountered or extremely rare regular word forms are subject to rule-based decomposition. In this view, the full-form activation of a known word such as *getanzt* 'danced' also activates the morphemic constituents, such as the affixes *ge-* and *-t* and the stem *tanz*, and phonologically or orthographically related representations, such as *stanzen* 'to stamp'. Frauenfelder & Schreuder (1992, Morphological Race Model) agree that both processing routes are active simultaneously, but suggest that stem frequency and word-form frequency, as well as phonological transparency, determine the route.

The Interactive Activation Model (e.g. Schreuder & Baayen 1995; Baayen, Dijkstra & Schreuder 1997; Baayen & Schreuder 1999) suggests that both processing routes are active and operate interactively. The full-form route maps full-form access representations into the associated concept nodes. These activate the corresponding semantic and syntactic representation. Meanwhile, the symbolic computation route works in three stages: segmentation, licensing and combination. First, the visual or auditory input is segmented into form-based access representations and these activate their associated concept nodes. The licensing stage evaluates whether co-activated representations' can be integrated into one adequate morpheme combination. Finally, the combination stage computes the meaning and syntactic function of a complex word from the meaning of its constituents. The Interaction Activation Race Model suggests that semantic transparency and computational complexity are additional factors that determine whether a word form has its own access representation (Schreuder & Baayen 1995: 133). Which of the two routes is more efficient depends on a number of linguistic word-form properties, such as frequency, suffix productivity, semantic and phonological transparency, suffix allomorphy, morphological family size and lexical neighbourhood (Frauenfelder & Schreuder 1992; McQueen & Cutler 1998; Bertram, Schreuder & Baayen 2000).

Some proponents of a dual-system model make a strong case for a fundamental distinction between default and non-default forms (Pinker 1999; Clahsen 1999; Ullman 2001a,b; Pinker & Ullman 2002). In this particular view, non-default forms are accessed as full forms in an associative lexicon. The non-default past participle *gesungen* 'sung' is represented and accessed on the basis of its full-form properties [gesungen]. Default forms are decomposed into their morphological constituents by a system of abstract rules. The default participle *getanzt* 'danced' is decomposed by grammatical rules and accessed through their morphological constituents [ge],

[tanz] and [t], which are represented in the lexicon. The grammatical rules operate on linguistic categories such as noun or verbs. The dual-system model thus differentiates between linguistic categories and all members of one word class processes in the same way (e.g. Pinker & Ullman 2002). This is a crucial characteristic of associative models, which do not differentiate between linguistic categories, but between entities, based on their full-form properties without regard to the linguistic category. In the dual-system model, the distinction between regular forms and non-regular forms reflects the duality of the human language faculty. The duality of language is assumed to be reflected in all aspects of language, such as language acquisition, language processing, language impairment and even the neurological representation of language in the human brain (esp. Ullman 2001a, 2004). Ullman (2004) formulated a hypothesis about the neurological representation of language based on the *words-and-rules* theory. He suggested that the distinction between stored and computed representations in language is related to two distinct brain systems, declarative and procedural memory. The declarative memory system is devoted to learning and remembering facts; the procedural system is responsible for combinatorial processes and sequencing of representations. Applied to the components of a dual language system, the mental lexicon is represented in the declarative memory and the mental grammar, containing inflectional rules, is stored in the procedural memory. We will come back to this model in the next section, when we discuss empirical evidence.

The dual-system processing theory predicts that default forms are decomposed by grammatical rules and non-default forms are recognised through their full-form properties. Hence, default forms, such as *-t* participles, should show indications of decomposition but no indications of full-form properties. The processing of non-default forms should show indications of full-form processing but no indications of decomposition. For example, full-form frequency and phonological form should influence the processing of *-n* participles but not that of *-t* participles.

The dual-system approach is compelling, its strong assumptions yielding precise predictions. However, one frequent criticism of the model is that listing forms and also accounting for them by rule seems mutually exclusive (‘rule/list fallacy’, Langacker 1987: 29). However, despite a theoretically strict distinction between rule-based processing for regular default forms and lexical processing for irregular non-default forms the words-and-rules-theory is open to the idea that usage influences processing to a certain extent. Pinker (1999) suggested that inflected default forms primarily rely on rules, but they *can* be stored in memory. More precisely, he discussed the possibility that rule application for specific default forms may leave memory traces leading to quicker rule application for high-frequency forms and slower rule-application for low-frequency forms in recognition. Unlike non-default forms, however, default forms do not *have* to be stored (e.g. Ullman 1993, 2001a, b). Whether a default form leaves noticeable memory traces depends on item-specific factors such as frequency (Baayen et al. 1997; Alegre & Gordon 1999) and form properties (cf. Balota & Ferraro 1993; Coltheart et al. 1993). Whether a stored default form is retrieved on the basis of its full-form properties or its morphological constituents may depend on, for example, task-specific factors (e.g. Baayen et al. 1997; Alegre & Gordon 1999; Pinker & Ullman 2002: 458). We will look for indications of memory representation for default forms in the data from the current experiments.

Authors have also discussed adjustments to more accurately explain the full-form representation of inflected forms. Prasada & Pinker (1993) and Pinker (1999) stressed that current dual-system approaches do not assume unanalysed full-form representations for non-default forms. Rather, they argued that representations of stored inflected forms are clustered according to form overlap and semantic associations, similar to entries in associative network models (explained below). Common patterns of different forms and can be applied to novel words which exhibit systematic phonological similarity to existing non-default past-tense forms ('phonological neighbourhood effect' or 'gang effect', Penke 2006: 65). An associatively organised mental lexicon in a dual system explains the observation that participants inflect novel verbs not always by default rule but also by analogy to existing non-default forms (Bybee & Moder 1983; Marcus et al. 1992; Prasada & Pinker 1993; Weyerts 1997; Berent, Pinker & Shimron 2002; Ramscar 2002).

Furthermore, Anderson (1992) proposed that full-form lexical entries for transparently derived forms represent internal morphological structure, as in [afford[able]], and only opaque derived forms, such as [strength], are represented as unanalysed wholes. Clahsen et al. (2003) adopted this theoretical approach and suggested that morphologically structured representations of derived forms are also relevant in the mental representation. They propose a refined version of the dual-system model, including a tripartite mode of representation: (a) frozen irregular forms stored in entries, (b) productively derived stem entries and (c) productively inflected word forms not represented in lexical entries (Clahsen 2003: 125ff). Traditionally, inflected forms have been divided into stored entries and productively inflected word forms. Much subregularity has been observed in German past participles and, according to some, should be more explicitly considered in the model. We will test whether the refined version of dual-system model is also a sensible refinement for inflected forms: (a) suppletive forms should be stored in full-form entries, e.g. *sind* '(they) are'; (b) subregular forms might be represented in combinatorial entries, e.g. [ge-[worf]-en] 'thrown' or [ge-[lauf]-en] 'walked'. Finally, (c), default forms are not represented as full forms but generated by combinatorial processes [ge-]+$[mach]_V$+[-t].

In section 4.4 we will review previous research, which has produced a large amount of supporting evidence for the dual-system model. Research on the processing of inflected word forms has investigated unimpaired and impaired adult language, and unimpaired and impaired child language, using a wide range of methods. Offline studies, also reviewed in section 3.3, have consistently shown that default (but not non-default) inflection is generalised to new forms independent of context, indicating that the underlying mechanisms, possibly grammatical rules, apply to any item of a given category. Reaction-time studies, such as priming studies, have suggested that inflected default forms are represented according to their morphological structure but that non-default forms are not represented as full forms (e.g. Sonnenstuhl et al. 1999). Finally, neurophysiological evidence has suggested that default forms are decomposed into morphological constituents and that the whole-form representations of non-default forms are lexically stored (e.g. Weyerts, Münte, Smid & Heinze 1996; Gross et al. 1999; Münte, Say, Clahsen, Schiltz & Kutas 1999; Rodriguez-Fornells, Münte & Clahsen 2002; Lück, Hahne & Clahsen 2006).

4.2 Word Production in Adults

Morphological processing models have mostly been tested on word recognition. We will now discuss how they can account for word production in adults. Generally, processing theories differentiate between three layers in word production: the concept, the lemma and the word form. The concept level represents the concept of an entry; the lemma contains semantic and grammatical information, such as word category and gender, and the word form provides the phonological information. The phonological word form activates phonological segments and the metrical form, known as phonological encoding (Shattuck-Hufnagel 1979). The phonological and metrical forms are converted into an articulatory gesture which initiates motor activity (Levelt, Roelofs & Meyer 1999).

Decompositional approaches

Early decompositional models (e.g. Taft 1979) do not specify whether production of morphologically complex words involves activation of their morphological constituents. For recognition, morphological constituents are represented in a morphological peripheral file, which is accessed in order to access the full-form entry in the 'master file'. For production, the 'master file' is accessed through the semantic peripheral file (Taft 1979: 269), which seems to leave aside access to the morphological peripheral file. Current decompositional models in the tradition of Distributed Morphology (e.g. Halle & Mohanan 1985; Yang 2002; Stockall & Marantz 2006) posit that stems of non-default verbs are clustered together in the master file. The entries are specified for affixes and, in some cases, additional 'stem readjustment' rules (e.g. Halle & Marantz 1993). This implies that a word form's internal structure (roots, stems, affixes) is represented in a similar way for default and non-default forms in both recognition and production. Thus, in word production, all inflected forms are subject to rule-based processes. Regular English past-tense forms like 'walked' are composed from their morphological constituents 'walk' and the ending '-ed'. Irregular English past-tense forms like 'taught' are composed from the stem 'teach' plus the application of a stem readjustment rule, yielding the past-tense form 'taught'. Applied to German past participles, the model predicts the same compositional processing strategies for *-t* participles and *-n* participles. The *-t* participle *getanzt* 'danced' should be composed from its stem *tanz* and the affixes *ge-* and *-t*. The *-n* participle *gebrochen* 'broken' should be composed from its stem *brech*, the affixes *ge-* and *-n* plus the application of a stem readjustment rule which turns *brech* into *broch*. Accordingly, fully rule-based models predict that there are no fundamental differences between the production of default and non-default forms. They predict that morphological properties of inflected forms are relevant in production but do not predict full-form properties to affect processing. If there are processing differences between default and non-default forms, these should be only gradual, possibly reflecting whether additional readjustment rules are required or not.

Full-form models

Recent full-form models state that all inflected words are produced based on their full-form phonological, orthographic or semantic codes in the associative memory (e.g. Sereno & Jongman 1997; Joanisse & Seidenberg 1999; Seidenberg & MacDonald 1999; Rumelhart & McClelland 1986; McClelland & Patterson 2002). Accordingly, the full-form frequency, semantic and phonological full-form properties of words should affect word production in all inflected forms. This processing strategy does not involve a word form's morphemic structure in production. The predictions for the production of German past participles are quite straightforward. The production of *-t* participles and *-n* participles should be affected by their individual word-level properties but not by their morphological structure. According to full-form models, we should expect differences between participle forms only when they differ in their number of shared full-form properties.

Dual-system models

One morphological processing theory that has particularly focused on production comes from Pinker and his collaborators (e.g. Pinker 1991, 1999; Prasada & Pinker 1993) and has been further elaborated by, for example, Clahsen (1999) and Pinker & Ullman (2002). In this model, elements of associative models and elements of rule-based accounts are combined. The production of inflected words in Pinker's (1999) *words-and-rules* model is illustrated in Figure 2. The lexical route retrieves full word forms directly from a mental lexicon. The lexicon is organised according to frequency, phonological and semantic associations, as associative models of full-form representation. Thus, the production of inflected words via the lexical route should show influence from full-form properties such as phonological and semantic associations, their frequency distribution and similarity to other word forms. In decompositional processing, an inflectional default rule, which is part of the mental grammar, combines stems and affixes to produce inflected forms. Thus, the production of words via the decompositional route should be influenced by the properties of their morphemes.

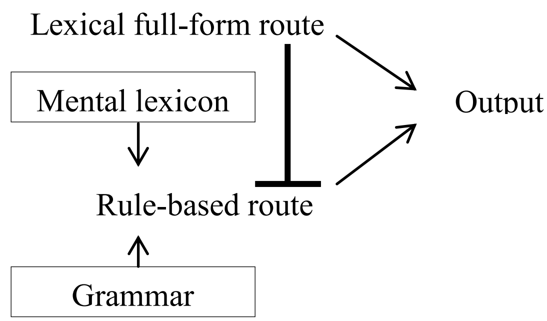

Figure 2: Words-and-rules model (cf. Pinker 1999)

We saw in Chapter 3 that proponents of the words-and-rules model assume an interplay between lexical full-form processing and rule-based processing in children's production of inflected forms. A full-form entry inhibits the application of the default rule. This interplay also holds for the production of inflected forms in adults. This 'blocking mechanism[13]' (Pinker 1999: 130; Pinker & Prince 1999: 16) is indicated in Figure 2 by the thick vertical line. Pinker (1999) explained that memory traces for default forms might affect the interaction between full-form processing and rule-based processing in production differently than in recognition. If the lexical processing route is involved in the production of default forms and acts out the inhibitory effect on the rule-based processing route, this leads to slower production of default forms with memory traces compared to default forms without memory traces. Evidence for this hypothesis will be illustrated in section 4.4.

In adults, the full representations are usually strong enough to successfully block the rule in the vast majority of cases. However, if a lexical entry is not activated in time, it cannot successfully inhibit the rule and would allow overgeneralisation errors, as also observed in adult speech errors or aphasic populations (e.g. Ullman 2004). Many studies have investigated neuro-cognitive correlates of default and non-default inflection in production (e.g. Ullman et al. 1997; Ullman 2001a,b; Pinker & Ullman 2002; Beretta et al. 2003; Ullman 2004; Joanisse & Seidenberg 2005; Sahin, Pinker & Halgren 2006). As mentioned in the section on adult word recognition, Ullman (2004) suggested that the declarative memory has access to stored items such as the inflected past-tense form [went] and is responsible for the blocking mechanism (e.g. inflected past-tense

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13 The blocking mechanism was first introduced in word-and-paradigm theories (Aronoff 1976). In these theories, the blocking mechanism prevents one cell being filled with two inflected forms. In this sense, the two blocking mechanisms express a similar concept to that in the words-and-rules theory.

form ‘went’). In his view, the rule-driven composition of words is located in the procedural system. Hence, the rule is applied in the procedural system, also producing – incorrect – forms such as ‘goed’. Sahin, Pinker & Halgren (2006) put forward neural evidence for a blocking mechanism in the production of English past-tense forms using the functional magnetic resonance imaging (fMRI) technique. Participants read base forms (‘walk’) and produced *-ed* past-tense forms and irregular past-tense forms in the sentence context ‘Yesterday, they___’, among other things (Sahin et al. 2006: 546). The results showed that *-ed* past-tense forms elicited greater activity in a region which the authors associate with conflict resolution or inhibition of habitual processes (Sahin et al. 2006: 556): the anterior cingulate and supplementary motor area regions. They therefore suggested that the stronger activity for irregular forms compared to regular forms reflected blocking processes or competition between similar irregular forms (Sahin et al. 2006: 555). However, the study shows serious methodological shortcomings. For example, the overt inflection condition (e.g. they walked) was not directly contrasted to a baseline condition but to zero inflection (e.g. they walk, p. 552). The authors argued that the production of ‘walked’ differed from ‘walk’, in that the former but not the latter required the retrieval of the phonological form of the suffix, its concatenation to the stem and, in irregular forms, phonological adjustments. However, it seems likely that producing ‘walk’ and producing ‘walked’ after reading ‘walk’ differ in more than just the affixation process. ‘Walk’ is also identical to the input stimulus, while ‘walked’ requires the participant to perform. The full picture of differences between the two conditions remains unclear, which is why the interpretation of the results remains, to this reader, speculative (cf. Trompelt 2010: 25).

The words-and-rules model yields specific predictions about the production of inflected forms. Non-default forms are produced as full forms via the lexical route and should be influenced by full-form properties. Default forms without memory traces are represented according to their morphemes, are subject to the decompositional route. The production of default forms should therefore be influenced by morphological properties. Default forms with memory traces may show a frequency disadvantage due to an inhibitory effect of the lexical route on the decompositional route.

4.3 Mental Representation and the Processing of Inflected Forms in Children

This section discusses to what extent morphological processing models for adults apply to children; specifically, whether children use the same mechanisms as adults in morphological processing or rely on different mechanisms. Finally, we discuss how general cognitive factors could affect children's language processing and lead to adult/child differences.

Applying experimental online techniques that have been used to study adult real-time language processing to children has been controversially discussed. Researchers have pointed out that the available methods rely mostly on reading ability or meta-linguistic knowledge. As children are still developing those skills and knowledge, their concerns were that these methods could produce non-interpretable results for children. Only over the past ten years have researchers applied online methods established for adults to children who cannot read yet, such as the speeded production technique (Clahsen, Hadler & Weyerts 2004) or the Event-Related Potential (ERP) violation paradigm (Clahsen, Lück & Hahne 2007). Researchers have also conducted reading studies with children (Feldman, Rueckl, DiLiberto, Pastizzo & Vellutino 2002; Rabin & Deacon 2008; Schiff, Raveh & Kahta 2008; Casalis, Dusautoir, Colé & Ducrot 2009; Deacon, Campbell & Tamminga 2010; Quémart, Casalis & Colé 2011; Ravid 2011) and obtained meaningful results. These online methods enable us to experimentally study children's development of morphological processing and to compare results found for children's online processing to those obtained for adults. We can thus test theories about how children's language processing develops over time.

Existing theories have made suggestions about how morphological processing might develop in children and how it compares to morphological processing in adults. Two perspectives on this question can be distinguished: children rely on the same mental mechanisms in language processing as adults (cf. *continuity assumption*, Pinker 1984). In this view, processing differences between adults and children stem from non-linguistic cognitive factors such as limited cognitive capacity and a less elaborated lexicon (e.g. Clahsen et al. 2004; Clahsen et al. 2007). Alternatively, researchers have suggested that children, at least at a very young age, rely on fundamentally different mental mechnisms in language processing than adults (cf. *discontinuity assumption*, e.g. Tomasello 2003; Cameron-Faulkner et al. 2003). Adult-like language processing only gradually develops over time. Processing differences between adults and children, in this view, reflect basic differences in processing mechanisms.

Fundamental differences between adults and children could be due to incomplete mental and neurological maturation processes in children which lead them to rely on different mechanisms from adults. Evidence for fundamental neural differences between children and adults comes from Schlaggar et al. (2002), who used fMRI to investigate the functional neuroanatomy of visual lexical single-word processing in adults and school-age children. The authors found differences in brain activation between children and adults in circumscribed left frontal and extrastriate regions. Although it was not entirely clear whether these neurological differences reflect general performance differences or maturational differences in functional neuroanatomy, the authors showed that at least a subpart of these brain regions was still subject to maturational processes at the age of ten. They suggest that even children of school age are not yet able to make full use of the processing resources located in that area. If language processing mechanisms in adults are located in certain brain regions (e.g. Heim et al. 2002; Martin 2003), and these are not yet fully matured in children, children might avoid these and rely on other processing mechanisms.

Experimental evidence from psycholinguistic studies could help solve this question. Results from children could be compared to those from adults to find out whether children exhibit similar patterns to adults in language processing and, if not, what factors can be held accountable for the findings. For example, experimental evidence showing that children process language in a fundamentally different way from adults supports the hypothesis of language development that children construct the language system only gradually (e.g. Tomasello 2003). In contrast, where experimental results are similar for adults and children, this supports the hypothesis, which claims that developmental differences between adults and children result from factors other than a changing language faculty (Pinker 1984; cf. Clahsen 1999: 1007). Adult/child differences would then be explicable not by differences in linguistic competence but by performance factors. Experimental studies on child language processing have indicated that development results from increases in the child’s lexicon in terms of lexical and morphological items. Limited cognitive resources in children (compared to adults) may also affect child language processing (e.g. Clahsen et al. 2004). Some researchers have specified which component of children’s cognition they believe to be responsible for language processing and how language experience specifically affects word recognition and production. Klingberg et al. (2002) have shown that working memory capacities are positively correlated with activity in the superior frontal and intraparietal cortexes, which are subject to maturational change until early adulthood. Clahsen et al. (2004: 25) proposed that children show differences from adult processing due to their slower speed of lexical access.

The challenges in research on children‘s language processing are to determine to what extent their language processing abilities are different from those of adult speakers, whether any differences can be explained by fundamental differences in adults‘ and children‘s language architecture, and to what extent they can be explained by non-linguistic factors such as cognitive capacities and language experience. We will now discuss how the factors ‘working memory span’ and ‘speed of lexical access’ may influence children’s morphological processing in the current study.

4.3.1 The Role of Working Memory

Working memory is responsible for the temporary storage and manipulation of information (Baddeley 2003). Baddeley & Hitch (1974) described working memory as a ternary structure with a verbal-acoustic subsystem (phonological loop), a visuospatial subsystem and the central executive, an attentional-limited control system on which the first two subsystems rely. A fourth subsystem, the episodic buffer (Baddeley 2002), has since been added to this model.

The incremental nature of language processing requires the continuous (though temporary) storing of information until the target lexical representation is identified. The relevance of working memory has been investigated in a number of studies on adult language (e.g. King & Just 1991; Just & Carpenter 1992) and child language development (e.g. Baddeley, Gathercole & Papagno 1998; Booth). Variation in working memory capacity, it has been argued, is a reason for inter-individual performance differences in offline and online studies on unimpaired and impaired child language. For example, Blake, Austin, Cannon, Lisus & Vaughan (1994) studied the relationship between memory span and the complexity of spontaneous language production in 2–5-year-old preschool children. Memory span was assessed by a word repetition task. Spontaneous speech was assessed by an analysis of spontaneous speech, determining the mean length of utterance[14] (Blake et al. 1994: 94). The authors concluded that memory span was a good predictor of syntactic complexity in spontaneous speech in the age group 2;0–3;6. However, they did not find this effect for children in the age group 3;6–5;0 (Blake et al. 1994: 100). Adams & Gathercole (2000) explored the relationship between speech production skills and working memory capacities in 4-year-old children. Children were grouped according to their working memory capacity, assessed by a non-word repetition task. Their speech production performance was assessed by a picture description task. The authors found that children with strong mental performance exhibited more elaborated speech production than children with weak mental performance. Their speech was characterised by a wider range of vocabulary, a greater mean utterance length and a larger variety of syntactic constructions (Adams & Gathercole 2000: 106). The same pattern was found in older children of four to 13 years (Baddeley, Gathercole & Papagno 1998). Working memory capacity has also been described as crucial factor in impaired language acquisition. Many studies of impairments in first language acquisition have shown that SLI children with exhibited poor performance in digit-span tests paired with a below normal performance on non-word repetition (Baddeley et al. 1998; Gathercole & Baddeley 1990). Weismer, Evans & Hesketh (1999) tested 20 SLI and 20 normally developing children in true/false comprehension questions and a word recall task. The two groups performed similarly in the true/false comprehension questions, but SLI children had a substantially poorer word recall. The authors interpreted these finding as evidence for the idea that SLI is caused by limitations in general processing capacities. Working memory has also been identified as a determinant of child language comprehension on the sentence level. Felser, Marinis & Clahsen (2003) used an offline task to study comprehension of complex sentences involving relative clauses such as those in (13) below. Children with relatively high working memory spans behaved as adults, who took into account the preposition linking the two possible antecedents when forming their preferences. Children with low working memory spans tended to attach the relative clause locally to the most recent antecedent, irrespective of the linking preposition.

(13)

a. *The doctor recognised the nurse <u>of</u> the pupil who was feeling very tired.*

b. *The doctor recognised the nurse <u>with</u> the pupil who was feeling very tired.*

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[14] For critical discussion of the mean length of utterance as a measure of syntactic complexity, see Blake et al. (1994: 100).

Roberts, Marinis, Felser & Clahsen (2007) found that working memory capacity affected performance in both an adult and a child group. The authors used the cross-modal priming technique to investigate filler–gap dependencies in adults and children. Participants listened to sentences such as (14) below, and were presented with pictures on screen. Participants were asked to make an *alive* or *not alive* decision. The results showed a substantial difference between high-span participants and low-span participants in both age groups. While children and adults with relatively high working memory span showed antecedent priming effects at the gap site, children and adults with relatively low working memory span did not. These studies support the suggestion that non-linguistic factors influence language processing in children (cf. Felser, Marinis & Clahsen 2003, Clackson 2012).

(14)
John saw [the peacock]$_i$ to which the small penguin gave the nice birthday present t_i in the garden last weekend.

Previous processing studies have included a working memory measure (e.g. Clackson 2012). This enables researchers to relate individual language performance to individual working memory capacity. Our study to will therefore also include a working memory measure. A well-established working memory measure is an auditory digit-span test (adults: HAWIE, Tewes 1991, children: HAWIK, Tewes 1983), in which participants listen to auditorily presented strings of digits and are asked to repeat them in the same or reverse order. It has been shown that scores in digit-span tests specifically predict performance on listening and reading comprehension (Gathercole, Willis & Baddeley 1991; Baddeley et al. 1998; Engle 2001, 2002). This type of test is therefore included in the current study to detect any influence of working memory capacity on task performance and explain any differences between adults and children.

4.3.2 The Role of Speed of Lexical Access

It is a frequent finding in processing studies that children need more time to respond than adults. Clahsen et al. (2004) have suggested that longer reaction times reflect relatively slow speed of lexical access. Participants who are slower in accessing lexical entries should have longer response times than participants with faster lexical access (Clahsen et al. 2004: 24).

There is empirical evidence that overall reaction times are indeed related to frequency effects, at least in production. The authors investigated the production of German past participles in two child groups (5;3–7;9 and 11;0–12;8) and an adult control group. They reported a frequency effect for non-default forms for all age groups and unexpected anti-frequency effects for default forms in children. In a next step, Clahsen, Hadler & Weyerts (2004) analysed the influence of overall production latencies, as a measure of speed of lexical access, on frequency effects. The authors found that adults with short overall production latencies also showed a frequency disadvantage for default forms, similar to the one found for children. The group of 'fast' adults did not. The authors concluded that speed of lexical access is generally slower in children than in adults and affects production latencies for default forms. This finding motivates us to test individual mean production latencies as a measure of 'speed of lexical access' in our experiments to assess whether this factor affects the processing of inflected forms.

4.4 Experimental Studies on Morphological Processing

Research on language acquisition has shown that the linguistic distinction between default and non-default inflection affects how children acquire and represent these forms in the mental lexicon. This section reviews experimental studies which investigate whether that distinction also affects how adults access and retrieve these forms in real time from the mental lexicon. Many studies have revealed differences between the processing of default and non-default forms, but as in the debate in language acquisition research, there is controversy over how these differences should be explained.

The majority of the processing studies have tested morphological processing theories in word recognition only. However, there are reasons to expect differences between morphological processing in recognition and in production: acquisition researchers have highlighted a discrepancy between children's recognition and production, at least in very young children (Smolensky 1996; Johnson, de Villiers & Seymour 2005; Brandt-Köbele & Höhle 2010). In processing research on adults, Pinker (1999: 130) has also drawn attention to divergent effects of frequency on inflected forms in adult recognition and production. This chapter reviews processing studies on default and non-default inflected word forms in adults and children for recognition and production. We will discuss three main questions. How can differences between default and non-default word forms be explained? Do default and non-default word forms behave similarly in production and recognition? Are these differences similar for adults and children?

4.4.1 Studies on Adult Processing of Inflected Forms

Acceptability Judgements

Acceptability judgements require participants to rate the well-formedness of novel inflected words, manipulated for their phonological or orthographical resemblance to existing words. Such judgments have been used to assess whether, and under what circumstances, participants have preferences for default or non-default inflection. For example, associative theories, which locate all forms in an associative lexicon, predict that phonological similarity to existing words positively affects ratings in all inflected forms. By contrast, dual-system theories, which locate only non-default forms in an associative mental lexicon, predict that only ratings for these non-default forms are positively affected by phonological similarity to existing inflected word forms. Many studies have confirmed the predictions of the dual-system model showing that participants judge the well-formedness of non-default, but not of default forms, depending on their phonological similarity to existing words (e.g. Bybee & Modor 1983; Prasada & Pinker 1993).

In one of the first acceptability judgement studies, Prasada & Pinker (1993, cf. Bybee & Moder 1983) studied the generalisation of English regular (e.g. walk – walked) and irregular past-tense inflection (e.g. swing – swung) to novel verbs. Novel forms which were phonologically highly similar to existing regular and irregular word forms (e.g. plip rhyming with grip, dip, nip), less similar (e.g. smaig – consonant clusters that appear in no English verb form) or only minimally similar (e.g. *ploamph* – a final consonant cluster that never occurs in English, Prasada & Pinker 1993: 8). The results showed similarity effects for irregular but not for regular past-tense forms. In line with dual-system models, the authors concluded that the regular *-ed* inflection generalises freely to new forms, while an irregular inflection generalises only if novel verbs are phonologically similar to existing forms. However, connectionist proponents have argued that it was the high frequency of the regular inflection that was responsible for the free generalisation of *-ed* forms (e.g. Plunkett & Marchman 1993; Hare, Elman & Daugherty 1995).

To test generalisation patterns in inflected forms whose default status is not correlated with frequency, Marcus, Brinkmann, Clahsen, Wiese & Pinker (1995) elicited acceptability judgements on German past participles. The German default past participle inflection *-t* is about as frequent as the *-n* inflection and not confounded with frequency like the English default past tense inflection *-ed* (Weyerts & Clahsen 1994; Marcus et al. 1995: 217; but see Bybee 1995, 1999 for a criticism of this view). All past participles were used in a new meaning and were either derived from nouns (condition 1) or from verbs (condition 2). An example for past participles derived from a noun is given in (15a). In this example, filling a cabinet with pipes is called '(to) pipe'. An example for past participles derived from a verb is given in (15b) (cf. Marcus et al. 1995: 224). In this example, whistling to directors at an audition is called '(to) be-whistle directors'. In each example, the verb was used in an extended meaning. The crucial difference between the two conditions was that nouns cannot have stored information on marked participle roots. Verbs derived from nouns ('denominal verbs') therefore cannot access information on marked participle roots. Existing verbs, however, which are used in an 'extended semantic meaning', do have stored verb root information (examples, see Neubauer & Clahsen 2009: 11).

(15)

a. Die kleinen dreieckigen Pfeifen für Yuppies sind bei der Kundschaft gut angekommen. Täglich muss Tabakhändler Meier die Regale auffüllen, auf denen die Pfeifen ausgestellt werden. Morgens ist daher immer seine erste Sorge:
['The little triangular pipes for yuppies are a success with the customers. Every day the tobacconist Meier, fills the cabinets on which the pipes are exhibited. His first concern every morning is:']

Sind die Regale auf schon bepfiffen? ['Have the cabinets already been pippen?']
Sind die Regale auch schon bepfeift? ['Have the cabinets already been piped?']

b. Die schöne Ilse glaubt, mit ihrem Pfeifen Karriere beim Film machen zu können. Wenn sie beim Vorstellungsgespräch gefragt wird, was sie kann, fängt sie keineswegs an, aus Goethes Faust zu zitieren. Nein, nein, Ilse beginnt zu pfeifen.
['Pretty Ilse thinks she'll have a movie career by her whistling. When asked at the audition what she can do, she doesn't start reciting Goethe's Faust at all. No, Ilse starts to whistle.']

Mittlerweile hat sie schon sieben fassungslose Regisseure bepfiffen.
['She has already be-whustle seven speechless directors.']
Mittlerweile hat sie schon sieben fassunglose Regisseure bepfeift.
['She has already be-whistled seven speechless directors.']

The results showed that adult native speakers of German rated *-t* participles of denominal verbs significantly better than *-n* participles, even though the *-n* items were homophonous with existing *-n* inflected participles. Semantically stretched past participles of existing verbs, however, were judged better with *-n* rather than *-t* participle endings. The results, it was argued, showed that the *-t* suffix was applied as the default when forming German past participles of new verb roots. This interpretation of German *-t* participle suffix is consistent with previous results for the English *-ed*. These results were replicated by Neubauer & Clahsen (2009) with 26 German native speakers (and with 34 Polish L2 speakers of German). Again, native adults preferred denominal items in the *-t* participle versions and extended items in the *-n* suffixed participle version.

Ramscar (2002) has put forward an alternative interpretation of the generalisation of *-t* to denominal verbs. He argued that *-t* participles were preferred in a new semantic context because *-n* participles already carried a different meaning. The *-t* ending was used in contrast to the *-n* ending to ensure the distinctness of the two meanings. However, Pinker (1999: 150) has pointed out that semantic stretching is a frequent phenomenon in language and should not lead participants to strategically use different inflections. Indeed, there are many cases in which a verb has different meanings (e.g. *brechen* – 'to break' *vs.* 'to throw up') whose semantic distinctness is not marked through different inflection (Er hat [etwas] gebrochen – He broke [sth.] *vs.* Er hat gebrochen – 'He threw up.') (cf. Neubauer & Clahsen 2009). Furthermore, this explanation cannot explain the dissociation between the two conditions, as *all* verbs were used in a new semantic context, and, following Ramscar's argument, should have opted for the distinct *-t* inflectional marker. In this sense, the two experiments make a strong case for distinct generalisation properties of *-t* and *-n* participle inflection.

Frequency Effects in Visual Lexical Decisions

In a visual lexical decision task, participants read visually presented strings of letters and are asked to decide whether the string is an existing word or not. Lexical decision tasks with non-inflected forms have consistently reported full-form frequency effects. Low-frequency items produced slower reaction times than high-frequency items (cf. Forster & Chambers 1973; Whaley 1978; Balota 1994; Clahsen, Prüfert, Eisenbeiss & Cholin 2002). Most researchers agree on interpreting this finding as a memory effect: since memory traces in the mental lexicon are strengthened by exposure, high-frequency items, which experience more exposure than low-frequency items, are accessed more quickly. Therefore, full-form frequency effects with (inflected) words are used as a diagnostic for full-form representation. Accordingly, stem-frequency effects with (inflected) words are seen as an indication that these are represented according to their morphological constituents (see section 5.1.3 for more details).

As indicated in Chapter 4 on processing theories, word recognition involves a number of processing steps. Marslen-Wilson et al. (1994) stressed the distinction between the modality-specific access representation and the central level representation and explained that the lexical decision task assesses participants' modality-specific access representations, which convey the visual input to the central lexical representations. Therefore, conclusions based on lexical decision results provide information about the modality-specific access representation but should be complemented by evidence from other techniques in order to gain a more complete picture of word recognition (cf. Neubauer & Clahsen 2009: 21).

Many lexical decision studies have reported clear differences between reaction times to default and non-default forms. Clahsen, Eisenbeiss & Sonnenstuhl (1997), for example, studied reaction times for word/non-word decisions by adult speakers for German *-t* participles (e.g. *getanzt* 'danced') and *-n* participles (e.g. *geschlafen* 'slept') in two experiments. Reaction times to high-frequency and low-frequency *-t* participles were compared to reaction times to high-frequency and low-frequency *-n* participles without stem change (*schlafen – geschlafen* 'sleep – slept', experiment 1) and *-n* participles with stem change (*fliegen – geflogen* 'fly – flown', experiment 2). The results clearly showed that reaction times to high-frequency forms were significantly shorter than to low-frequency forms in *-n* participles irrespective of stem change, but not in *-t* participles. Similar results were presented by Neubauer & Clahsen (2009), who used a visual lexical decision experiment to study the representation of 18 *-t* participles and 18 *-n* participles, all without stem changes, in visual recognition. Thirty native speakers (and 31 L2 speakers) of German took part in the experiment. Each participle group was further divided into a high word-form frequency group and a low word-form frequency group. Stem frequency and length were held constant across participle groups. An analysis of reaction times showed that native speakers had significantly shorter reaction times for high-frequency *-n* participles than for low-frequency *-n* participles. No significant difference, however, was found between the two groups of *-t* participles. The consistent results from the two experiments for *-n* participles and *-t* participles provide strong support for the hypothesis that *-n* participles, but not *-t* participles, are stored as full forms in memory.

Alegre & Gordon (1999) produced a different interpretation of their results. They tested English regularly inflected forms (e.g. walked) and simplex forms in a range of word-form frequency values in adult native speakers. Stem frequencies were held constant. For simplex forms, they found the expected word-form frequency effects. Regular forms were split into high-frequency (more than six per million, experiment 2) and low-frequency groups and produced an interesting result: the group of high-frequency forms showed a significant advantage. For low-frequency regular forms, however, there was no corresponding frequency advantage. It was concluded that regular forms can obtain full-form representations if they exceed a frequency threshold, in this case of more than six per million. Baayen, Dijkstra & Schreuder (1997) provided further evidence for the idea that regularly inflected forms could also have full-form representations. The authors tested the productive Dutch noun plural *-en* in a lexical decision experiment and found shorter reaction times for plurals with high full-form frequency than for those with low full-form frequency (experiment 1, p. 99).

In contrast to results by Alegre & Gordon (1999) and Baayen et al. (1997), Sereno & Jongman (1997, experiments 2 and 3) found no significant difference between reaction times to non-inflected and regularly inflected forms. The authors conducted a series of lexical decision tasks on uninflected English nouns (bare nouns) and regularly inflected English nouns with adults. For both inflected and uninflected nouns, they report shorter reaction times for items of higher word-form frequency than items of lower word-form frequency. The authors argue that the word-form frequency effect in both inflected and uninflected nouns supports a unitary associative system for all word forms, independent of internal morphological structure. However, both Baayen et al. (1997) and Sereno & Jongman (1997) tested noun inflection. It is not clear whether lexical decision times for inflected and non-inflected nouns can be interpreted together with lexical decision times for inflected and non-inflected verbs. Sereno & Jongman (1997: 428) themselves speak of "inherent differences between grammatical classes" and have shown that verbs and nouns generally behave differently in a lexical decision task (experiment 1).

Lexical decision experiments have produced clear frequency effects for non-default irregular forms, but conflicting results for regularly inflected forms. Baayen et al. (1997) and Sereno & Jongman (1997) reported full-form frequency effects for regular noun plural forms. Clahsen et al. (1997) and Neubauer & Clahsen (2009) reported no effect of frequency for *-t* participles. Clahsen et al. (1997) explained the discrepancy between these studies on linguistic grounds. They argued that Baayen et al. (1997) may have tested 'regular' but not 'default' forms. We briefly discussed this difference with the example of German past participles in section 2.1.2. 'Regular' forms and 'default' forms are often treated as equivalents, but there is a substantial difference between 'regular' in the common textbook sense and 'default' as described by Pinker & Prince (1994: 326). German plural formation provides an example. The plural rule '*heit*/*keit* + *-en* → plural' is perfectly regular in that all nouns ending in 'keit' or 'heit' take the plural affix *-en*. Nevertheless, the plural rule 'heit/keit + *-en* → plural' is not the default rule. The default rule should meet (most of) the 20 criteria of linguistic default processes as described by Marcus et al. (1995: 197). For example, it should extend to novel verbs and be overapplied in children's speech production. Clahsen (1999) has argued that the *-s* plural suffix is the German default plural. The dual-system theory only makes predictions for default forms, not for regular forms. If the Dutch plurals tested are regular but do not meet the criteria for the default inflection, Baayen and his colleagues may have identified a phenomenon for which the dual-system approach does not predict rule-based processing.

The interpretation of frequency effects in lexical decision tasks has been controversial. Even if the results for Dutch noun plural inflection cannot directly be transferred to German verb inflection, they suggest that regular forms show full-form effects. Particularly important for our study are the results from Alegre & Gordon (1999) on verb inflection. The strict distinction between decomposed representation for default forms and full-form representation for non-default forms may be difficult to maintain. It has also been shown that inflected forms produced full-form frequency effects in uni-modal visual lexical decision times but not in cross-modal priming experiments (e.g. for German noun plurals, Sonnenstuhl & Huth 2002).

Decompositional Effects in Priming

In priming tasks, participants are presented with two consecutive stimuli, a prime and a target. The participant is asked to respond quickly to the target by, for example, making a word/non-word decision. The relationship between the prime–target pairs is manipulated so that they overlap in, for example, meaning or morphological structure. When a semantic overlap between prime and target (e.g. professor – teacher) results in shorter reaction times, this has been seen as evidence that prime and target share semantic properties and that the target has been semantically pre-activated. When a morphological overlap between prime and target (e.g. walked – walk) leads to shorter reaction times, this has been interpreted as evidence that the prime and target share a morphological representation and that the target has been morphologically pre-activated. To determine the strength of the morphological priming effect, reaction times to the target after a morphological prime (*geschlafen – schlafe*) are compared to reaction times after an identical prime (*schlafe – schlafe*) and an unrelated prime (*greifen – schlafe*). The reaction times for a target item after an identical item are taken to show the maximum amount of facilitation. The reaction times for a target after an unrelated control item are taken to show the minimum amount of facilitation. If reaction times to the target after a morphological prime are similar to those after an identical prime but significantly shorter than after an unrelated prime, we speak of a 'full priming effect'. If reaction times to the target after a morphologically related prime are significantly longer than after an identical prime and significantly shorter than after an unrelated prime, we speak of a 'partial priming effect'. There is no priming effect if reaction times to the target after a morphological prime are significantly longer than after an identical prime and do not differ significantly from reaction times after an unrelated prime (see section 5.1.2 for more details).

Current processing theories account differently for morphological priming. Dual-mechanism models of morphological processing assume that complex words are recognised either by applying rule-governed computations that parse the word into its constituent morphemes or by retrieving the representation of the whole word from memory. Full morphological priming happens when the prime and the target share a morphemic unit. The activation of this shared unit causes the facilitation effect for the target word. Thus, full morphological priming effects are believed to reflect a process of morphological decomposition in morphologically complex words. Partial priming is explained in the mental lexicon. The activation of the prime representation is spread via associations with the representation of the target (Stanners et al. 1979; Marslen-Wilson et al. 1994; Marslen-Wilson & Tyler 1998; Pinker 1997; Sonnenstuhl et al. 1999; Neubauer & Clahsen 2009). In contrast, Seidenberg & Gonnerman (2000) and Gonnerman & Seidenberg (2007) assume that there is only one underlying mechanism for the processing of all words, including inflected words. Word recognition involves the establishment of stable activation states (attractors) over sets of many processing units that represent the orthographic, phonological, and semantic properties of a word. In this approach, supposedly morphological influence from one word form to another reflects orthographic, phonological or semantic overlap between the two forms.

Morphologically related primes are also semantically, phonologically and orthographically related to the target word. In order to distinguish between the influence of morphological structure and that of semantic, phonological and orthographic overlap on reaction times, the three types of overlap are held constant between participle types in cross-modal priming experiments. For example, the German participles *geschlafen* ‘slept’ and *gebadet* ‘bathed’ have the same amount of semantic, orthographic and phonological overlap with their stem *schlaf* and *bad.* A single-system representation would predict similar priming effects for the two participle types. If priming differences between these participle types still occur, they may reflect differences in the morphological representation of the participle types.

Stanners, Neisser, Hernon & Hall (1979) were among the first to test for (uni-modal) repetition priming effects in English inflected verbs (*-s* present tense, *-ed* and irregular past forms, *-ing* gerundive) and derived adjectives (-able forms). Participants were asked to read two consecutive stimuli (e.g. walked – walk) and make a word/non-word decision by pressing a button. They found full priming for *-ed* past-tense forms and *-s* present tense forms (experiment 1, p. 402) but only partial priming for irregular past-tense forms (experiment 2, p. 405) and derived adjectives (experiment 3, p. 407). The full priming effect for *-ed* forms and *-s* forms suggested repeated access to a lexical entry that is shared by the inflected forms and their base form. The partial priming effect for derived adjectives and irregular past forms suggested that these forms access separate lexical entries from their base verb form (Stanners et al. 1979: 410). A control experiment showed that orthographic similarity of irregular past tense forms could not explain the observed effects. However, it has been argued that priming effects from stimuli presented in one modality could reflect modality-specific representation. In cross-modal priming tasks, participants are presented with two subsequent stimuli in two modalities (auditory and visual) so that any observed effects cannot be explained by modality-specific facilitation. Hence stimuli presented in two modalities allow the assessment of modality-independent, central effects (e.g. Marslen-Wilson et al. 1994, Marslen-Wilson & Tyler 1997). Such effects cannot be due to pure form overlap but must stem from a common central representation.

Sonnenstuhl, Eisenbeiss & Clahsen (1999) conducted a cross-modal priming experiment with German *-t* participles and *-n* participles without stem change. Participants listened to a prime and were asked to make a lexical decision on a visually presented target word which immediately followed the prime. The target items were 1st person singular present tense forms. As shown in Table 4, the target items were preceded by the same form in the identity condition, by the corresponding participle in the morphological test condition and by an unrelated 1st person singular present tense form in the control condition. Reaction times were measured.

	***-t* participles**	***-n* participles**
Identity	*wünsche* '(I) wish'	*schlafe* '(I) sleep'
Test	*gewünscht* 'wished$_{[part]}$'	*geschlafen* '*slept*$_{[part]}$'
Control	*öffne* '(I) open'	*sage* '(I) say'

Table 4: Example stimulus set from Sonnenstuhl et al. (1999: 209)

For both participle types, the authors reported significantly shorter reaction times to the target in the test condition than in the control condition. However, reaction times in the test condition and mean reaction times in the identity condition were different for *-t* and *-n* participles: morphological prime–target pairs of *-t* participles produced similar facilitation to the identical prime–target pairs. Morphological prime–target pairs of *-n* participles produced significantly longer reaction times than identical prime–target pairs. Sonnenstuhl et al. concluded that *-t* participles yielded the full morphological priming effect, while *-n* participles yielded only a partial morphological priming effect. They also concluded that *-t* participles were decomposed in the mental lexicon. Therefore, *-t* participles activated the same lexical representation as the target form, thus yielding direct priming and a full priming effect. Meanwhile, *-n* participles, it was suggested, were stored as whole forms, linked to each other via semantic and phonological relations, thus yielding only indirect priming facilitation reflected by a partial priming effect. However, there was a puzzling aspect to the data. When comparing the raw reaction times in priming conditions *between* participle types, we see that the participle types do not differ in reaction times after unrelated primes or morphological primes, but only after identity primes. This difference between participle types was not predicted, since the materials were matched for a number of linguistic criteria. Reaction times to targets in the identity condition and the unrelated condition should have been similar, while meaningful differences between participle types were only expected in the morphological test condition. This issue will be illustrated in more detail later.

Similar patterns have been found in other priming studies. Neubauer & Clahsen (2009) replicated Sonnenstuhl et al.'s (1999) findings using the masked priming technique (cf. Forster & Davis 1984; Forster 1998, 2004). While cross-modal priming studies present the prime overtly and investigate late decompositional processes in the recognition of inflected words, masked priming studies present the prime for a short period of time only, so that participants do not consciously process it. The prime affects only very early automatic processes in word recognition (Forster & Davis 1984; Marslen-Wilson 2007). Neubauer & Clahsen (2009) studied early automatic processes in the recognition of inflected forms in a masked priming experiment. They tested 39 adult native speakers (and 39 L2 speakers) of German on *-t* participles (*geöffnet*) and *-n* participles without stem change (*gelaufen*) with first person singular present tense forms (*öffne*, *laufe*) as targets. The targets were closely matched for length and frequency and the unrelated prime was not semantically related to the target (p. 24). Native speakers showed a full priming effect for *-t* participles and a partial priming effect for *-n* participles, reflecting an influence of morphological structure on word recognition for *-t* participles but not for *-n* participles. These results are consistent with previous masked-priming studies which also produced morphological priming effects for inflected and derived word forms in a range of languages (e.g. Rastle, Davis, Marslen-Wilson & Tyler 2000; Rodriguez-Fornells, Münte & Clahsen 2002; Silva & Clahsen 2008). Neubauer & Clahsen argued that adult native speakers rely on morphological parsing for *-t* participles and on lexical processing for *-n* participles, and that L1 speakers showed sensitivity to morphological structure for *-t* participles but relied on lexical storage for *-n* participles.

However, priming results for irregular forms have not been consistent across different studies; some researchers found partial priming (uni-modal: Stanners et al. 1979; cross-modal: Sonnenstuhl et al. 1999; masked: Neubauer & Clahsen 2009), others found no priming (uni-modal auditory: Kempley & Morton 1982) or full priming (Forster et al. 1987) for non-default forms. Furthermore, Sonnenstuhl et al.'s (1999) interpretation of their results were controversial. A closer look at the results shows that reaction times after *-n* participles were as short as those after *-t* participles (test condition *-n* participles: 582ms *vs*. *-t* participles: 578ms). However, reaction times after identical primes for *-n* participles were significantly *shorter* than after identical primes for *-t* participles (identity condition *-n* participles: 548ms *vs*. *-t* participles: 578ms, Sonnenstuhl et al. 1999: 212). Thus, the statistical significance of the difference between morphological test condition and identity condition in *-n* participles is due to differences in the identity condition. Smolka et al. (2007) criticised Sonnenstuhl et al. for not matching their materials for surface- and lemma-frequency and suggested that differences in priming patterns (full *vs.* partial priming) could be due to differences in these frequencies between verb groups.

Smolka et al. (2007) correctly point out this flaw in the material design. However, the differences in the priming effects might still hold because the crucial comparison of reaction times in priming experiments is not *between* participle types but *within* participle types. Differences in material properties of the target word which may have led to shorter reaction times in the identity condition should have done the same in the morphological test condition. Keeping this criticism in mind, the results from Sonnenstuhl et al. (1999) can still be taken to indicate differences in *-t* and *-n* participles, which needed to be – and were – verified by more carefully designed research by Neubauer & Clahsen (2009).

Smolka, Zwitserlood & Rösler (2007) addressed these issues and ran a modified version of Sonnenstuhl et al.'s cross-modal priming experiment. Their materials were controlled for surface- and lemma-frequency across verb groups. Smolka et al. included 'participle type' as a two-level factor (*-t* participles, *-n* participles *with* stem change). As shown in Table 5, materials were designed in two priming conditions. In the test condition, the experimental targets infinitives were preceded by participle primes. In the control condition, experimental targets infinitives were preceded by an unrelated past-participle prime. Participants were asked to make a lexical decision.

	***-t* participles**	***-n* participles**
Identity	*kaufe* '(I) buy'	*grabe* '(I) dig'
Test	*gekauft* 'wished$_{[part]}$'	*gegraben* 'dug$_{[part]}$'

Table 5: Example stimulus set from Smolka et al. (2007: 343)

The results showed a partial morphological priming effect for all participle types, which suggested that participles of all types pre-activated their stem form to the same degree. The authors concluded that participles in all verb groups were subject to decomposition. These results, the authors concluded, support a single-processing system with an independent morphemic level for default and non-default forms (cf. Smolka et al. 2009: 368), and were taken to be evidence against a dual-mechanism model which would predict different effects for default and non-default forms.

The results from Smolka et al. (2007) are not consistent with Sonnenstuhl et al.'s (1999) findings. It seems that this discrepancy is due to differences in priming method and experimental design. For example, Sonnenstuhl et al. (1999) and Neubauer & Clahsen (2009) compared reaction times in the morphological test condition to both an unrelated and identity condition. Smolka et al. (2007) only compared reaction times in the morphological test condition to reaction times in an unrelated condition. But both comparisons are necessary in order to differentiate between a partial and a full priming effect, as explained at the beginning of this section. It was therefore not possible for Smolka et al. to reveal priming differences between *-t* participles and *-n* participles, as done by Neubauer & Clahsen (2009). Smolka et al. (2007) would have made a considerably stronger case for a single-system model if they had been able to report similar priming effects for *-t* participles and *-n* participles in an identity condition. Another problem with the design is the uni-modal stimulus presentation. Smolka et al. used a uni-modal priming design, presenting both prime and target overtly in the visual modality. Many researchers have argued that this design is more directly affected by semantic and orthographic overlap between primes and targets than cross-modal or masked priming experiments (Marslen-Wilson 2007). However, Smolka et al. did not include any orthographic or semantic control condition, which makes it difficult to assess whether the reported priming effects were indeed morphological in nature. Moreover, Smolka et al. (2007) compared *-t* forms without stem changes to *-n* participles with stem changes, which makes it hard to properly assess the contribution of the different types of exponent (affix type, stem type) to the observed priming effects. Secondly, Smolka et al. (2007) used *-n* forms (infinitives) as target words. Consequently, *-n* but not *-t* participle primes had the same ending as the corresponding target words, which may have artificially enhanced priming effects for *-n* forms.

Brain Studies

In studies of ERPs, participants perform experimental tasks while their electrophysiological brain responses are measured. Brain responses can be described in terms of latency, polarity and distribution on the scalp, and have been associated with specific language processing steps. For example, the N400, centro-parietal negativity after 400ms, has consistently been found when participants processed lexical violations, such as incorrect plural inflection on words as **childs* or **mouses*. The N400 has therefore been interpreted as an indicator of word-form processing. The LAN, a left-anterior negativity after 300ms, has been associated with grammatical violations. Penke, Weyerts, Gross, Zander, Münte & Clahsen (1997) used the ERP technique to investigate morphological processing in German adults. They compared the processing of *-t* participles to that of *-n* participles in an ERP violation paradigm to investigate the mental processes underlying the combination of stem and suffix. Participants read correctly inflected *-t* participles (e.g. *gemacht*) and *-n* overregularised participles in which the *-t* suffix was replaced by an *-n* suffix (e.g. *gemachen*). Correspondingly for *-n* participles, participants read correct *-n* participles (e.g. *geschlafen*) and *-t* overregularised participles in which the *-n* suffix was replaced by a *-t* suffix (e.g. *geschlaft*). The results showed that ERP responses to correct and incorrect forms were different in the two participle types. Participles overregularised with *-t* elicited more negative ERP responses in the fronto-temporal brain region than correct *-n* participles, which was categorised by the authors as a left anterior negativity (LAN); the LAN generally indicates grammatical processing and was taken to indicate rule-based processing of the *-t* affix. Their results also included an unpredicted finding. Correctly inflected and *-n* overregularised *-t* participles did not elicit significant differences. This is an unexpected finding under any theoretical approach, because the processing of an incorrect form should elicit different brain responses from the processing of a correct form. Many studies have elicited a negativity after 400ms (N400) in forms which were classified by the participant as lexical errors. In any case, the results were replicated in a study by Gross, Say, Kleingers, Clahsen & Münte (1998) on Italian first, second and third conjugation participles. The second conjugation was considered as an irregular form. Overregularised irregulars produced a negativity while overirregularised first and third conjugation elicited no effect (p. 85). Different ERPs for German *-t* and *-n* participles and for Italian conjugations have been seen as evidence for different mental strategies in the processing of German participles and Italian conjugations.

Lück, Hahne & Clahsen (2006) conducted an ERP study to investigate morphological processing for another linguistic phenomenon and another modality, German *-s* plural forms and *-n* plural forms. The *-s* plural form is considered as the default process and *-n* plural forms as the non-default plural, which needs to be memorised as a full form (cf. Marcus et al. 1995). Participants listened to stimuli in a sentence context. The authors studied *-s* overapplication and *-n* overapplication in comparison to grammatical forms. The results showed that *-s* overapplication to word forms requiring *-n* suffix elicited a left anterior negativity between 300 and 800ms, indicating syntactic processing, and a posterior positivity between 800 and 1200ms (P600), indicating reanalysis after syntactic violation. In addition, *-n* overapplication to word forms requiring *-s* suffixes elicited the N400, an ERP component associated with lexical processing. The authors conclude that *-s* plural suffixes are added to the stem through combinatorial processes while *-n* plural forms are accessed as full forms in the mental lexicon. This difference replicates results from visual ERP studies (Lück et al. 1997) for a new linguistic phenomenon and supports the distinction between combinatorial and memory-based processing of morphologically complex words.

The ERP studies reviewed so far largely support a dual-system view of processing in adults with grammatical processing of default forms and lexical processing of non-default forms. In contrast, Smolka, Khader, Wiese, Zwitserlood & Rösler (2013) interpreted their electrophysiological findings to support the processing of inflected forms in a single system. The authors tested the same stimulus set of *-t* participles, *-n* participles with stem change and *-n* participles without stem change in an ERP study of primed visual word processing. Targets (*leite* 'lead') were primed in four conditions: identity (*leite*, 'lead')[15], participle (*geleitet*, 'led'), semantic control (*führe*, 'guide') or unrelated control (*nenne*, 'name'). The prime appeared for 50ms followed by a blank screen of 40ms. Negativity was found for *-t* participles from 390 to 480ms after target onset at the frontal, temporal and parietal areas. Similar effects were reported for *-n* participles without stem change but reduced in amplitude and only in the frontal and temporal areas. For *-n* participles with stem change the effects produced were, again, smaller with negativity in the left parietal area (p. 12, figure 2). Similar response patterns were also obtained in the reaction time measurements, with partial priming effects in all participle types (p. 11-12).

Smolka et al. (2013) chose an interesting design that combines brain response measurements and reaction time measurements. They did not find significant differences between *-t* participles and *-n* participles, but only gradual differences between the three participle types in both measurements. One reason why potential differences between participle types did not become significant might lie in the experimental design of the material. Smolka et al. chose a within-subject and within-target design, so that each participant saw each target five times. They spread targets in a Latin-Square Design so that possible repetition effects would be equally balanced across conditions. However, the repeated presentation of the same target word could have led to a weak but constant activation of the target word throughout the experiment. The effects of the primes on the target may thus have been reduced and, at least in part, responsible for non-

[15] In contrast to Smolka et al. (2007), Smolka et al. (2013) included an identity condition, which allows for differentiation between full and partial priming.

significant results. Another concern about this study is that Smolka et al. (2013), like Smolka et al. (2007), use a uni-modal priming paradigm. As discussed above, approaches of this kind have certain limitations. In particular, it is difficult to tell whether the results reflect properties of a peripheral representation, i.e. the access level, or properties of a modality-independent representation, the central-level representation of an inflected form. If we interpret the findings to indicate that the access-level representation might be similar, that does not necessarily indicate that the central-level representation is similar.

One last issue regards the interpretation of differences in the results. Smolka et al. (2013) do report differences between participle types but they argue that these were too small to indicate fundamentally different processing systems. However, proponents of dual-system theories have not suggested that membership of one processing system is an "all-or-none matter" (Smolka et al. 2013: 2), at least not in the more recent literature. Rather, they proposed that rule-based forms can also be stored (Pinker & Ullman 2002: 458); full-form representations, at least of derived forms, could also have an encoded morphological structure (Clahsen, Sonnenstuhl & Blevins 2003: 3, 21). Thus, the results reported by Smolka and her colleagues might also be explained in a dual-system theory, assuming, potentially, stored *-t* participles or morphologically encoded *-n* participles.

Partial Breakdown in Aphasic Patients

Many brain-damaged patients exhibit agrammatic language production. Characteristically, their language production lacks function words and morpho-syntactic markers while content words seem well-preserved. These symptoms may arise from a selective loss of the ability to compute word forms. Researchers took these patients as a test case to investigate whether such a selective ability actually exists. Marslen-Wilson & Tyler (1997) have studied three agrammatic patients and a control group in an auditory primed lexical decision task on the English past tense. Target stems (e.g. walk, bring) were preceded by an *-ed* verb (walked) or an irregular verb (brought). Consistent with previous priming studies, healthy control subjects showed priming for both participle types relative to an unrelated control condition. Two agrammatic patients showed priming for irregular verb forms such as 'brought' but, in contrast to the controls, a delay after listening to regular *-ed* forms. The third patient, who also showed right brain lesions, produced the opposite pattern, with a priming effect for *-ed* verbs but none for irregular past-tense forms

(Marslen-Wilson & Tyler 1997: 593). The authors interpreted this finding as evidence for different types of mental computation underlying 'walk' and 'brought' and that these combinatorial mechanisms are neurologically dissociable. The results also indicate that the combinatorial mechanism underlies both word production (as deficits were reported from spontaneous speech) and word recognition (as tested in the experiment). Evidence that the combinatorial mechanism underlies processes in both verbs and nouns comes from Miozzo (2003). He reported results from one patient in a series of tasks (picture naming, forced choice recognition task, word repetition, picture–picture matching, picture–description matching task). Interestingly, the patient had a selective deficit for irregular inflection across word types, in both verbs (e.g. brought) and nouns (e.g. mice).This observation indicated that the combinatorial mechanism affected is not specific to word type or modality but is active in both. Ullman and his colleagues carried this idea even further, suggesting that the 'procedural system' is a memory system that underlies all combinatorial cognitive processes, including combinatorial language processes. A 'declarative system', in this view, is responsible for the storage of lexical forms.

The declarative/procedural (DP) model was briefly introduced earlier in this chapter. Ullman and his collaborators investigated the idea that the lexicon belongs to the declarative memory located in the temporal-parietal/medial-temporal brain areas which are also responsible for word memory (Ullman et al. 1997, 2001a). Grammar, on the other hand, belongs to a procedural system located in the frontal/basal-ganglia area (Ullman et al. 1997: 267) which is also responsible for the processing of rules. The declarative and procedural memory systems work mostly independently (e.g. Squire & Knowlton 2000; Eichenbaum & Cohen 2001; Poldrack & Packard 2003) but interact in specific ways: rules represented in the procedural system apply to lexical entities represented in the declarative system. Moreover, the procedural system can abstract rules from the lexical forms stored in the declarative system (p. 247). The declarative/procedural systems are not language-specific but, according to the DP model, host the language-specific mental grammar and lexicon (Ullman 2004: 244, 246, 247). Hence, this theory predicts a double dissociation for aphasic patients with circumscribed brain lesions in these areas. Aphasic patients with specific brain lesions in temporal or parietal brain areas should be worse at lexically-based than at rule-based processing. Aphasic patients with specific brain lesions to the frontal cortex should be worse at rule-based than at lexically-based processing. Following the dual mechanism account, the former patient group should be better at default than at non-default inflection, while the reverse should be true for the latter patient group (Ullman et al. 1997: 268).

Ullman (2004) reviewed PET and fMRI studies on adults which showed that syntactic processing elicits activation in the basal ganglia and anterior superior temporal gyrus, whereas lexically stored syntactic knowledge (e.g. argument structure) produces inferior temporal lobe activation (Kuperberg et al. 2000). Lexical knowledge and conceptual-semantic knowledge has been associated with activation in the temporal/temporo-parietal regions (Damasio et al. 1996; Newman et al. 2001). Based on this evidence, Ullman concludes that the mental lexicon is based on declarative memory and the mental grammar is based on procedural memory.

Ullman, Pancheva, Love, Yee, Swinney & Hickok (2005) also assume that regular and irregular past-tense forms are processed by different mental processes. They investigated whether these processes involve distinct neural structures in aphasic patients with circumscribed brain lesions. Eleven non-fluent agrammatic aphasic patients with left-frontal lesions and nine fluent anomic aphasic patients with left-temporal/temporo-parietal lesions participated in reading and acceptability judgements of irregular and regular past-tense forms and in production and judgement tasks of real versus novel forms. The performance of each aphasic patient was compared to an unimpaired control person. The results showed that all non-fluent aphasics had more difficulties in producing, reading and judging regular past-tense forms than irregular (p. 201ff). Fluent patients showed better results in all tasks for irregular past-tense forms than for regular (p. 204ff). Other factors such as frequency, phonological complexity and articulatory difficulty were controlled for. The authors argue that the double dissociation between default and non-default inflection in fluent and non-fluent aphasic patients strongly supports the idea that words represented as full forms, such as *-n* participles, are processed in neural structures in the left-temporal/temporo-parietal lobe, while words processed according to their morphological structure, such as *-t* participles, involve left-frontal structures. In particular, they suggest that morphological affixation and possible syntactic processes rely on the same neural mechanisms. This finding, as the authors argue, is not consistent with a single-system model predicting that *-t* participles and *-n* participles are processed via the same mental mechanisms and thus the same neural structures.

The DP model had a significant impact on the debate on language representation in the brain. The model's strict division into rule-based and lexicon-driven processes and focus on how these are represented in the brain yields testable predictions which have inspired much research (e.g. Opitz & Friederici 2004; Friederici & Wartenburger 2010). However, some of the predictions are not compatible with theoretical assumptions and empirical findings. The DP model cannot explain the dissociations found for inflection and derivation by Tyler & Ostrin (1994), Marslen-Wilson & Tyler (1997, 1998), Marangolo et al. (2003) or Marangolo, Piras, Galati & Burani (2006). For inflection, the dual-system theory suggests combinatorial processing for default forms and full-form processing for non-default forms. However, the refined dual-mechanism model (Clahsen et al. 2003) suggests that transparently derived forms do not follow this distinction but involve both full-form and combinatorial processing. It is hard to see how the DP model could account for this finding. If derived forms were part of the declarative system, they would not elicit full priming effects as reported by Clahsen et al. (2003). If derived forms were part of the procedural system, derived forms would not elicit full-form frequency effects as reported by Neubauer & Clahsen (2009). The DP model leads to the prediction that rule-based processes and lexicon-driven processes are strictly dissociated, which has been not confirmed in many studies. Instead, research has consistently shown that the grammatical and lexical-semantic processes involved in word processing are not restricted to one brain region but show manifold interactions (e.g. Patterson et al. 2001; McClelland & Patterson 2002; Bird et al. 2003; Rogers et al. 2004; Faroqi-Shah 2007). As a result, the hypothesis of strict neurophysiologic division for rule-based processes and lexicon-driven processes is highly controversial.

Generalisation Effects in Production

A number of studies have tested offline production of inflected forms in elicited production experiments (e.g. Bybee & Moder 1983; Prasada & Pinker 1993; Clahsen 1997; Say & Clahsen 2002). In these experiments, participants listen to a novel verb or read a text passage containing a blank, and are asked to fill in the blank with an inflected form of the novel verb. These experiments assess whether participants actually apply default and non-default inflection. The phonological similarity of novel verbs to non-default forms of the language varies. One aim is to assess whether participants apply default and non-default inflection as a function of phonological similarity to non-default forms. Prasada & Pinker (1993: 25) tested English past-tense verbs and found that only four out of 60 novel verbs elicited as many regularly inflected as irregularly inflected forms (*preed*, *queed*, *spling*, *cleef*). Novel verbs that were phonologically similar to irregular clusters elicited more irregular inflection than those that were not. Meanwhile, the application of regular inflection did not vary as a function of phonological similarity to regularly inflected forms. Similarly, Clahsen (1997) found for German that *-n* participle inflection only generalises to nonce-words rhyming with existing *-n* participles. The suffix *-t* is applied to novel words irrespective of phonological form. These results corroborate those from other elicited production experiments (cf. Bybee & Moder 1983 for English strong verbs; Say & Clahsen 2002 for Italian second and third conjugation). They have been interpreted as evidence for the idea that non-default inflection is generalised by analogy to real phonological forms. Default inflection is generalised freely irrespective of phonological form, possibly through a default rule. The generalisation properties of non-default and default inflection observed in production are concordant with those observed in comprehension. This implies that the generalisation mechanism for non-default inflection acts similarly in production and comprehension.

Frequency Effects in Speeded Production

Several studies have used the speeded production technique to investigate production of inflected word forms by adults in real time. In this task, participants read verb stimuli and are asked to produce a morphologically related form, e.g. the past-tense form, as quickly and as accurately as possible (see section 5.1.1 for more details). In the first study of this kind, Prasada, Pinker & Snyder (1990) conducted a speeded production task of the English past tense in adults. The study was designed in a 2x2 design with the factors 'participle type' (regular *vs.* irregular) and 'past tense word-form frequency' (high *vs.* low). The stem frequency was held constant. The authors visually presented verb stems and asked participants to produce the corresponding past-tense form. The production latency was measured as the time between the presentation of the verb stem and the participant's response. Prasada et al. reported that production latencies (RT) were significantly longer for high- than for low-frequency irregular target forms (RT_{high}=774ms, RT_{low}=790ms). They found no significant difference between production latencies for regular forms of high and low frequency forms (RT_{high}=705ms, RT_{low}=706ms). The authors suggest that the frequency effect for irregular forms indicates full-form representation and processing via the lexicon. No frequency effect was found for regular forms, which is consistent with the interpretation that processing of regulars is not sensitive to full-form frequency and does not rely on full-form representations in the mental lexicon.

Prado & Ullman (2009) also put forward empirical evidence on the production of inflected forms in English adults. They studied frequency effects in the production latencies of English regular and irregular past-tense forms, and found a significant effect of frequency for irregular forms (β=-.018, $t(3730)=6.26$, $p<0.0001$). This effect was also observed, though less strongly, for regular forms (β=-0.007, $t(3729)=2.49$, p=.013). As the difference between these effects is significant (β=0.011, $t(3730)=2.80$, p=.005), the authors interpret this finding as evidence for full-form processing of irregular forms and for a weaker tendency to use full-form processing in regular forms.

Taken as a whole, speeded production studies in English have found a robust frequency effect for irregular forms, that is, shorter production latencies for low-frequency than for high-frequency irregular forms. The results with regard to regular forms were less conclusive across studies. Beck (1997) found a significant anti-frequency effect in production latencies for high- and low-frequency regular forms. Lalleman et al. (1997) reported an advantage for high-frequency over low-frequency regular forms, although this difference was not as pronounced as in irregular inflected forms. Prasada et al. (1990) observed that low-frequency regular forms yielded shorter production latencies than high-frequency regular forms. The influence of default forms' full-form frequency on production latency indicates their full-form representation in the mental lexicon. A *negative* effect of word-form frequency on production latencies times, however, is unexpected from any theoretical perspective. One attempt to explain an anti-frequency effect was made by Beck (1997: 107), who conducted a speeded production task and presented isolated words as stimuli to the adult participants. She suggested that the observed anti-frequency arose because the regulars and irregulars were presented together in a single experimental session. She went on to argue that irregular forms, which involved whole-word form processing, would bias the participant towards whole-word form processing also in regulars. Beck's (1997) explanation can be criticised from a variety of perspectives. First, in the study by Clahsen et al. (2004), each stimulus is presented in sentence contexts which are assumed to be processed using rules. The stimuli should therefore not bias the participant towards whole-word processing. Second, the task of speeded production involves early automatic processes which have traditionally been assumed to be somewhat impenetrable to cognitive control (Fodor 1983). It is unlikely that highly unconscious processes are significantly influenced by exposure to a relatively restricted number of words over a short period of time. Pinker (1999) made another attempt to explain the anti-frequency effect observed in the production of regular English past-tense forms. He suggested that high-frequency regular forms, but not low-frequency regular forms, may leave behind memory traces in the lexicon. Hence, high-frequency regular forms invoke memory access in addition to rule-based processing. Since retrieval from memory inhibits the rule system, participants take longer to produce high-frequency regulars, which have left memory traces in the lexicon, than to produce low-frequency regulars, which have not left memory traces in the lexicon and are produced purely by rule.

The finding that regular default forms show full-form frequency disadvantages is unknown in recognition studies. These have produced frequency advantages for irregular non-default forms or have, most of the time, reported no significant influence of full-form frequency on regular default forms.

Partial Processing Breakdown in Impaired Production

The production of inflected words as also been studied in impaired adult populations. Ullman, Corkin, Coppola, Hickok, Growdon, Koroshetz & Pinker (1997) used a past-tense production task following the pattern. “Every day I *dig* a hole. Just like every day, yesterday I ____ a hole.” (p. 268). They were the first to test these ideas in groups of Alzheimer’s and Parkinson’s disease patients, who showed complementary lesion sites. The Alzheimer’s patients had more damage to temporal or parietal areas while the Parkinson’s patients exhibited lesions at the frontal/basal-ganglia system. The patient groups showed complementary language impairments consistent with the prediction of a dual-system approach: the Alzheimer’s patients were lexically impaired with relatively well preserved grammatical processing and accordingly had greater difficulties producing irregular past-tense forms than past-tense forms for regular or novel verbs. The Parkinson’s patients were particularly impaired in rule processing and had rather limited word recognition abilities. They showed the reverse pattern to Alzheimer’s patients, with relatively high performance in producing regularly inflected forms and relatively low performance in producing irregularly inflected past-tense forms. The authors conclude that the mental grammar and the mental lexicon are distinct mental mechanisms with distinct neural representations. Moreover, they argue that the mental grammar, as part of declarative memory, is represented in the temporal-parietal/medial-temporal areas, while the procedural memory is represented in the frontal/basal-ganglia areas.

Brain Responses in fMRI Studies

Beretta, Campbell, Carr, Huang, Schmitt, Christianson & Cao (2003) combine event-related technique with fMRI to study neural brain activation patterns in the production of *-t* participles, *-n* past participles with stem change and *-n* past participles without stem change. Eight German participants read verbs and were instructed to silently produce the corresponding past-participle form (*laufen – gelaufen* 'run'). While performing the task, the participant's brain activity was scanned in an fMRI scanner. Brain images showed considerable differences between brain activation when producing *-t* participles compared to *-n* participles. The analysis yielded an effect of regularity. The cortical activation was significantly greater for *-n* participles than for *-t* participles (t=4.269, p<.005). Furthermore, the authors found an effect of brain hemisphere. Participles with *-t* suffix caused greater lateralisation to the left hemisphere than *-n* participles (t=3.028, p<.02). Beretta et al. assumed that more neural activation implies a larger neural processing load (p. 83), and explain the overall greater activation for *-n* participles by the fact that retrieving a (low-frequency) form from associative memory is more demanding on neural resources than applying a symbolic affixation rule. The authors argue that these results show that two fundamentally different mental mechanisms are involved in the production of regular and irregular forms and that these mechanisms rely on different brain areas. Similar dissociations have been reported by Jaeger et al. (1996) and Newman et al. (2007).

Comparing Results from Production and Recognition

We have reviewed a number of studies on recognition and production and have found several differences, primarily in lexical decisions and speeded production of regular English past tense and German *-t* participles. These observations lead us to ask whether the same or different processing mechanisms are active in production and recognition, or whether the same processing mechanisms are used, but to different extents.

In recognition studies, participants have consistently produced high-frequency irregular forms more quickly than low-frequency irregular forms and showed varying results for regular forms. For example, Clahsen, Eisenbeiss & Sonnenstuhl (1997) and Neubauer & Clahsen (2009) found no frequency effect in the recognition of *-t* participles. In contrast, Alegre & Gordon (1999) found a significant frequency advantage in a group of high-frequency regular forms but not in a group of low-frequency regular forms. Similar results were found for plural forms. Clahsen, Eisenbeiss & Sonnenstuhl (1997) and Sonnenstuhl & Huth (2002) reported that the recognition of the German default -*s* plural was not affected by full-form frequency. In contrast, the German -*n* plural showed a frequency advantage. The Dutch default -*n* plural elicited frequency effects in studies by Baayen et al. (1997) and Baayen et al. (2003). The default -*n* plurals were even below the frequency threshold suggested by Alegre & Gordon (1999). This result indicated language- and/or phenomenon-specific differences in how frequency affects the recognition of default forms. These studies further indicate that not only non-default but also default forms may produce full-form frequency effects, at least in recognition tasks.

Similarly, in production studies, participants have produced high-frequency irregular forms more quickly than low-frequency irregular forms, but showed varying results for regular forms. Several production studies have found that participants also responded more quickly to high-frequency than to low-frequency non-default forms. Others have found that the production of default forms was not influenced by frequency; Clahsen et al. (2004) have found, for subgroups of adults and children, slower production of high-frequency than low-frequency default forms. As mentioned above, a first explanation for this finding was put forward by Pinker (1999) and was supported by Clahsen et al. (2004).

The dissociation between recognition and production may arise from the fact that the lexical decision task and the speeded production task encourage participants to rely on different mental mechanisms (cf. Pinker 1999; Clahsen et al. 2004: 30). A lexical decision task asks participants to match stimuli against memory. The participant can answer if he or she identifies the presented string of letters as a lexical entry in the mental lexicon. If the participant applies the rule to decompose the stimulus into affix and stem, he or she additionally needs to check whether the presented stem can legally be combined with the affix in the language. The lexical decision task thus leads participants to rely more heavily than in a production task on full-form entries in the mental lexicon. In production, the rule is constantly active and produces default forms. A full-form representation can only block the rule. It is therefore quickest to produce the target form by ‘adding -*t*/-*n* suffix’ (Pinker 1999: 138). This would explain the discrepancy of the frequency advantage for high-frequency -*t* participle forms in lexical decision tasks and the frequency disadvantage for such forms in production tasks.

Results from previous experimental methods such as lexical decision tasks, previous production studies on *-ed* forms in English, German past participles support the asymmetry between recognition and production. An early study further confirms this assumption. Forster & Chambers (1973) compared naming latencies and lexical decision times in a sample of English words and found that frequency had a positive effect on lexical decision times *and* naming latencies (Forster & Chambers 1973: 629). This finding substantially advanced understanding of the lexical search procedures in the mental lexicon at that time. However, the experiment tested solely monomorphemic words (Forster & Chambers 1973: 634) and no inflected words, thus tapping into lexical processing but not into morphological processing. Further support for this explanation comes from a more recent study by Balota, Law & Zevin (2000), who examined full-form frequency effects in speeded lexical reading (experiment 1) and speeded rule-based reading (experiment 2). In the first task participants were instructed to read visually presented stimuli, while in the second task they were asked to read the words according to English grapheme–phoneme correspondence rules (e.g. 'have' should be pronounced so that it rhymes with 'gave'). The authors argued that while in the first experiment participants could rely on their memory, the second task forced them to read letter-by-letter, although for what they call regular forms (i.e. words spelled according to the English grapheme–phoneme correspondence rules) it yielded the same result. In the end, the authors compared production latencies for regularly spelled word forms in both tasks. The results showed that words in the normal reading task produced a frequency effect while words in the letter-by-letter reading task produced an anti-frequency effect. The authors argue that results in normal reading indicated that participants relied on the lexical route, while results in the letter-by-letter reading indicated that both lexical and sub-lexical routes were working in parallel, that participants were not able to turn off the lexical route, and that it inhibited the sub-lexical route (Balota, Law & Zevin 2000: 1085).

Taken as a whole, the dual-route account offers an explanation for the dissociation between default and non-default forms as well as between recognition and production. These results from lexical decision experiments and production studies suggest an asymmetry between reaction times in recognition and production: memory forms of high-frequency default forms speed up lexical decision times in recognition tasks, but prolong production latencies in production tasks. However, as results from different studies have been compared which differ in more than just modality, such dissociations could be due to a number of factors. Therefore, this intriguing production/recognition dissociation needs more systematic investigation.

4.4.2 Studies on Child Processing of Inflected Forms

This section reviews results from processing studies on children and compares them to results from processing studies on adults.

Acceptability Judgements of Novel Verbs

Ambridge (2010) investigated acceptability judgements for 40 novel verbs by 20 six- to seven-year-olds and 20 nine- to ten-year-olds. The novel verbs were varied independently along the dimensions of similarity to existing regulars and existing irregulars. Ambridge used a quantitative measure of how similar each novel verb was to existing regulars and irregulars, which also ensured that verbs were phonologically well-formed (unlike 'ploamph' by Prasada & Pinker 1993; Albright & Hayes 2003; Ambridge 2010: 1499). Judgements were obtained on a five-point scale. The 'similar-to-regular' novel verbs showed an interaction of similarity to existing regulars by age group. There was also an effect of similarity to regulars in the older group ($p<.001$) but not in the younger group ($p=.28$, p. 1500). Meanwhile, the main effect of similarity was obtained for 'similar-to-irregular' novel verbs in all age groups. Similarity-based generalisation is usually taken to indicate full-form representation. The results indicate a dissociation for the representation of regularly and irregularly inflected forms. Full-form representations of irregularly inflected forms are present already in children as young as six to seven, and full-form representations of regularly inflected forms are formed at a later stage, in nine- to ten-year-old children.

Visual Lexical Decisions

Burani, Marcolini & Stella (2002) used the visual lexical decision task to investigate lexical and morpholexical reading strategies in Italian children at the age of eight to ten years. Among other things, participants made lexical decisions on high- and low-frequency existing word forms and morphological and non-morphological pseudowords. Morphological pseudowords consisted of existing roots or existing derivational suffixes and non-morphological pseudowords had no morphemic constituents. The results showed full-form frequency effects for children of all age groups and an advantage for morphological over non-morphological pseudowords. The result patterns obtained for children were similar to those found in adults and showed shorter reaction times for high-frequency than low-frequency existing words and a higher rate of false 'correct' decisions for morphological pseudowords than for non-morphological pseudowords. The authors concluded from the full-form frequency effect in existing words that lexical reading was available in young readers. From the effect for morphological structure in pseudowords, the authors conclude that even young readers access the morphological structure of derived words in reading. The results indicate that, first, children as young as eight can perform visual lexical decision tasks and produce interpretable results. Hence, even if auditory tasks are more natural for children, the lexical decision task is still suitable for use with children as young as eight years. Further, Burani, Marcolini & Stella (2002) found that even children with a small amount of reading experience are sensitive to morphological derivational structure.

Brain Responses in an ERP Study

Clahsen, Lück & Hahne (2007) used the ERP violation paradigm to investigate the mental processes involved in children's online recognition of *-s* and *-n* noun plural forms. Participants were assigned to one of four age groups: 6–7 years, 8–9 years, 11–12 years and an adult control group. The stimuli were designed in a 2x2 design with the factors default status (default *-s* plural *vs.* non-default *-n* plural) and correctness (correct *vs.* incorrect). Participants listened to sentences containing correct and incorrect *-s* plural nouns and *-n* plural nouns, as shown in Table 6. Incorrect *-n* plural nouns were *-s* suffixed (e.g. *Apothekes). Since the *-s* plural is applied under default circumstances (Bartke 1998) and show all the properties of rule-based processing (Clahsen 1999 for review), the overapplication of the *-s* suffix was considered as an overregularisation error (cf. Marcus et al. 1995). From a dual-system perspective, overregularisations such as **Apothekes* represent combinatorial rule-based violations in which two components appear in an illegal combination. They were therefore classified as a grammatical violation. Incorrect *-s* plural nouns were incorrectly *-n* suffixed (e.g. *Waggonen). The *-n* plural is applied only in analogy and shows full-form processing. Overapplication of the *-n* suffix is not a combinatorial error but may be perceived as an unexpected word form, i.e. a lexical violation.

	correct	incorrect
-s plural	*Waggon-**s***	**Waggon-e**n***
	‘wagons’	‘wagons’
***-n* plural**	*Apotheke-**n***	**Apotheke-**s***
	‘pharmacies’	‘pharmacies’

Table 6: Overview of experimental conditions and examples (Clahsen, Lück & Hahne 2008)

The condition of incorrect *-n* suffix application (Waggons and *Waggonen) was not analysed because of low accuracy rates in children for the correct *-s* plurals (6–7-year-olds: 30%, 8–9-year-olds: 58%, 11–12-year-olds: 70%, Figure 1). The youngest child group showed no clear response to incorrect *-n* plurals, i.e. an unspecific broad negativity and no positivity. In older children and adults, overregularisation errors (*-s* suffix in *-n* plurals, *Apothekes) produced an anterior negativity and unspecific late positivity. While results or overregularisation errors in young children were rather too vague for clear interpretation, the early negativity and late parietal posterior positivity in older children and adults were classified as LAN and P600. Both components had been observed in previous studies in response to grammatical violation. These results are in line with a dual-system theory predicting rule-based processing for default *-s* plural but less so with an associative theory predicting lexical violation for default *-s* plural.

Clahsen, Hahne & Lück (2007) made a valuable contribution to research on morphological processing in children. They were the first to present electrophysiological evidence on the processing of inflected forms in children. The high time resolution in ERPs allows brain responses to be measured as they occur. Thus, the time-course of morphological processing in children can be compared to that of adults. Also, children’s and adults’ brain responses showed interesting developmental features. While 6–8-year-olds show unspecific brain responses, older children showed adult-like responses. The authors conclude that this pattern reflects children’s developing lexicon and processing efficiency (Clahsen, Hahne & Lück 2007: 23).

Decomposition Effects in Priming

The cross-modal and visual priming studies on adults reviewed above tested for online decomposition of inflected forms. Decomposition in children has also been tested in uni-modal online masked or overt priming experiments and in cross-modal offline priming experiments. Schiff et al. (2008), for example, used the masked priming technique to test 60 third- and seventh-grade children with a prime duration of 50ms. Targets were read after an identical, morphologically related or orthographically related prime. In the morphological priming condition, the targets were derived from non-default root forms in Hebrew which were either fully contained (experiment 1) or contained (experiment 2) in the target. They found that morphologically related forms produced stronger priming effects than orthographic controls in a similar way in both child groups. Unlike adults, children did not show any priming for morphologically related forms without overlapping surface forms (experiment 2). Schiff et al. (2008: 739) attribute this difference to children's incomplete lexical representations at "a level that abstracts away from differences in surface form". Regarding the design of our study, it is encouraging to see that children in third grade are already able to process masked primes of 50ms and that morphological awareness becomes visible in their online responses.

Overt priming with a prime duration of 75ms or 250ms was used by Casalis et al. (2009) to test visual lexical decisions to words after a morphological prime (LAVEUR–lavage 'cleaner–cleaning'), and orthographic prime (LAVANDE–lavage 'lavender–cleaning') or an unrelated prime (MOUTARDE–lavage 'mustard–cleaning). A group of 54 French nine-year old children participated in the experiment. The results showed significantly more facilitation for derived prime words than for orthographic controls in the long prime duration (=250ms), but not in the short prime duration (= 75ms), when both prime types produced similar effects. The authors conclude that morphological information is activated in nine-year-olds' reading.

Quémart et al. (2011) extended previous studies. The authors used primes of similar (60ms, 250ms) and longer (800ms) duration, compared to previous studies, to investigate how far semantics, and not morphology, was responsible for larger priming effects for morphologically related word pairs such as *ducks*/*duck* (relative to *decks*/*duck*). The stimulus design allowed the disentangling of morphological from semantic and orthographic effects. Quémart et al. included pseudo-derived primes such as *baguette–BAGUE* 'bread–ring' in addition to morphological (tablette–TABLE 'little table–table'), orthographic control (abricot–ABRI 'peach–shelter) and semantic control primes (tulipe–FLEUR 'tulip–flower'). The pseudo-derived pairs are semantically unrelated but the prime word contains a pseudo-affix. The rationale was that if reaction times after morphological primes and pseudo-derived primes are similar, but shorter than after control primes, the morphological priming effect cannot be reduced to semantic or orthographic overlap. French-speaking children between the ages of 8;0 and 14;3 were asked to make lexical decisions about the target words after being presented with the prime. The results showed the same significant facilitation for pseudo-derived primes as for properly derived prime words (e.g. *armure/arme* 'armour/weapon') relative to orthographic and semantic control conditions. An adult control group showed similar patterns to the children, with morphological priming starting earlier than in children. Quémart et al. (2011) conclude from these findings that children make use of morphemic decomposition during reading.

Priming studies have also been run offline with children to investigate their morphological awareness at different stages of their reading development during the primary-school years (Feldman, Rueckl, DiLiberto, Pastizzo & Vellutino 2002; Schiff, Raveh & Kahta 2008; Rabin & Deacon 2008; Casalis, Dusautoir, Colé & Ducrot 2009; Deacon, Campbell & Tamminga 2010; Quémart, Casalis & Colé, 2011; Ravid 2011). As in online priming studies, the children are presented with two successive stimuli and they are asked to respond to the second. In contrast to online priming studies, reaction times are not measured but only the children's final response to the target. A further difference from online priming studies is that not just one response (e.g. word/non-word decision) but a range of responses are correct. The critical measure is how often the morphologically related form was produced. One example of an offline priming technique is the fragment-completion task (Feldman et al. 2002; Rabin & Deacon 2008; Deacon et al. 2010). In this task, participants complete a letter fragment of the target word after reading a morphologically or orthographically related prime word. For example, Deacon et al. asked 88 participants in three age groups (9, 12 and 14 years) to complete a list of target words after reading and simultaneously listening to a root word (harm), an inflected form (harmed), a derived form (harmful) and an orthographically related form (harmony). Technically all responses are correct. The authors recorded how often participants opted for the target root word in the completion task (e.g. *ha*__). These results showed that participants opted for the root word more often in the morphological than the orthographic priming condition.

Priming studies have consistently shown that sensitivity to morphological structure affects reading in children as young as nine. Results from masked priming experiments indicate such sensitivity to morphology in early automatic reading, and results from overt priming experiments indicate that it also affects reading at later processing stages. However, a number of questions remain unanswered. Children's online decomposition was tested only in visual uni-modal designs; cross-modal designs were only used when testing offline for morphological effects. It is therefore unclear whether the results for online decomposition only apply to the written modality or whether they can be transferred to a more abstract level of lexical representation. The role of semantic relatedness in morphological priming effects was only assessed in one study. But this and other priming experiments on children have mostly tested derived words so that claims can only be made for derivational morphology. Further research is necessary to fill in these gaps. Therefore, in the current study, we use a cross-modal priming task to test online decomposition of inflected forms on a central level of lexical representation in children of two age groups.

Frequency Effects in Speeded Production

Clahsen, Hadler & Weyerts (2004) adapted the speeded production task to study child language production. They tested adults' and children's (two age groups, mean age: 5;3–7;9 and 11;0–12;8 respectively) production of high- and low-frequency German *-t* and *-n* past participles with and without stem change. The production latency and the error rate were measured. The analysis of the error data showed that children produced more errors than adults, mainly overapplying the ending *-t* to verbs that required an ending *-n*, which was not overapplied to forms that require *-t* endings. They also reported an advantage for high-frequency over low-frequency items, as children's error rate was lower for the former than the latter (children 5–7 years: error $rate_{high}$= 6.3% *vs.* error $rate_{low}$=27.4%; children 11–12 years: error $rate_{high}$= 0.3% *vs.* error error $rate_{low}$=8.6%). Production latencies were generally longer for children than for adults. A significant advantage for high- over low-frequency *-n* participles was found in all participant groups (see Table 7). These findings are consistent with previous speeded production studies on adults (e.g. Prasada et al. 1990, Lalleman et al. 1997). For regular forms, the reversed pattern was found: low-frequency forms were produced faster than high-frequency forms. While this result did not reach significance in adults (RT_{low}=947ms, RT_{high}=958ms), it was reported as a significant anti-frequency effect in both child groups. To explain the differences between adults and children, Clahsen et al. explored the idea that processing efficiency was developing in children and was responsible for differences between adults and children. The authors used overall mean production latencies as a measure for processing efficiency. Indeed, a post-hoc analysis on overall mean production latencies showed a disadvantage for high-frequency *-t* participles in a subgroup of 'slow' adults, that is, adults who had relatively long overall production latencies across conditions. The authors argued that the anti-frequency effect was not specific to children and is related to processing efficiency. As explained in previous chapters, high-frequency *-t* participles might have an additional lexical entry which is also activated in production. However, according to the words-and-rule model, the lexical route inhibits the rule, leading to longer production latencies. In this view, the parallel activation of two processing routes creates an extra processing load which creates a problem for children and adults of low processing efficiency but not for adults (or children) of high processing efficiency.

Frequency	5–7-year-olds	11–12-year-olds
high	1,257	1,088
low	1,188	1,049

Table 7: Production latencies for *-t* participles in young and old children (Clahsen et al. 2004)

Brain Responses in an ERP Production Study

Budd, Paulmann, Barry & Clahsen (2013) examined neural correlates in two age groups of 8–12-year-olds and an adult control group in the production of regular and irregular past-tense forms and a control condition of 3rd singular present-tense forms. In the silent-production paradigm, participants read verb stimuli and produced inflected forms of the verb stimuli presented. Crucially, they were asked to hold back the production of the target form until they saw a production prompt. The critical EEG measurement was taken during the silent production and before the over production. The idea was that the neural correlates of production also arise during *silent* production and can be captured on the EEG while the motor artefacts due to muscle movement in overt production are suspended from the critical region. The adult control group showed no difference for the regular and irregular condition in the 3rd singular present-tense forms but showed significantly more negative responses for regular than irregular past-tense forms after 300–450ms. Children in the older age group showed more adult-like responses than children in the younger age group. The authors interpreted the negativity for regular past-tense forms compared to irregular past-tense forms as indicating combinatorial processes involved in regular English past-tense formation and children gradually developing adult-like processing routines.

4.5 Discussion

A number of studies have shown that default forms and non-default forms show consistent dissociations. Default inflection is generalised freely to novel words; non-default inflection is only generalised if phonologically similar forms exist. Frequency effects have consistently been found for non-default but not for default forms. Morphological decomposition effects were revealed for default forms but only in some cases for non-default forms. General differences in phonological/orthographic or semantic properties alone do not fully explain these differences. The idea that frequency alone affects processing was dismissed. Findings from, for example, ERP studies and cross-modal priming studies on the low-frequency but default *-s* plural made it possible to disentangle the effect of high frequency from that of default status. In cross-modal priming studies, researchers were able to control for phonological/orthographic and semantic properties of default and non-default inflection and still found significant differences between the two groups. Evidence for fundamental differences between default and non-default inflection also comes from brain studies on unimpaired and language-impaired participants, showing systematic differences in brain responses to the two types of inflection. These results are consistent with the assumption that default forms, more specifically inflectional default processes, are subject to rule-based processing which applies rules freely to all forms. In this view, non-default forms are represented as full forms in an associative lexicon and non-default inflectional patterns are guided by the parameters of the lexicon.

The offline studies reviewed show no differences between the production and recognition of inflected forms. Default forms show similar generalisation properties in acceptability ratings and production tasks and non-default forms show similar generalisation properties in acceptability ratings and production tasks. The online studies reviewed, however, showed considerable differences between the production and recognition of inflected forms. These differences were *not* observed for non-default forms such as irregular English past-tense forms or German *-n* participles, but were observed for default forms such as regular English past-tense forms or German *-t* participles. In particular, full-form frequency seemed to differentially affect recognition and production of default forms. High frequency positively affected recognition of default forms in visual lexical decision tasks, but had a negative influence on production latencies in a speeded production experiment. This finding was unexpected and the explanation is still an open question. Leaving this question aside, the finding suggests that default forms may also have full-form representations in the mental lexicon or that the processing of default forms may leave behind memory traces which grow stronger with exposure. The present study tests inflected words in production and recognition experiments. This allows us to assess whether differences in language recognition and production stem from item-based factors (target language, linguistic phenomena) or indicate that production and recognition involve different processing strategies.

This chapter has reviewed a selection of literature on how adults recognise and produce inflected default and non-default forms. The detailed research on morphological processing in adults shows that default and non-default forms show different processing effects. It further shows that default, but not non-default, forms show different processing effects in recognition and production. The current study investigates children's morphological processing.

The literature review on children has shown that children show differences in the processing of these forms, differences that are clear in, for example, the production of German participles (Clahsen et al. 2004) and English past-tense forms (Budd et al. 2013).

Studies testing morphological processing in children and adults have produced a number of similar results for children and adults. For example, Ambridge (2010) reported that nine–ten-year-old children were sensitive to similarity-based generalisation. Burani, Marcolini & Stella (2002) found that eight-year-old readers were sensitive to morpholexical properties of written words. This interpretation was also supported by findings from several priming studies on children. In production, Clahsen et al. (2004) reported that children behaved like a subgroup of adults, with relatively slow overall production latencies. However, studies have also revealed child/adult differences. Reaction time studies have shown that children have generally higher error rates and longer reaction times (Clahsen et al. 2004). Ambridge (2010) found no sensitivity to similarity-based generalisation in the youngest child group of six–seven-year-olds. This indicates that only older, not younger, children had acquired full-form representations of regulars. Burani, Marcolini & Stella (2002) found that young children were able to lexically read but were not yet sensitive to morpholexical properties of the visual words, as again had been shown for older children.

A number of factors were suggested to explain these differences. Some researchers propose differences between adults and children in working memory capacity, speed of lexical access or lexical elaboration (see section 4.3). Indeed, the overall longer reaction times of children and their overall higher error rate than adults could be due to children's generally less accurate and slower lexical retrieval (cf. Clahsen et al. 2004). Following the suggestion that overregularisation occurs when a word form is not successfully retrieved, the overall higher error rate in the child groups might be a result of less accurate and slower lexical retrieval and a lexicon that has not yet been fully elaborated. The same is true for differences in reading experiments. Children's limited reading experience might lead to slower reading speed and a restricted number of visual form representations. However, none of these studies independently assessed these factors.

As far as the similarities between children and adults are concerned, it seems that these do not reflect fundamental differences in language processing. We are encouraged to investigate the factors responsible for these differences further, particularly working memory capacity and speed of lexical access.

5 The Current Study

The purpose of the current study is to contribute new psycholinguistic evidence about how morphological structure affects children's word recognition and production, and how these compare to adult word recognition and production. Also, the role of working memory capacity and speed of lexical access was examined to investigate whether these factors explain the differences between adults and children and between younger and older children.

Like many other languages, German has two modes of word inflection: a default inflection, which can be productively applied and yields forms that are transparently decomposable into stem + affix, and a non-default inflection, which is restricted to lexically specified items and produces inflectional patterns that are to varying degrees systematic (Clahsen 1999: 994). To investigate morphological processing in children, a series of online production and recognition experiments were carried out. The focus of the current study is on the inflectional phenomena of German *-n* past participles and *-t* past participles. The children tested were more than six years old because the experimental techniques used – lexical decisions and cross-modal priming – require children to read. The children therefore had to be at least in primary school. In addition, we were primarily interested in studying processing rather than acquisition in children, and children older than six have acquired the main features of their native language.

The main research questions in the current study were the following:

- Which mental mechanisms do children use in morphological processing?
- Are these mechanisms similar to those observed in adults?
- How do children's processing patterns differ from those of adults?

The first experiment investigated modality-specific access-level representations of past participles in children's spoken production. We used the speeded production technique, introduced by Clahsen et al. (2004), to find out how children access mental representations of past participles in production. Refining their design, we differentiated between *-n* participles with stem change and *-n* participles without stem change. We also applied a working memory test to more thoroughly assess the role of individual working memory capacities in the production of morphologically complex forms.

The second experiment investigated the central-level representation of past participles in recognition. We adapted the established method of cross-modal priming for children. In a standard cross-modal priming task for adults, participants listen to a prime and see a visual target and respond to it by making a word/non-word decision. In the current study, participants responded to the target item by reading it out loud. An advantage of this variant of cross-modal priming is that the task does not require any kind of metalinguistic skills.

The third experiment in the current study addressed the modality-specific access representation involved in the visual recognition of past participles by children. The results from experimental studies on access-level representations involved in the recognition (e.g. Baayen et al. 1997; Clahsen, Eisenbeiss & Sonnenstuhl 1997; Alegre & Gordon 1999; Sonnenstuhl & Huth 2002; Baayen et al. 2003; Neubauer & Clahsen 2009) and production of morphologically complex forms (e.g. Pinker 1999; Clahsen, Hadler & Weyerts 2004) have indicated important differences. We systematically investigated the discrepancy between the recognition and production of complex forms and tested the same set of items in the recognition and the production tasks.

The methods used in this experimental study test for frequency effects and priming effects. The first section of this chapter explains the rationale behind these effects. In the second section, we will examine, for each experimental technique, the mental processing steps involved in the experimental task, which processing step we want to investigate, how stimuli to address this processing step should be designed and what processing theories predict.

5.1 Reaction-time Experiments and Effects

One of the best established online methods for investigating adults' morphological processing is the reaction time experiment. Reaction times are an indirect measure of the cognitive processes and grammatical representations involved in language processing. Reaction times to one experimental condition are compared to reaction times in another; any differences indicate that the experimental manipulation has led to differences in the processing of the two conditions

(Penke 2006: 25)[16]. The literature review in section 4.4 showed that experimental manipulations of frequency and morphological form in recognition and production have consistently led to processing differences.

The frequency of occurrence of a word in a language has been found to be one of the main factors that affect word recognition: words that are more frequently used are recognised faster than those that are less frequently used (e.g. Morton 1969; Balota 1994). Different approaches to word recognition agree that frequency effects reflect the fact that frequency is an important parameter in how a mental lexicon is built. In traditional search models (Forster 1976), access to the mental lexicon involves searching through a frequency-ordered word list which ranks high-frequency higher than low-frequency entries. Activation models of word recognition (e.g. Morton 1969; McClelland & Rumelhart 1981; Perry, Ziegler & Zorzi 2010) assume that high-frequency items have a lower activation threshold than low-frequency items and are therefore more easily activated. Within connectionist implementations of word recognition (McClelland et al. 1986; MacWhinney & Leinbach 1991; Plunkett and Marchman 1993), the weights on the connections between different levels of representation increase with the frequency with which words occur in the language. Connectionist activation models therefore predict that word frequency affects word recognition. In all models, high-frequency forms have a stronger mental representation than low-frequency forms. Access to words which are represented as full forms in the mental lexicon should vary as a function of their full-form frequency. Access to words which are represented as stems and affixes should vary as a function of stem frequency. Full-form frequency effects have therefore been used as a diagnostic to detect which word forms are represented as full forms in the mental lexicon.

Many priming studies have found that prior presentation of an inflected form facilitates the recognition of its corresponding stem to the same degree as the presentation of the stem iteself (Stanners, Neiser, Hernon & Hall 1979). It is generally agreed that the recognition of an inflected form, such as ‘walked’, implies an activation of forms which have the same stem, such as ‘walk’.

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[16] Experimental conditions and materials must be designed so that processing effects are predicted or explicitly not predicted. Following the predictions, the detection of a processing effect is taken as evidence in favour of or against a cognitive operation and representation. In reaction time experiments, the materials must be designed so that the participant does not develop strategies. For example, the participant is asked to click a button on seeing an existing word of the language. In half of the stimuli, this is the case. However, the main focus of the analysis is not the decision between words and nonwords, but the relative reaction times to existing words within experimental conditions. This must be taken into account in the selection of stimuli.

The presentation modalities of the prime and target are important in priming experiments. Prime and target can be presented in the same modality – visual or auditory – or different modalities – the auditory prime preceding the visual target word. The uni-modal presentation of stimuli has the advantage that participants need only to show solid performance in one modality. This is especially helpful in different age groups. On the one hand, young children might lack reading experience and might therefore feel more comfortable in auditory experiments. On the other, adults and children with impaired hearing might have difficulties comprehending auditorily presented stimuli, but show more stable responses to visual stimuli. However, cross-modal priming experiments have a crucial advantage: the lexicon is accessed via different modalities. Thus, any effects cannot be explained by peripheral phonological or orthographic overlap of prime and target. If morphological priming effects are reported, these can only arise from activation of the modality-independent central lexicon. In this regard, the cross-modal priming experiment complements the lexical decision experiment and the speeded production experiment, which test modality-specific access-level representations.

As mentioned in section 4.4, models of word recognition disagree about whether the activation of an inflected form implies *direct* activation of other inflected forms via a shared stem or only *indirect* activation of other inflected forms. Dual models suggest that inflected default forms are decomposed into stem and affix in lexical access (e.g. Pinker 1999; Sonennstuhl, Eisenbeiss & Clahsen 1999; Clahsen, Eisenbeiss, Hadler & Sonnenstuhl 2001). The recognition of default forms, on this view, implies the direct activation of the stem that is shared with other default forms, and inflected non-default forms are not decomposed in lexical access but recognised as full forms. The activation of inflected non-default forms spreads to other inflected forms through phonological and semantic associations. The recognition of non-default forms coactivates other inflected forms. Dual models of lexical access predict direct and full priming for inflected default forms and only indirect and partial priming for inflected non-default forms. Connectionist models of lexical access assume that all words, including morphologically complex ones, are represented and processed in terms of their surface forms and their semantic properties without any representation of their morphological structure (e.g. Seidenberg & Gonnerman 2000; Gonnerman, Seidenberg and Andersen 2007). What looks like preactivation through common morphological constituents of stem and default forms is, in their view, preactivation through common surface form and semantic relatedness of stem and default forms. The activation of inflected forms spreads to their stems through phonological and semantic associations. Connectionist models of lexical access predict indirect priming for all inflected forms. The strength of the priming effect is predicted to increase as more semantic and surface form properties are shared by inflected forms.

We will test for frequency effects in a lexical decision task and a speeded production task and for morphological priming effects in a cross-modal priming task. These methods tap into very specific aspects of recognition and production. It is vital to clarify exactly which aspects of recognition and production each experimental technique is addressing so that we know how to interpret the results. It is also important to clarify which psycholinguistic parameters of the stimuli we will manipulate to study their effect on processing, and which we need to hold constant, so that they do not bias the dependent variables in each experiment.

5.1.1 Word-Form Frequency Effect in Speeded Production

In a speeded production experiment, participants listen to a verb stimulus and are asked to produce an inflected form of the verb stimulus as quickly and as accurately as possible. The production latencies and the error rates are measured.

Full-form frequency effects in a speeded production task are employed to give insight about how morphologically complex word forms are represented at the access level. Researchers (Prasada et al. 1990, Ullman 1993, Lalleman et al. 1997) have manipulated the full-form frequency and have taken the effect of full-form frequency on production latencies as a diagnostic for full-form access-level representations.

The task of speeded production involves three distinct processes listed in (16): recognising the auditorily presented verb stimulus, accessing the lexical entry of the target past participles and articulating the past participle. First, the lexical entry of the verb stimulus is recognised (step 1). Next, the lexical entry of the corresponding past participle is accessed in the lexicon and subject to spell-out processes, i.e. morphological and phonological encoding (step 2a–b), to be transformed into an articulatory plan (step 3, cf. Levelt 2001:13465). The current study used a speeded production task to study the effect of word form frequency on lexical access in production of the target past participle (step 2).

(16)

1. Auditory word recognition
2. Lexical access to the target past participle
a. Morphological level: Assigning the morpheme order
b. Phonological level: Assigning the phoneme order
3. Articulation of the target word

We use the speeded production experiment to test lexical access to past participles, but the task also involves activities which are not part of the focus of our study, namely, recognition of the verb stimulus and articulation of the past participle. We therefore had to control for item-level properties which might influence these. We can conclude from Baddeley (1996) that the length of the verb stimulus and the target past participle, defined by the number of phonemes, affects word processing. A short form (e.g. *geh* 'go' = two phonemes) is more easily held in the working memory than a long form (e.g. *schlaf* 'sleep'= four phonemes). Levelt, Roelofs & Meyer (1999) have observed that a larger number of phonemes in the past participle may require more time for syllabification and articulatory planning than a small number of phonemes. The number of phonemes in both the verb stems and the target participles therefore had to be controlled for in our study. The complexity of morphological structure is important in phonological encoding, and frequency affects access to a lexical entry. We controlled lemma frequency and varied word-form frequency of the target past participle to investigate the effect of word-form frequency on production latencies (e.g. Oldfield & Wingfield 1965; Jescheniak & Levelt 1994).

In line with previous research and theories, we expected the following results: if a complex word form is stored as a whole in the mental lexicon, we expect word-form frequency to affect its production latencies. If a complex word form is not stored as a whole but decomposed in the mental lexicon, its word-form frequency should not affect its production latencies.

Theory-driven predictions are presented in Table 8. Whole-word representations of all inflected forms elicit word-form frequency effects with both *-t* participles and *-n* participles (e.g. Seidenberg & McClelland 1989; Bybee 1995). Decomposed processing of all inflected forms (Taft & Forster 1975; Yang 2002) predicts that neither *-n* participles nor *-t* participles yield word-form frequency effects. Finally, the rule-based processing of *-t* participles and full-form processing of *-n* participles, as expected by a Dual Mechanism Model (e.g. Clahsen 1999), would yield word-form frequency effects for *-n* participles but not for *-t* participles. Pinker (1999) has argued that *-t* participles which have left memory traces (cf. Pinker & Ullman 2002) should produce longer reaction times for high-frequency *-t* participles than *-t* participles which have not left memory traces.

Theoretical Approaches	**Participle Type**	**Frequency Effect?**
Single Mechanism Models		
a) Associative	*-t* participles	yes
	-n participles	yes
b) Decompositional	*-t* participles	no
	-n participles	no
Dual Mechanism Models	*-t* participles without memory traces	no
	-t participles with memory traces	negative
	-n participles	yes

Table 8: Theory-driven predictions for adults in a speeded production experiment

Previous research using speeded production experiments with adults has shown significantly shorter reaction times for non-default forms than for default forms (Prasada et al. 1990; Ullman 1993 for English; Lalleman et al. 1997 for Dutch). But the studies reported varying results with regard to default forms: Prasada et al. (1990) report an anti-word-form frequency effect and Lalleman et al. (1997) but Ullman (1993) found a word-form frequency effect. We therefore expected to repeat the results of speeded production studies with a clear frequency effect for *-n* participles and varying results for *-t* participles.

If children rely on the same mental mechanisms as adults in the production of inflected forms, we would expect similar effects for children and adults. If they rely on different mechanisms, their behaviour should differ. With regard to frequency effects, we can derive clear expectations from one study of speeded production in children. Clahsen, Hadler & Weyerts (2004) reported that children show similar performance patterns to adults for *-n* participles, a clear frequency effect. They also reported that children behaved unlike (fast) adults, in that frequency negatively affected production latencies for *-t* participles. If children's recognition of words develops over time to become adult-like, older children should behave more like adults than do younger children; in other words, older children might generally respond more quickly than young children. We would expect the effect of frequency of participle observed in older children to be more similar to those of adults than to those of younger children.

5.1.2 Morphological Priming Effects in Cross-Modal Priming

In a cross-modal priming task, the morphological relation between an auditory prime and a visual is manipulated. As exemplified in (17), the morphological prime is a stimulus which is morphologically related to the target word. In a control condition, primes which are not related to the target word are presented, while in an identity condition, primes are identical to the target word. As in previous priming studies, we measured the influence of the morphological prime on reaction times to the target and determined the strength of the morphological priming effects relative to reaction times after an identical prime and after an unrelated prime.

(17)

Target item:	*rufe*	'call'
Identical condition:	*rufe*	'call'
Morphological prime:	*gerufen*	'called'$_{\text{[past participle]}}$
Unrelated condition:	*sehen*	'to see'

In most previous cross-modal priming studies with adult speakers, participants are instructed to respond by making a lexical decision. In our experiment, participants read aloud visually presented target words, because some researchers have suggested that the word/non-word decision task, which was used in previous morphological priming studies with adults, could be problematic for children. It requires meta-linguistic skills and is therefore likely to produce many false positives and/or exceptionally long response latencies (Quémart et al. 2011: 493; Feldman et al. 2002: 530). Reading out aloud written words, Schiff et al. (2008: 740) argued, is a natural task for primary-school children.

We used the cross-modal priming task to examine central-level representations of word forms in the lexicon.The task of cross-modal priming involves three distinct mental processes, listed in (18). The participant recognises the auditorily presented verb stimulus. He or she recognises the visual target word and accesses the corresponding entry in the phonological lexicon. He or she prepares the articulatory shape in order to articulate the target word (Coltheart 2006: 9).

(18)

1. Auditory word recognition
   a. Lexical access: auditory access representation
   b. Selection of central-level representation
   c. Integration
2. Visual word recognition
   a. Lexical access: visual access representation
   b. Selection of central-level representation
   c. Integration
3. Articulation

In the cross-modal priming task, we are not testing the influence of linguistic stimulus properties on word recognition or production. The experimental manipulation addresses the relationship between prime and target. We therefore need to hold constant all the psycholinguistic parameters involved in the recognition of the prime and target word and articulation of the latter. As in previous experiments, the length of the stimulus in terms of letters and syllables, and its morphological complexity, may affect word processing and should be controlled for in both recognition and production. The word-form frequencies and lemma frequencies of primes and targets affect word processing, but are not the focus of this experiment, so should be held constant. Another important variable in the recognition of words is the orthographic neighbourhood size. Words which resemble a relatively small number of real words take longer to recognise than words which resemble a relatively large number of real words (e.g. Holcomb, Grainger & O'Rourke 2002). In addition, both the prime and the target activate semantic meaning. The semantic overlap is the same for all participle types in the identity and the control condition but not in the control condition. Semantic overlap might semantically preactivate the target and lead to shorter reaction times in the control condition. It is therefore necessary to ensure that there is no semantic overlap between unrelated prime and target in the unrelated condition in both participle types. As we are testing children, we tested our materials for (estimated) age of acquisition. And as participles can in some cases be used as adjectives, we held the number of participles which can be used as adjectives constant across participle types.

Inflected words and their bases share morphological structure. They also share meaning, and overlap both phonologically and orthographically. Words like *mache* and *gemacht* are semantically, orthographically and therefore phonologically related. However, any difference in priming effects between participle types should not be due to these properties because these relations between morphologically related prime–target pairs are held constant across participle types. Also, a number of studies have tested for these sources of priming by including an orthographic control condition and found that morphologically related, but not purely orthographically related, forms showed a priming effect. For example, Drews & Zwitserlood (1995) included a condition with orthographically similar pairs, which were, however, not morphologically related, such as *kerst – kers* 'Christmas – cherry' (cf. Kempley & Morton 1982; Allen & Badecker 2002).

The following stimulus properties were controlled in the cross-modal priming experiment: the prime words used in the unrelated condition were matched pairwise with the corresponding primes in the participle condition with regard to lemma frequency, word-form frequency, number of letters and semantic overlap. The three types of participle were also matched for mean lemma frequency, mean word-form frequency, and mean number of letters. Finally, the targets for the three critical prime types were matched with respect to mean neighbourhood size.

In consistency with previous priming studies on adults (e.g. Sonnenstuhl et al. 1999, see section 4.4.1), full priming effects are taken as indication that participle prime and target are represented according to their morphological constituents and share the same stem representation. Partial priming effects are taken as indication that prime and target are represented as full forms. Response to the target is facilitated only indirectly through connections or associations between prime and target.

Table 9 provides an overview of predicted outcomes for adults. According to proponents of single mechanism models such as Gonnerman et al. (2007), morphological structure and morphological relatedness are not directly represented in memory and priming effects for inflected word forms only arise from shared meanings and overlapping surface forms of primes and targets. This account predicts the same priming patterns for *-t* and *-n* participles without stem changes, due to parallel phonological, orthographic and semantic overlap between primes and targets. By contrast, *-n* participles with stem changes should produce less priming than *-n* participles without stem changes, because the former have less formal overlap between prime and target than the latter. The decompositional model proposes that all words are processed by morphological decomposition and therefore that all inflected forms activate the base stem, predicting full priming effects for all participle types (Taft & Forster 1975, Yang 2002). A number of studies across different languages have used morphological priming to investigate the role of decomposition of inflected forms on a central level: for example, in English (Marslen-Wilson & Tyler 1998), in Italian (Laudanna, Badecker & Caramazza 1992), in German (Schriefers, Friederici & Graetz 1992; Sonnenstuhl, Eisenbeiss & Clahsen 1999) and in French (Meunier & Marslen-Wilson 2004). The studies have been largely supportive of the dual-system theory, which predicts different priming effects for *-t* and *-n* participles, corresponding to their distinct morpho-lexical representations. If *-t* participles are represented as morphologically structured word forms and are derived from an affixation rule, they should produce full priming effects. If *-n* participles are stored as lexical (sub)entries, they should produce only partial priming effects, irrespective of any additional stem change.

Theoretical Approaches	**Participle Type**	**Priming Effects**
Single Mechanism Models	*-t* participles	partial
a) Associative	*-n*/with	partial
	-n/without	less than -n/with
b) Decompositional	*-t* participles	full
	-n/with	full
	-n/without	full
Dual Mechanism Models	*t* participles	full
	-n/with	partial
	-n/without	partial

Table 9: Theory-driven predictions for adults in a cross-modal priming experiment

Priming studies have also been carried out with children in different languages (Feldman et al. 2002; Rabin & Deacon 2008; Rosa & Nunes 2008; Schiff et al. 2008; Casalis et al. 2009; Deacon et al. 2010; Quémart et al. 201; Ravid 20121); all these have shown morphological priming effects in school-children, indicating that children at this age are aware of morphological structure. The results of visual lexical decision experiments confirm children's sensitivity to the morpholexical structure of complex forms.

If children rely on the same mechanisms as adults, they should show the same priming patterns. However, as we noted earlier, children are developing their reading abilities, which may lead to different priming effects from those in skilled adult readers. If children rely on different mental strategies, they should deviate in their priming patterns from those found in adults. It may be easier to represent inflected forms of one stem as a stem and affixes than representing each inflected form separately. If this is correct, children would rely more strongly on decomposed representations and show stronger morphological priming effects than adults.

5.1.3 Word-Form Frequency Effects in Visual Lexical Decisions

In a visual lexical decision task, participants are presented with a string of letters and are asked to decide as quickly and as accurately as possible whether it is an existing word of the language, usually indicating their response by pressing a button. Reaction times are measured as the time between the presentation of the visual stimulus and the participant's response.

One of the first visual lexical decision experiments was conducted by Meyer & Schvaneveldt in 1971, and this type of experiment has become one of the most frequently used ways of measuring visual word recognition (Coltheart 2006: 6). More recently, Clahsen, Eisenbeiss & Sonnenstuhl (1997), Penke & Krause (2002) and Neubauer & Clahsen (2009) have used this type of task to test for frequency effects in the recognition of inflected forms (see section 4.4.1). Frequency effects are taken as evidence for full-form access-level representations. While visual lexical decisions test the access-level representations involved in recognition, speeded production tests those involved in production.

As shown in (19) below, each trial in a lexical decision task involves two distinct steps: recognition of the target word and the initiation of a button press. As explained in section 4.1, a word is recognised in several steps: through (a) the access representation, (b) selection of the central-level representation and (c) integration of the lexical entry. The visual lexical decision task taps into processing step (a), the recognition of the target word on a modality-specific access level (cf. Marslen-Wilson 2007).

The visual lexical decision task thus taps into the access-level representation while the cross-modal priming experiment taps into the central-level representation. These levels of representation of a lexical entry may be structured differently, so although the two experiments both involve the recognition of stimuli, they tap into different levels of representation. The speeded production experiment is used to study the access-level representation involved in the production of participles while the lexical decision task is used to study the access-level representation involved in the recognition of words, so although the two techniques involve different modalities, they tap into the same level of representation.

(19)

1. Visual word recognition
   a. Lexical access: visual access representation
   b. Selection of central-level representation
   c. Integration
2. Motor planning and pressing a button

In the visual lexical decision task, we are interested to test the effect of word-form frequency on the recognition of past participles. The stimuli used in the visual lexical decision task have word-form properties other than frequency that may influence recognition, so must be controlled for. Yap & Balota (2009), among others, have observed that the length of the target word affects word recognition (but see New, Ferrand, Pallier & Brysbaert 2006), so the number of letters in the experimental stimulus should be controlled for. Levelt, Roelofs & Mayer (1999) found that the complexity of the morphological structure is relevant in word recognition – a small number of morphemes is more easily assigned than a large number – so the number of morphemes in the experimental stimuli must be held constant. Again, items of high frequency are more easily recognised than items of low frequency (e.g. Oldfield & Wingfield 1965; Jescheniak & Levelt 1994). As the full-form frequency of the target past participle is our variable of interest, we vary it systematically. In order to distinguish between stem frequency and full-form frequency effects, the verb stem frequency is held constant. In sum, the following psycholinguistic variables will be controlled for in the stimuli: the number of letters, the number of morphemes and the lemma frequency. The full-form frequency is varied systematically between participle types.

The current study of visual lexical decision investigates reaction times to German *-t* and *-n* participles in German children and an adult control group. Following previous studies on children, we expected that words represented as full forms in the mental lexicon yield full-form frequency effects, but words represented according to their morphological constituents do not.

Predictions from single- and dual-mechanism models make different predictions of how word form frequency affects reaction times to different participle types in adults. These are summarised in Table 10. The associative single-system model (e.g. Seidenberg & McClelland 1989; Bybee 1995) assumes that all words are processed through whole-word representations. This hypothesis predicts that word-form frequency affects the recognition of both *-t* participles and *-n* participles. The decompositional model proposes that all words are processed by morphological decomposition, and predicts that word-form frequency affects the recognition of neither *-n* participles nor *-t* participles (Taft & Forster 1975; Yang 2002). The Dual Mechanism Model (e.g. Clahsen 1999) hypothesises that *-t* participles are decomposed, while *-n* participles are processed via a whole-word route, which predicts that word-form frequency affects recognition of *-n* participles but not that of *-t* participles. Pinker (1999) and Pinker & Ullman (2002: 458) have emphasised that regular forms, in our case default *-t* participles, may also be stored in the mental lexicon if they are frequent in the language. If *-t* participles are stored in memory as full forms and are accessed through these full forms, we also expect a frequency advantage for *-t* participles.

Theoretical Approaches	**Participle Type**	**Frequency Effect?**
Single Mechanism Models		
a) Associative	*-t* participles	yes
	-n participles	yes
b) Decompositional	*-t* participles	no
	-n participles	no
Dual Mechanism Models	*-t* participles of high frequency	yes
	-t participles of low frequency	no
	-n participles	yes

Table 10: Theory-driven prediction for adults in a lexical decision experiment

The literature review has shown how children have differed from adults in previous processing studies, usually showing longer reaction times (Clahsen et al. 2004; Clahsen et al. 2007). If 7–11-

year-old children have developed adult-like visual representations of inflected words, one would expect the same frequency effects as in adults (outlined above). However, the current study requires children to read, and children under study are in the process of learning to read. While skilled adult readers access familiar words directly via a direct lexical route (Coltheart, Rastle, Perry, Langdon & Ziegler 2001) and only unfamiliar words via a phonological decoding strategy, the children in our study are developing their reading skills and may be transferring from a phonological decoding strategy to automatic recognition of familiar words (Wimmer & Goswami 1994; Schmalz, Marinus & Castles 2013).

Children may differ from adults because they have considerably less reading experience. If, for example, children have not yet developed visual access-level representations of participles at the age range tested, visual recognition might not be enhanced by high-frequency as opposed to low-frequency stimuli. Generally speaking, if children's recognition of words develops over time to become adult-like, older children should behave more like adults than do younger children. For example, if older children have developed visual representations of participles that younger children have not, visual recognition might be enhanced by frequency only in the older group. Also, if participles differ in how their potential full-form representations are established in children, children might show frequency effects only for those participle types that are represented as full forms, but not for those that are not represented as full forms.

6 Speeded Production

This chapter reports an experiment assessing children's and adults' production latencies and error rates in the production of German past participles. The experiment uses the speeded production technique to test for full-form frequency effects in the production of inflected words. These effects give indications about how the inflectional types tested are represented.

The design used in previous speeded production experiments can be improved with respect to the stimulus selection. Like most previous psycholinguistic studies, Clahsen et al. (2004) distinguished regular from irregular past participles on the basis of suffixation (*-t vs. -n*), irrespective of stem change. Regular participles were defined by *-t* suffixation and irregular by *-n* suffixation (e.g. Clahsen 1999, Clahsen et al. 2004) for the reasons outlined in section 2.1.1. However, the stimulus design neglects the fact that *-n* participles are a heterogeneous group, in that some undergo unpredictable stem change. The participle of *laufen* 'run' is *gelaufen*, with no stem change; the participle of *schießen* 'shoot' is *geschossen*, with a stem change (see section 2.1.2). The current study considers suffixation and stem change in the selection of past participles and distinguishes between *-n* participles with stem change and *-n* participles without stem change.

The stimulus design also requires improvement with respect to frequencies. Clahsen, Hadler & Weyerts (2004) vary the word-form frequency in their stimuli but do not control for stem-form or lemma frequency. This leaves room for the interpretation that the effects observed were due to variation in stem-form or lemma frequency. In the current study, verb-stem frequency were controlled to enable us to relate potential differences in the dependent variables to differences in word-form frequency.

Another concern about previous speeded production studies relates to their results for regulars, which, one could argue, are consistent with more than one current theory of morphological processing. For example, Lalleman (1997), Ullman (1993) and Prado & Ullman (2009) found an advantage for high-frequency over low-frequency regular forms which reflects the same trend as has been found for irregulars, suggesting that regulars and irregulars may be processed by one system. At the same time, the advantage for high-frequency over low-frequency regulars was considerably less pronounced for regulars than for irregulars (Ullman 1993; Prado & Ullman 2009), which led the authors to argue for different mechanisms for regulars and irregulars. Meanwhile, the advantage for low-frequency items over high-frequency items reported by

Prasada et al. (1990) for adults and by Clahsen et al. (2004) for children was the reversed frequency effect and was not compatible with any processing model, as none of them predicts a frequency disadvantage for any word form. It nevertheless suggested that full-form representation of the lexicon was somehow involved in the processing of regular forms by children. Clahsen et al. accounted for the reversed frequency effect by slowed lexical retrieval. It is true that speed of lexical retrieval plays a general role in the processing of morphologically complex forms, as was discussed in section 4.3.2. The authors argued that morphological processing in adults and children relied on the same underlying mechanisms and that the anti-frequency effect was due to slower processing speed. An alternative interpretation would be that this finding indicated a generally stronger implication of whole-word processing in children than in adults. It remains to be confirmed that mean production latencies are particularly related to processing patterns in *-t* participles. As shown in section 4.3.1, other studies have pointed out that working memory capacity may affect language processing (e.g. King & Just 1991; Adams & Gathercole 2000). Working memory might even have a specific effect on participants' behaviour in the speeded production task, as it requires them to retain a verb stimulus in memory before retrieving and producing the corresponding participle form. However, Clahsen et al. (2004) did not test for a relation between working memory capacity and the reversed frequency effect. The current study considers the factors of speed of lexical access and working memory capacity to determine their relevance to the production of regular forms. A standardised auditory digit-span test (*Hamburg-Wechsler Intelligenztest für Kinder* (HAWIK), Tewes 1983; *Hamburg-Wechsler Intelligenztest für Erwachsene* (HAWIE), Tewes 1991) was run in order to independently measure individual participants' working memory capacity.

6.1 Methods

The experimental procedure used for this task was adopted from Clahsen, Hadler & Weyerts (2004), who introduced a child-friendly version of Prasada et al.'s (1990) speeded production task. This technique has produced replicable results showing dissociations between default and non-default forms. Non-default forms have shown a frequency advantage – shorter production latencies for high-frequency than low-frequency items – which does not apply to default forms. Another advantage of the speeded production technique is that it offers a simple, well-structured and experimenter-independent production situation which can be used with children. Finally, it yields both online and offline measures. The online measure production latency is the crucial online measure for automatic processes in children's spoken word production (Clahsen 2008); the offline measure usefully complements the online measure as it allows us to relate new results to previous offline production acquisition studies of past participles.

6.1.1 Participants

Forty 6–10-year-old primary school children in two age groups (6- to 8-year-olds: mean age 7;6, S.D.: .82, 11 girls; 9- to 11-year-olds: mean age 9;10, S.D.: .56, 11 girls) were tested, recruited from the after-school *St. Bernward* programme in Salzgitter-Steterburg and the *Clemens' primary school* in Hornburg (Germany). Parental consent was obtained prior to the testing. Children younger than six were not selected, since it was necessary for the participants to have passed the 'milestones' of first language acquisition, such as syntactic structures and the phonological system. At the same time, participants older than 11 years were not selected, as they would have been pre-pubertal, and thus approaching the age at which child-specific aspects of language processing might disappear (e.g. Kannengieser 2012: 54, 226).

The experiment was also administered to a control group of twenty adults (age range: 24–71; mean age 40.2; S.D.: 16.3, 11 females), recruited from the native German student community at the University of Essex and from the region of Braunschweig, Germany. All the participants were monolingual native speakers of German, and none had any history of language, hearing or vision impairment. They were asked to provide their date of birth and, for adults, years of education and profession. Ethical approval for the speeded production experiment was gained prior to testing from the University of Essex ethics committee.

In the standardised auditory digit-span test (HAWIK Tewes 1983; HAWIE Tewes 1991), all child and adult participants were asked to repeat auditorily presented strings of two to nine digits either in the same order (Subtests *Zahlen nachsprechen*) or in the reverse order (Subtest *Zahlen rückwärts nachsprechen*). Points were assigned on the basis of correctly repeated sequences. This test was chosen because, first, both it and the speeded production experiment involve retaining auditory stimuli. In the digit-span test, participants have to retain the auditory information until they have reproduced it. In the speeded production experiment, participants have to retain auditory information – the verb stimulus – until they have accessed and produced the corresponding past participle form. Secondly, it is one of the few working memory tests which have been standardised for both adults and children.

Table 11 presents the mean working memory scores as measured by the *HAWIK-Test* in the child groups and *HAWIE*-Test in the adult group. The table shows that the mean working memory scores gradually increase with age. The score of the youngest child group (11.1) was slightly lower than that of the older child group (12.7), which itself was considerably lower than the score of the adult group (16.3).

	6–8-year-olds	**9–11-year-olds**	**Adults**
Working memory score	11.1	12.7	16.3
(S.D.)	(2.85)	(2.90)	(3.40)

Table 11: Mean working memory score per participant group

Independent-sample *t*-tests confirm that the differences in working memory scores between child groups are marginally significant (6–8-year-olds *vs.* 9–11-year-olds: $t(38)=1.760$, $p=.086$) and highly significant between child groups and the adult group (9–11-year-olds *vs.* adults: $t(38)=3.598$, $p=.001$; 6–8-year-olds *vs.* adults: $t(38)=-5.242$, $p<.001$). The results may show that auditory short-term memory develops over time until it becomes adult-like.

To ensure that children had acquired the target participles, children were post-tested with a lexical decision task. A randomised list of the 55 target items and 55 non-words were auditorily presented to the children. The non-words were systematically derived from the target participles by changing the suffix and one sound. For example, the participle *geschlafen* 'slept' yielded the non-word *geklaft*. The experimenter read the list of words to the child and asked them to indicate an existing word by pressing a buzzer. The results showed that all the children performed at 100% for all target participles, indicating that the children were familiar with them.

6.1.2 Materials

The materials were designed to exemplify three participle types (*-t* participles *vs. -n* participles with stem change *vs. -n* participles without stem change) in two frequency conditions (high *vs.* low) yielding six experimental conditions, as illustrated in Table 12. There were five experimental items for each condition, yielding a total of 30 experimental items in the experiment[17]. For a list of the critical items, see Appendix 1.

Participle Type	Frequency	Sentence Context	Verb Stimulus	Target Past Participle
-t	high	*Das Mädchen hat die Süßigkeiten…* 'The girl has the candy'	*spare* 'save'	*gespart* 'saved'
-t	low	*Der Affe hat im Baum …* 'The monkey has in the tree'	*lache* 'laugh'	*gelacht* 'laught'
-n/with	high	*Das Baby ist im Bett...* 'The baby has in the bed…'	*bleibe* 'stay'	*geblieben* 'stayed'
-n/with	low	*Die Eule hat im Käfig…* 'The owl has in the cage…'	*schreie* 'scream'	*geschrien* 'screamed'
-n/without	high	*Der Jogger ist auf der Bahn…* 'The jogger has on the track…'	*falle* 'fall'	*gefallen* 'fallen'
-n/without	low	*Die Ente hat das Krokodil ...* 'The duck has in the crocodile…'	*stoße* 'push'	*gestoßen* 'pushed'

Table 12: Example stimuli and target participles for the experimental conditions

The materials were matched as closely as possible with respect to a number of relevant criteria. Both stem frequency and lemma frequency were held constant within each participle type while word-form frequencies varied. Items were selected on the basis of *spoken* frequencies from the *CELEX database* (Baayen et al. 1995) because the stimuli were presented auditorily. Independent-samples t-tests on mean word-form frequency in high-frequency and low-frequency conditions per participle type confirmed significant differences between items of high and low word-form frequency (*-t* high *vs.* low $t(8)=2.795$, $p=.04$; *-n/with* high *vs.* low $t(8)=4.721$, $p=.002$; *-n/without* high *vs.* low $t(8)=3.992$, $p=.004$), while there was no such difference between the items in terms of verb-stem frequency (*-t* high *vs.* low $t(5.582)=1.147$, $p=0.285$; *-n/with* high *vs.* low $t(8)=.266$, $p=.797$; *-n/without* high *vs.* low $t(8)=.572$, $p=.583$) and participle length in terms of phonemes (*-t* high *vs.* low $t(5.582)=.894$, $p=.397$; *-n/with* high *vs.* low $t(8)=.354$, $p=.733$; *-n/without* high *vs.* low $t(8)=1.265$, $p=.242$). For a list of stimulus properties, see Appendix 2.

[17] The number of items per condition in the speeded production experiment was rather small and smaller than in previous speeded production studies (e.g. Clahsen et al. 2004). Unfortunately, it was not possible to include more items per condition given the limited number of *-n/without* participles in German.

To ensure that the children were familiar with all the experimental items, participles were included only if they occur in the CHILDES corpus (MacWhinney 2000) at least once as children's output and at least five times as children's input. Only *ge-* prefixed participles were included, to control for the influence of different onsets on the measurement of production latency (e.g. Kessler et al. 2002). Prefixed verbs such as *verschreiben* 'subscribe' take no prefix in their participle form *verschrieben.* Base verbs such as *schreiben* 'write' take the *ge-* prefix in their participle forms *geschrieben* (see section 2.1.2 for more details). The mean length of the verb stimuli and of the target items was held constant in terms of morphemes. In addition, the duration of the auditorily presented verb stems was held constant across participle types. The mean stem duration, shown in Table 13, did not differ significantly between participle types. As the processing of an auditorily presented stimulus starts from the beginning of its presentation, the similar durations of the stimuli ensures that their length does not influence the production latencies.

Participle type	**Mean stem duration per condition in ms (SD)**
-t	871 (64)
-n/with	903 (56)
-n/without	908 (75)

Table 13: Mean duration of stems per participle type

There are two German auxiliaries, *haben* and *sein*, which combine with participles to form the present perfect tense. Both were included in the sentence contexts and distributed as similarly as possible across participle types (see Table 14).

Participle type	***sein***	***haben***
-t	1	9
-n/with	2	8
-n/without	1	9

Table 14: Number of *sein-/haben*-verbs per participle type

To ensure that participants could not anticipate the target participle form before the critical verb stimuli were presented, an offline predictability test was conducted with 25 adult native speakers of German. Only sentential contexts with a predictability of less than 5% for the targeted participle were included. Ninety sentences were added, with the same structure as the experimental sentences. To ensure that participants were not biased towards producing *ge-* before processing the verb stimuli, 60 filler items were included: these were prefix verbs with a prefix other than *ge-* in their participle form (see Appendix 3).

Note that it was not possible to control for the number of phonemes in the verb stem stimuli. Additionally, the limited number of *-n* past participles and the control variables did not allow for frequency matching *between* participle types. The target stimuli differ between participle types with respect to the absolute mean word-form frequency and with regard to the mean verb-stem frequency (see Appendix 3).

Unlike Clahsen et al. (2004), we decided not to present verb stimuli as bare verb stems because a test run of the materials suggested comprehension difficulties. These were partially due to the phonetic devoicing of voiced plosive sounds in word final position. For example, the verb stem *bad* 'to bath' is pronounced */bat/,* which corresponds to the 3rd person singular past tense of *bitten* 'ask' and the noun *Bart* 'beard'. To avoid this devoicing, a stem-final *schwa* was added to all verb stimuli.

6.1.3 Procedure

The experiment was carried out in a quiet room. Before the experiment, a short-term memory test was conducted. After the experiment, children were presented with the offline lexical decision task. The length of the experiment itself did not exceed 15 minutes, and the whole session did not exceed 35 minutes for children and 20 minutes for adults.

A set of practice trials consisting of ten sentences (two *-t* participles, three *-n* participles and five filler items, see Appendix 4) was run before the main experiment to allow participants to familiarise themselves with the task. The experimental procedure was taken from Clahsen et al. (2004) and is illustrated in Table 15. Participants listened to a sentence context illustrated by pictures. Then, a cartoon figure, an alien in a flying saucer, appeared on screen and produced a verb stimulus, which was grammatically ill-formed in the given sentence context. At the beginning of the experiment, the cartoon figure was introduced to participants as not speaking German very well. Participants were asked to produce the correct form as quickly and accurately as possible.

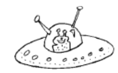
	Sentence context		**Verb**	**Response**
Picture Stimulus				
Auditory Stimulus	*"Das Kamel hat…* The camel has…	*das Krokodil…* the crocodile…	*stoße ?*" push?	*" gestoßen"* *"pushed"*
	'The camel has pushed the crocodile'			

Table 15: Sequence of stimulus presentation

The experiment was divided into eleven parts consisting of ten sentences each. An automatic break was given after each part, which the participant could end at will. The presentation order of the items was pseudo-randomised[18] and was presented in two versions. Version 2 was presented in the opposite order to version 1 to avoid presentation position effects. To make the experiment more appealing to children and to let them monitor their progress, a board game was provided on which the children could advance one field when reaching a break.

Sentences with the correct target past participle forms were spoken and recorded prior to the experiment by a female native speaker of German; another female native speaker spoke the verb stimuli with a question-like rising intonation. Different speakers recorded the sentence contexts and verb stimuli to convey the difference between the sentence context, spoken by one speaker, which was always correct, and the verb stimulus, spoken by the 'alien voice', which was always ungrammatical. The rising intonation in the alien's production of the verb stimulus was employed to indicate insecurity about the correct form. The participle forms were removed from the sound files at their onset and replaced by these verb stimuli using the sound editor *praat* (Boersma & Weenink 2011). Care was taken to guarantee a natural pronunciation of the sentences. All the pictures were selected from the database of normed pictures made available by the International Picture Naming Project (Szekely et al. 2004), which provides child-friendly black-and-white drawings standardised for a range of psycholinguistic parameters, such as age of acquisition, visual complexity and quality of depiction. Picture stimuli were presented on a 15-inch laptop screen and audio stimuli were presented through loudspeakers using the presentation software

[18] Pseudo-randomisation of stimuli: no more than three items of either filler or experimental items are presented in a row. No more than two items of the same participle type are presented in a row.

DMDX (Forster & Forster 2003). The participants' responses triggered voice key measurements via a head microphone which was connected to the laptop. The target threshold for triggering the measurement was individually determined for each participant before the experiment. In addition, responses were recorded on a digital audio recorder to enable double-checking of the voice key measurements.

6.1.4 Data Analysis

The online measure 'production latency' and the offline measure 'error rate' were analysed separately as dependent variables. Error rates were calculated as the number of incorrect cases over the total number of correct and incorrect cases. As shown in Table 16, incorrect responses were further classified into suffixation errors and stem-formation errors and other incorrect responses. An overregularisation of an *-n* participle stem change was thus marked as two errors. For instance, **gebleibt* 'stayed' instead of *geblieben* was an incorrectly unmarked stem **bleib* and an incorrect *-t* suffix instead of an *-n* suffix. No cases of suffix omission errors (e.g. **gemach* instead of *gemacht*) were detected in the data.

Error Type	**Example**
<u>Stem error</u> e.g. unmarked stem for a form that required a marked stem or vice versa	*gedenkt* instead of *gedacht*
<u>Suffix error</u> e.g *-n* suffix for a regular verb or *-t* suffix for an irregular verb	*gebliebt* instead of *geblieben*
<u>Other erroneous productions of the target participles</u> verb stimulus, infinitive, prefix omission, 3rd person singular present	*geziert* instead of *gezogen*

Table 16: Categorisation of error types

Production latencies were measured as the time span between the end of the auditorily presented verb stimulus and the onset of the participant's response as measured by the voice key. Each voice key measurement was double-checked using the audio back-up recording.

For the main analysis of production latency, the raw data was cleaned as follows. The item *gezogen* 'drawn' was excluded from both the error and the production latency analysis because more than half of both adults and children misunderstood the verb stimulus. For the analysis of production latencies, we included only correct initial responses, excluding self-corrections, incorrect participle forms, null responses, and participle forms of a different lexeme. In addition, trials with extremely long reaction times (RT>2000ms) and outliers (<2.5 SDs from a subject's mean) were removed, which led to the exclusion of 2.9% of the child and 2.5% of the adult data set.

Before any statistical analysis, the raw production latencies were log-transformed and converted to *z*-scores on the basis of individual participants' mean and standard deviations. While mean response latencies in milliseconds are displayed, all statistical analyses were performed on these *z*-score averages. Faust, Balota, Spieler & Ferraro (1999) pointed out that generally slower reaction times in one group could affect experimental conditions differently and hence lead us to overestimating effects: the 'overadditivity effect'. The current children's overall response latencies were 1.3 times longer than those of the adult group. Under such circumstances, Faust et al. (1999) recommend performing statistical analyses on *z*-score averages.

6.2 Results

This section presents an analysis of error rate and production latency. It focuses on the comparison of frequency effects (high *vs.* low) in (i) different participle types (-*t* participles *vs.* -*n* without stem change *vs.* -*n* with stem change) and (ii) different age groups (6–8-year olds *vs.* 9–11-year-olds *vs.* adults) and asks (iii) whether cognitive factors of speed of lexical access and working memory ('WM') affect production latencies in the experimental conditions.

6.2.1 Error Analysis

This section presents an analysis of morphological errors. The purpose of this analysis was to collect empirical evidence for or against a default past-participle inflection and to detect frequency effects in the error distribution of -*t* and -*n* participles. Empirical evidence for a default past-participle inflection would be overregularisation errors formed by applying the default participle inflection (unmarked stem and -*t* suffix) to a participle which requires non-default inflection (stem change and/or -*n* suffix). A frequency effect in the error distribution would manifest itself in a significantly larger number of errors in low-frequency items than high-frequency items. Analogously, an anti-frequency effect in the error distribution would be detected by significantly fewer errors in the high-frequency items than the low-frequency items. A developmental change would be detected if the absolute number of errors or their distribution across conditions differed significantly between age groups.

Adults' productions of participle forms were almost always correct, with just one error, **geschreit* instead of *geschrien* 'shouted', and were excluded from the error analysis. In the child data, there was a mean overall error rate of 6.3% (68 errors out of 1,074 correct forms). Children produced 52 incorrect participle forms and 16 other forms, such as bare stems, infinitives and 3rd singular forms. In incorrect participle forms, the *-t* suffix and the unmarked stem were overapplied to verbs that required an *-n* suffix and/or a marked stem. By contrast, overapplications of *-n* suffix and marked stems to verbs that require *-t* suffix and an unmarked stem were rare. In total, there were 15 cases of overapplications of the unmarked stem and the *-t* suffix (20a), nine cases of pure unmarked stem overapplications (20b), and 17 cases of pure *-t* overapplications (20c). There were, however, only two cases of marked stems for verbs that require unmarked stems (20d) and nine cases of *-n* instead of *-t* suffixation (20e).

(20)

a.	*bleib* 'stayed' → **gebleibt*	(correct: *geblieben*)
b.	*bleib* 'stayed' → **gebleiben*	(correct: *geblieben*)
c.	*schlafe* 'slept' → **geschlaft*	(correct: *geschlafen*)
d.	*stecke* 'plug in' → **gestackt*	(correct: *gesteckt*)
e.	*störe* 'disturb' → **gestören*	(correct: *gestört*)

The suffixation errors and stem errors were analysed separately. Percentages and standard deviations for both age groups per experimental condition are shown in Table 17 for stem errors and in Table 18 for suffixation errors. As Tables 17 and 18 show, the overall error rate did not differ greatly between the age groups, neither for stem errors (6–8-year-olds: 2.87%; 9–11-year-olds: 1.81%) nor for suffixation errors (6–8-year-olds: 3.82%; 9–11-year-olds: 3.81%). Suffixation errors and stem errors in both age groups exhibited clear differences between the default inflection (unmarked stem, *-t* suffix) and non-default inflection (marked stem, *-n* suffix) in terms of both absolute error rates and error distribution across frequency conditions.

Condition	**6–8-year-olds**	**9–11-year-olds**
-t high	0.00% (0.00)	0.00% (0.00)
-t low	2.06% (14.28)	0.00% (0.00)
-t total	1.14% (10.65)	0.00% (0.00)
-n/with high	1.28% (11.323)	0.00% (0.00)
-n/with low	13.95% (34.85)	9.57% (29.58)
-n/with total	7.93% (27.10)	5.20% (22.27)
-n/without high	0.00% (0,00)	1.10% (10.483)
-n/without low	0.00% (0.00)	0.00% (0.00)
-n/without total	0.00% (0.00)	0.53 (7.31)
Overall	2.87% (16.71)	1.81% (13.36)

Table 17: Stem Errors in percentages (S.D.)

Condition	**6–8-year-olds**	**9–11-years-olds**
-t high	2.53% (15.81)	2.11% (14.43)
-t low	1.03% (10.15)	4.17% (20.09)
-t total	1.70% (12.98)	3.14% (17.49)
-n/with high	1.28% (11.32)	1.27% (11.25)
-n/with low	6.98% (25.63)	7.45% (26.39)
-n/with total	4.27% (20.28)	4.62% (21.06)
-n/without high	5.75% (23.41)	4.40% (20.61)
-n/without low	5.21% (22.34)	3.13% (17.49)
-n/without total	5.46% (22.79)	3.74% (19.03)
Overall	3.82% (19.20)	3.81% (19.16)

Table 18: Suffixation Errors in percentages (S.D.)

In terms of absolute stem error rates, errors were most frequent in participles which required an irregular stem change, i.e. *-n* participles without stem change, in both age groups (6–8-year-olds: 7.93%; 9–11-year-olds: 5.20%). In most cases, the unmarked stem was erroneously maintained in the *-n* participles with stem change (e.g. **gebleib* instead of *geblieben* 'stayed'). In both age groups, stem errors rarely occurred in participles with no stem change (*-n/without* and -t). In only three cases (2.06% of the low-frequency *-t* participles and 1.10% of high-frequency *-n/without* participles) a stem change was erroneously applied in a past participle (e.g. *stecke* → **gestack*). Regarding the absolute suffixation error rate, Table 18 shows that the overall amount of suffixation errors was the highest in both age groups in the two participle groups which require the *-n* suffix (6–8-year-olds *-n/with*: 4.27% and *-n/without* 5.46%; 9–11-year-olds *-n/with*: 4.62%, *-n/without*: 3.74%). In all these cases, the *-t* suffix was erroneously applied instead of the *-n* suffix. The number of suffixation errors was lower in both age groups for *-t* past participles (6–8-year-olds: 1.70%; 9–11-year-olds: 3.14%).

With regard to the error distribution, *-n* participles without stem change showed a clear distinction between high-frequency and low-frequency items, while participles with no stem change did not show such a distinction. Low-frequency *-n* participles with stem change exhibited more stem errors than high-frequency *-n* participles with stem change (6–8-year-olds: *-n/with* high: 1.28% *vs.* low: 13.95%; 9–11-year-olds: *-n/with* high: 0.00% *vs.* low: 9.57%). In contrast, the past participles with no stem change showed no sensitivity to frequency. A similar picture emerged for the suffixation error distribution. Within the *-n* participles with stem change, the distribution of suffixation errors was different for high-frequency and low-frequency items. There were considerably more errors in low-frequency items with stem change (6–8-year-olds: 1.28%; 9–11-year-olds: 6.98%) than in high-frequency items with stem change (6–8-year-olds: 6.98%; 9–11-year-olds: 7.45%). The suffixation error rates in participles with no stem change, *-n* participles without stem change and *-t* participles were the same in high-frequency and low-frequency items.

In sum, stem errors were most frequent in *-n* participles with stem change. Suffixation errors occurred most often in participles with *-n* suffix (with and without stem change). In contrast, stem errors in participles without stem change and suffixation errors in participles with *-t* suffixation were rare. Most of the errors were due to overapplication of the default inflection to participles which require the non-default inflection.

To statistically analyse the data presented in Table 17 and in Table 18 repeated-measures ANOVAs were conducted with the factors ‘participle type’ (*-t vs. -n/without vs. -n/with*), ‘frequency’ (high *vs.* low) and ‘participant group’ (6–8-year-olds *vs.* 9–11-year-olds). For the suffix error data, the analysis yielded a significant main effect of participle type ($F_1(2,76)=27.171$, $p<.001$, $F_2(2,23)=.481.p>.05$) and a significant main effect of frequency ($F_1(1,38)=24.868$, $p=0.000$, $F_2(1,23)=.607.p>.05$) in the by-participant analysis. Both the suffix error analysis and the stem error analysis showed a significant interaction between participle type

and frequency (suffix error analysis: $F_1(2,76)=17.856$, $p<.001$, $F_2(2,23)=.944$.p>.05, stem error analysis: ($F_1(2,76)=4.271$, $p=.02$, $F_2(2,23)=4.086$, $p=.03$). The significant interactions of participle type and frequency in the stem error and suffixation error data indicate that the effect of frequency on the error rate differed in the three participle types. Since the ANOVA results did not indicate an effect or interaction between age group, the planned comparisons were then run across both age groups. Pairwise t-tests on the stem error data and suffixation error data showed that the mean error rate of low-frequency *-n* participles with stem change was significantly higher than that of high-frequency *-n* participles with stem change in both stem error data ($t_1(39)=2.975$, $p<0.01$, $t_2(7)=$
1.913, $p=.097$) and suffixation error data ($t_1(39)=4.760$, $p<.001$, $t_2(7)=1.448$, $p=.191$). At the same time, t-tests showed no significant difference between the mean error rate of high-frequency participles and low-frequency participles in the group of *-t* participles (stem error data: $t_1(39)=$ 0.117, $p>.05$, $t_2(8)=1.0$, $p=.347$, suffixation error data: $t_1(39)=1.433$, $p=0.16$, $t_2(8)=-.088$, $p=0.91$) and in the group of *-n* participles without stem change (stem error data: $t_1(39)=0.394$, $p=0.70$, $t_2(8)=1.0$,$p=.347$, suffixation error data: $t_1(39)=1.000$, $p=0.32$, $t_2(8)=.236$,$p=.819$). Taken together, the inferential statistics revealed a frequency effect in *-n* participles with stem change for both the stem error and suffixation error data, while no frequency effect was detected for *-t* participles and *-n* participles without stem change in the suffixation error or stem error data.

In sum, inferential statistics on the error data confirmed the observations in the descriptive statistics. No significant difference between the age groups in terms of absolute error rate was found. Both participant groups showed a clear distinction between default *-t* and non-default *-n* inflection features in terms of overapplication. The *-t* suffix and the unmarked stem were overapplied to both the *-n* participles with stem change (overapplication of *-t* suffix and the unmarked stem) and the *-n* participles without stem change (overapplication of *-t* suffix) more often than marked stems and *-n* suffix were applied to *-t* participles. With respect to a frequency effect, the children showed a clear distinction between participles with stem change (significant frequency effect) and participles without stem change (*-t* participles and *-n/without*: no frequency effect). The frequency effect detected for *-n* participles without stem change suggests whole-word processing, while no such indication was found for *-t* participles and *-n* participles without stem change.

The predominant overapplication of unmarked stem and *-t* suffix found in the current data is consistent with previous findings from elicited and spontaneous production errors in German-speaking children for both verb inflection (Clahsen and Rothweiler 1993; Weyerts & Clahsen 1994; Clahsen et al. 2002; Clahsen et al. 2004) and plural inflection (Clahsen et al. 1992). All these studies report that default inflection (unmarked stem and regular *-t* suffix) was significantly more often overapplied to words that required the non-default inflection (marked stem and/or *-n* suffix) than *vice versa*.

6.2.2 Production Latencies

This section presents an analysis of *z*-scores of log-transformed production latencies with the factors GROUP (6–8-year olds *vs.* 9–11-year-olds *vs.* adults), PARTICIPLE TYPE (*-t* participles *vs.* *-n/without* participles *vs.* *-n/with* participles) and FREQUENCY (high *vs.* low). The analysis focused on the detection and comparison of frequency effects in different participle types and age groups. A frequency effect manifests itself in significantly shorter mean production latencies for high-frequency items than low-frequency items. Accordingly, an anti-frequency effect occurs when low-frequency items exhibit significantly shorter mean reaction times than high-frequency items. No frequency effect is detected when the two frequency conditions within one participle type do not differ in terms of mean production latency. The significance of all effects was assessed on a 5% level (α=.05). All *p*-values are reported as two-tailed.

Results of a one-sample Kolmogorov-Smirnov test on the participant file and the item file revealed normal distribution in all conditions ($p>.05$). The normally distributed data allows for parametric ANOVAs and t-tests. Table 19 presents mean production latencies (based on subject means) and standard deviations for each participant group in each condition, and shows that overall mean production latencies were considerably shorter for adults (244ms) than for 9–11-year-olds (366ms), which were in turn shorter than 6–8-year-olds (505ms). A one-way ANOVA on the log-transformed overall mean production latencies shown in Table 19 revealed a significant effect of ‘participant group’($F_1(1)=20.7$, $p<.001$, $F_2(1,28)=206.95$, $p<.001$), indicating general differences between participant groups with respect to production latency.

Regarding different participle types, Table 19 shows that high-frequency *-n* participles with stem change yielded shorter production latencies than low-frequency *-n* participles with stem change in all participant groups. The production latency advantage for high-frequency over low-frequency *-n* participles with stem change was most pronounced in the child group of 9–11-year-olds (179ms), followed by the group of 6–8-year-olds (134ms) and the adult group (123ms). The reverse trend was produced by *-t* participles: high-frequency *-t* participles elicited longer mean production latencies than low-frequency items in all age groups. Again, the difference between the mean production latency for high-frequency *-t* participles and low-frequency *-t* participles was most pronounced in the child group of 9–11-year-olds (85ms), considerably less pronounced in the group of 6–8-year-olds (46ms) and virtually nonexistent in adults (7.8ms). With respect to *-n* participles without stem change, the results showed longer production latencies for high-frequency than low-frequency items in the 9–11-year-olds (85ms). The adult group and the youngest age group showed slightly shorter mean production latencies for high-frequency over low-frequency *-n* participles without stem change (6–8-year-olds: 25ms, adults: 6ms).

Taken together, all the participant groups showed shorter production latencies for high-frequency than low-frequency *-n* participles with stem change. With respect to *-t* and *-n* participles without stem change, the 9–11-year-olds showed shorter production latencies for low-frequency items than high-frequency items, while the group of 6–8-year-olds and the adults showed no such difference, or a considerably less pronounced difference between the mean production latencies of these participle types.

	6–8-year-olds	**9–11-year-olds**	**Adults**
-t high	564 (341)	435 (292)	252 (157)
-t low	518 (287)	350 (238)	244 (177)
-n/with high	444 (292)	256 (168)	192 (149)
-n/with low	579 (303)	436 (304)	316 (165)
-n/without high	457 (312)	399 (311)	227 (184)
-n/without low	483 (264)	313 (263)	233 (147)
Overall Means	**505** (302)	**366** (274)	**244** (167)

Table 19: Mean production latencies (S.D.) per condition in ms

We assessed these observations statistically in a repeated-measures ANOVA with the factors participle type (*-t vs. -n/without vs. -n/with*), frequency (high *vs.* low) and participant group (6–8-year-olds *vs.* 9–11-year-olds *vs.* adults). These analyses yielded a main effect of frequency ($F_1(1,54)=14.57, p=.001$, $F_2(1,23)=3.375$, $p=.08$) and a main effect of participle type ($F_1(2,108)=7.72$, $p=.001$, $F_2(2,23)=2.162$, $p=.14$), which was marginally significant in the item analysis. More importantly, an interaction between participle type and frequency was found ($F_1(2,108)=38.61$, $p<.001$, $F_2(2,23)=8.695$, $p=.002$), as well as an interaction between frequency and participant group ($F_1(2,54)=3.63, p=.033$, $F_2(2,46)=1.704$, $p=.069$), the latter in the participant analysis only. The interaction between participle type and frequency indicates that participle types differed with respect to how word-form frequency affects production latency, whereas the interaction between frequency and participant group shows that participant groups' production latencies differed with regard to frequency. To further investigate these interactions, separate analyses were carried out for the three participant groups.

A 3x2 repeated-measures ANOVA for the adult age group with the factors participle type (*-t vs. -n/without vs. -n/with*) and frequency (high *vs.* low) yielded a significant main effect of frequency in the participant analysis ($F_1(1,18)=14.431$, $p=.001$, $F_2(1,23)=4.964$, $p=.178$) and an interaction between frequency and participle type ($F_1(2,36)=12.78$, $p<.001$, $F_2(2,23)=4.244$, $p=.027$). Subsequent planned comparisons on the mean production latency of participle types revealed that high-frequency *-n* participles with stem change were produced significantly faster than low-frequency ones ($t_1(19)=6.483$, $p<.001$, $t_2(7)=4.378$, $p=.003$). There was no such contrast for the production latencies of *-t* participles ($t_1(19)=.358$, $p=.724$, $t_2(8)=201$, $p=.845$) and *-n* participles without stem change ($t_1(19)=.718$, $p=.482$, $t_2(8)=-.416$, $p=.688$). Overall, the results for adults showed a significant frequency effect for participles with stem change (*-n/with* participles) and no frequency effect for participles without stem change (*-t* participles and *-n/without* participles).

For the older child group, the same 3x2 repeated-measures ANOVA revealed a main effect of participle type in the by-participant analysis ($F_1(2,36)=3.800$, $p=.037$, $F_2(2,23)=1.719$, $p=.20$) and an interaction between participle type and frequency ($F_1(2,36)=25.441$, $p<.001$, $F_2(2,23)=10.197$, $p=.001$) indicating that production latencies in the three participle types were differently affected by word-form frequency. Subsequent planned comparisons revealed significantly shorter production latencies for high-frequency than low-frequency *-n* participles with stem change ($t_1(19)=5.482$, $p<.001$, $t_2(7)=4.366$, $p=.003$), in parallel to in the findings with the adult group. The corresponding comparison, however, revealed a significant *disadvantage* for high- over low-frequency -*t* participles ($t_1(19)=2.806$, $p=.011$, $t_2(8)=1.184$, $p=.271$) and -*n* participles without stem change ($t_1(19)=3.115$, $p=.006$, $t_2(8)=2.264$, $p=.053$). Like the adult group, the 9–11-year-olds showed a significant frequency effect for participles with stem change (-*n/with* participles) but, unlike the adult group, a significant anti-frequency effect for participles without stem change (-*t* participles and -*n/without*).

For the younger child group, the 3x2 repeated-measures ANOVA showed an interaction between participle type and frequency ($F_1(2,36)=6.257$, $p=.007$, $F_2(2,23)=3.690$, $p=.041$), similar to that of the older children and adults, indicating that word-form frequency differentially affected production latencies in the three participle types. Subsequent planned comparisons revealed significantly shorter production latencies for high- than for low-frequency -*n* participles with stem change ($t_1(19)=-3.869$, $p=.001$, $t_2(7)=-2.295$, $p=.055$), similar to the adult group. The comparison between high- and low-frequency forms, however, revealed no effect of word-form frequency on the production of -*t* participles ($t_1(19)=.901$, $p=.379$, $t_2(8)=.999$, $p=.347$) and -*n* participles without stem change ($t_1(19)=.407$, $p=.688$, $t_2(8)=.974$, $p=.359$) in the younger child group. The observed frequency effect for -*n* participles with stem change is parallel to the findings in the adult group and the older group of children. Like the findings in the adult group but unlike those in the older child group, no frequency effect for participles without stem change (-*t* participles and -*n/without*) was found.

Researchers have discussed the influence of a range of subject-specific factors, such as participants' WM capacity and speed of lexical access, on language processing. We looked to see whether production latencies were influenced by auditory WM, measured as the score of a digit-span test in children (HAWIK, Tewes 1983) and adults (HAWIE, Tewes 1991). Each age group was divided according to its median working memory score (WM) into a subgroup of high WM and a subgroup of low WM. The median rather than the mean WM score was used to create equally large subgroups; these are necessary in order to ascribe observed differences in effects between groups to WM differences and not to differences in statistical power. The influence of the factor WM on production latency was analysed by conducting a repeated-measures ANOVA with the factors participle type, frequency and the between-subject variable WM for each participant group separately.

In the participant group of 6–8-year-olds, the analysis revealed no significant effect or interaction with WM (Fs<1.50p>.20). Similarly, for the adult group, the analysis revealed no significant effect or interaction with WM (Fs<1.55, p>.20). Only in the participant group of 9–11-year-olds did the results show a significant interaction between WM and frequency ($F_1(1,18)=15.486$, $p=.001$). The results in the younger child group and in the adult group did not indicate a relationship between auditory WM capacity and language performance. For the older child group, however, the results indicated differences in production latencies between high- and low-frequency participles, depending on WM score.

To assess the interaction in the older child group, we conducted planned comparisons of production latencies in the two subgroups of relatively high and relatively low WM score. Table 20 shows the mean production latencies in 9–11-year-olds in the experimental conditions for the subgroups. It can be seen from the data that the overall production latencies in the two groups were similar (high WM: 370ms, low WM: 361ms). The two groups also showed similar tendencies with regard to each participle type. For the *-t* participles, both groups showed an advantage for low-frequency items over high-frequency items. This advantage, however, was more pronounced for the low WM group (114ms) than the high WM group of 9–11-year-olds (73ms). For *-n* participles with stem change, both groups showed an advantage for high-frequency over low-frequency participles, which was greater in the high WM group (231ms) than in the low WM group (111ms). With respect to the group of *-n* participles without stem change, low-frequency items were produced faster than high-frequency items. However, while the high WM group showed only a slight advantage for low-frequency over high-frequency *-n* participles without stem change (33ms), the low WM group produced low-frequency items considerably faster than high-frequency items (159ms).

	9–11-year-olds	
	High WM (n=10)	**Low WM (n=10)**
	RT	RT
-t high	437 (195)	436 (136)
-t low	364 (239)	322 (103)
-n/with high	240 (138)	279 (124)
-n/with low	471 (228)	390 (105)
-n/without high	355 (222)	452 (176)
-n/without low	322 (223)	293 (108)
Overall	**370 (321)**	**361 (213)**

Table 20: Mean production latencies in ms (S.D.) in subgroups of 9–11-year-olds per condition

This was also confirmed statistically. We conducted paired-samples t-tests for each subgroup. For the subgroup of 9–11-year-olds with a relatively high WM score, the results revealed a significant frequency effect for *-n* participles with stem change ($t_1(9)$=5.7858, p<.001, $t_2(8)$=3.441, p=.011), while there was no such effect for *-n* participles without stem change ($t_1(9)$=.539, p=.60, $t_2(8)$=.730, p=.486) or *-t* participles ($t_1(9)$=1.093, p=.30, $t_2(8)$=.304, p=.769). For the subgroup of 9–11-year-olds with a relatively low WM score, the analysis yielded a significant frequency effect for *-n* participles with stem change ($t_1(9)$=2.630, p=0.02, $t_2(8)$=3.007, p=.020) and an anti-frequency effect for *-n* participles without stem change ($t_1(9)$=5.267, p=.001, $t_2(8)$=2.080, p=.080) and *-t* participles ($t_1(9)$=3.266,p=.01, $t_2(8)$=3.037, p=.769).

To summarise, the high WM subgroups showed a frequency effect for *-n* participles with stem change and no significant effect for *-n* participles without stem change or *-t* participles. The low WM subgroup showed a frequency effect for *-n* participles with stem change and an anti-frequency effect for *-t* participles and *-n* participles without stem change. As the anti-frequency effect for regulars was found only in the low WM subgroup, these results might indicate that the anti-frequency effect is related to WM capacity.

Referring to the questions asked in the beginning of this section, the results show that

(i) age groups were differently affected by WM score. Production latencies in 9–11-year-olds were affected by WM score, while production latencies in 6–8-year-olds and adults were not. It is surprising that WM did not have an effect on production latencies in 6–8-year-olds, who have the lowest mean WM scores, but on production latencies in 9–11-year-olds, who have higher mean WM scores than younger children. We argued in section 4.3.1 that WM differentially affects rule-based and full-form processing. The different effects of WM on production latencies in the two child groups might indicate that they rely differently on the two processing routes. We will explore this suggestion in more detail in the final chapter.

(ii) WM scores differently affect production latencies for the three participle types. Frequency effects in *-n* participles with stem change are similar in both subgroups, but *-t* participles and *-n* participles without stem change vary according to WM score. The group of 9–11-year-olds of low WM show an anti-frequency effect for *-t* participles and *-n* participles without stem change while the high WM group does not show such an effect. Finally,

(iiii) The results show that the WM score is not directly related to the overall production latency; in other words, a higher WM score is not associated with shorter production latencies.

Clahsen et al. (2004) suggested that the disadvantage for high-frequency *-t* participles might be due to slowed retrieval from lexical memory, so we used the mean overall production latency as a measure of individual speed of lexical access. The rationale for this is that participants who are faster at accessing lexical entries should have shorter production latencies than participants with slower lexical access. As in the analysis of WM capacity, we focus on the questions (i) Are production latencies differentially related to individual speed according to age group? And (ii) Are participle types differentially affected by the participants' individual speed? To investigate these questions, we divided each participant group by the median of the individual mean production latencies into a group of relatively short production latencies ('fast') and a group of relatively long production latencies ('slow'). We then included the between-subject factor 'speed' in a repeated-measures ANOVA with the factors 'participle type' and 'frequency' for each participant group separately. For the adult group, the analysis reveals a two-way interaction between participle type and speed ($F_1(2,32)=5.308$, $p=.010$, $F_2(2,23)=9.246$, $p=.001$) indicating that production latencies differ in participle types with respect to overall production latency. No such interaction was found for younger children (all $Fs_{1/2}<1$, $p>.50$) or older children (frequency*speed $F_1(1,16)=3.892$, $p=.066$, all other $Fs_{1/2}<1$, $p>.20$).

To investigate the nature of the interaction in the adult group, mean production latencies per condition were compared in the experimental conditions separately for the fast group and the slow group. Table 21 shows the mean production latencies in the experimental conditions in the subgroups of 'fast adults' and 'slow adults'. We found that the two groups show different trends with regard to each participle type. For participles without stem change (*-t* and *-n/without* participles), slow adults show an advantage for low-frequency items over high-frequency items. The reverse trend is observed in fast adults. Regarding *-n* participles with stem change, both groups show an advantage for high-frequency participles over low-frequency participles, which is slightly more pronounced in the fast adults (126ms) than in the low WM (115ms). The similar frequency advantage observed for participles with stem change is consistent with the observations by Clahsen et al. (2004). The observation that *-n* participles (with and without stem change, Clahsen et al. 2004) are more affected by frequency than *-t* participles in slow and fast adults is also consistent with previous observations. In contrast to Clahsen et al.'s (2004) study, which reported a frequency disadvantage for *-t* participles in the slow group, the current group of slow adults shows a frequency *advantage* for *-t* participles. Again in contrast to Clahsen et al. (2004), who reported a slight frequency advantage in the fast group, the current fast group shows a considerable frequency *disadvantage*.

	Adults	
	Slow (n=10)	**Fast (n=10)**
	RT	RT
-t high	311 (66)	187 (75)
-t low	338 (126)	149 (56)
-n/with high	258 (98)	126 (65)
-n/with low	373 (102)	252 (82)
-n/without high	331 (94)	126 (57)
-n/without low	309 (68)	152 (729)
Overall	**320 (73)**	**165 (54)**

Table 21: Mean production latencies in ms (S.D.) in subgroups of adults per condition

Paired-samples t-tests were conducted for each subgroup to statistically assess these observations. For the fast adults, the results reveal a significant frequency effect for *-n* participles with stem change ($t_1(9)$=-4.053, p=.003, $t_2(8)$=-4.135, p=.004), while there is no frequency effect for *-n* participles without stem change ($t_1(9)=-1.182$, $p=.267$, $t_2(8)=-1.189$, $p=.269$) or *-t* participles ($t_1(9)=1.484$, $p=.172$, $t_2(8)=.989$, $p=.352$). For the slow adults, the analyses yield a significant frequency effect for *-n* participles with stem change ($t_1(9)=-5.446$, $p=0.00$, $t_2(8)=-2.504$, $p=.041$) but no frequency effect for *-n* participles without stem change ($t_1(9)=.096$, $p=.926$, $t_2(8)=.017$, $p=.987$) or *-t* participles ($t_1(9)=-1.225$, $p=.252$, $t_2(8)=-.630$, $p=.546$). In sum, slow and fast adults show the same effect for participles with stem change, i.e. a frequency effect. The opposite trends observed in slow and fast adults for participles without stem change (*-t* and *-n/without* participles) are statistically not reliable.

With respect to the questions asked at the beginning of this section, we conclude that production latencies in the adult group, but not in child groups, are affected by individual speed. Furthermore, participle types are differentially affected by adult participants' individual speed. Participles with stem change show similar results in fast and slow adults, but participles without stem change (*-t* and *-n* participles without stem change) show different results in these two subgroups. The current findings are consistent with those of Clahsen et al. (2004) for *-n* participles with stem change in both subgroups. The current statistical analysis also reveals similar effects as those of Clahsen et al. (2004) for *-t* participles in fast adults (i.e. no significant frequency effect), even though the described trends in the fast participant groups differ in the two studies (Clahsen et al.: positive trend; current study: negative trend). However, the effects for *-t* participles in slow adults are different in the current study from the findings of Clahsen et al.: while we found no significant frequency effect in slow adults, Clahsen et al. report a significant anti-frequency effect in slow adults.

6.3 Discussion

The speeded production study investigated auditory access-level representations involved in the production of German past participles in two age groups of children compared to a control group of adults. This section discusses our main findings: (i) frequency affects[19] auditory access-level representation of participle types differently, (ii) participles without stem change yield an anti-frequency effect and (iii) there are developmental differences between younger children, older children and adults.

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[19] The frequency effect is defined as significantly shorter production latencies for high-frequency forms than for low frequency forms. The reverse effect is refered to as anti-frequency effect.

Frequency affected access to participle types differently

Production latencies for high-frequency *-n* participles with stem change were shorter than those for low-frequency *-n* participles with stem change. As outlined above, such an advantage for high-frequency over low-frequency *-n* participles with stem change in both production latencies and error rates is taken as evidence that these are represented and processed as whole-word forms on the access level. The current result for *-n* participles with stem change is consistent with findings from previous studies of speeded production, which also showed frequency effects for non-default forms (*-n* participles or irregular English past tense) in adults (Prasada et al. 1990) and in children (Clahsen et al. 2004[20]). Regarding the error rate in children, the results are also consistent with Clahsen et al. (2004), who reported considerably higher error rates in both stem data and suffixation data for low-frequency than for high-frequency *-n* participles with stem change. Also, the frequency effect found for overregularisation errors in *-n* participles with stem change replicates findings from offline studies on English (Marcus et al. 1992), Spanish (Clahsen, Aveledo & Roca 2002) and German (Weyerts & Clahsen 1994). The three theories of morphological processing can account for word-form frequency effects found in *-n* participles with stem change. In Yang's (2002) rule-based model word-form, frequency effects for *-n* participles with stem change are explained in terms of frequency ranks assigned to items within the same rule class. For example, in the English past tense, the forms 'lose → lost' and 'leave → left' belong to the rule class '*-t* & Vowel Shortening' (Yang 2002: 78). Yang explains that when verbs are grouped into classes defined by phonological rules, their performance is, virtually without exception, ordered by their input frequencies (Yang 2002: 80). These findings are also consistent with both single- and dual-mechanism models that interpret the advantage of high- over low-frequency irregular participles as a memory effect. As memory representations are

[20] Clahsen et al. (2004) reported generally longer mean production latencies than found in the current data set for children (Clahsen et al. 2004, Table 4: 1162ms *vs.* current data: 435ms) and adults (Clahsen et al. 2004, Table 4: 963ms *vs.* current data: 244ms). This difference is due to different ways of measuring production latency. While Clahsen et al. (2004) measured production latencies as the time from the onset of the verb stimulus presentation until the onset of the response, the current study measured production latency as the time from the offset of the verb stimulus until the participant's response. The mean duration of the verb stimuli in Clahsen et al. (2004) was around 650ms to 705ms (Clahsen et al. 2004: 13), which is equivalent to production latency differences in the two data sets. We chose our mode of measurement because the task includes both recognising the verb stimulus and producing the target item. Measurement by Clahsen et al. (2004) thus includes time for recognition and production. The current measurement excludes (at least part of) the recognition time and may therefore better reflect the time taken to produce the target item.

strengthened by exposure, high-frequency lexical entries are more reliably and faster retrieved from lexical memory than low-frequency ones.

For *-t* participles, no advantage for high-frequency over low-frequency forms was observed in production latencies or in error rates in young children and adults. These results have been taken to indicate that morphological structure, rather than full-form properties, affects how these forms are represented and processed on an auditory access level. The results for *-t* participles, indicating decomposed processing, are fully consistent with previous findings from speeded production studies (e.g. fast adults in Clahsen et al. 2004) and from language acquisition studies indicating that morphological structure is relevant to how these forms are acquired and represented in children's minds (e.g. Clahsen & Rothweiler 1993; Weyerts 1997). The dissociation between *-n* participles with stem change and *-t* participles is consistent with previous studies testing recognition of *-n* participles with stem change that have reported clear storage effects and no decomposition effects for *-n* participle forms, but clear decomposition effects and no storage effects for *-t* participles. For example, Sonnenstuhl et al. (1999) showed in a cross-modal priming experiment that *-t* participles, but not *-n* participles, yielded decomposition effects. Similarly, Neubauer & Clahsen (2009) showed, in an unprimed lexical decision task, that *-n* participles yield full-form storage effects while *-t* participles do not. The observed differences in how frequency affects production latencies of participle types are hard to explain in terms of any single-system model, as these models do not predict any effects of morphological structure. The differences are only consistent with dual-mechanism models that posit differences in the representation and processing of inflected word forms.

Similar patterns to those in *-t* participles were observed for *-n* participles without stem change. Production latencies for these forms were not influenced by frequency in adults and young children. However, while the results for *-t* participles are consistent with a large number of previous studies, decomposition effects for *-n* participles without stem change are not reported in the literature (Sonnenstuhl et al. 1999; Neubauer & Clahsen 2009; but see Smolka et al. 2007; Neubauer & Clahsen 2009). The results for *-n* participles without stem change are therefore somewhat unexpected. As outlined above, previous studies on German past participles have assumed that *-n* suffixed participles with and without stem change belong to the non-default class, and predicted that these should behave alike. The current study set out with the aim of distinguishing between *-n* suffixed participle types with and without stem change. Interestingly, the effects found for *-n* participles without stem change showed a considerable difference from those for *-n* participles with stem change, while showing a strong resemblance to effects found for *-t* participles. The results indicate that morphological structure is relevant to the access-level processing of *-n* participles without stem change. This indication is consistent with offline acquisition studies, which have provided evidence – a similar number of *-n* suffix omission errors and *-t* suffix omission errors – that morphological structure can also be relevant to the acquisition of *-n* participles without stem change. This finding was taken to indicate that *-t* participles and *-n* participles can be analysed into morphological components (Szagun 2011: 757). Weyerts & Clahsen (1994) argued that the omission of the *-n* suffix reflects sublevel regularities in the representation of *-n* participles, as suggested by proponents of a dual-mechanism approach (cf. Marcus et al. 1992). Even though acquisition studies on production errors tested much younger children (age range 0;8–6;0) than those in the current study (age range 6;3–10;7), the relevance of morphological structure in representations of *-n* participles without stem change may be as relevant in child language processing as it is in language acquisition.

We can imagine two ways that morphological structure could be represented on the access level that would explain the relevance of morphological structure in the current and previous studies. One would be to assume that inflected *-n* participles without stem change are represented in the mental lexicon by their morphological constituents, similar to *-t* participles. The word *geschlafen* ‘slept’ would be represented as [schlaf] ‘sleep’ and be joined with its inflectional morphemes by grammatical rules. However, previous research has repeatedly investigated decomposed representation. In particular, a cross-modal priming experiment by Sonnenstuhl et al. (1999) and a masked-priming experiment by Neubauer & Clahsen (2009) did not find any indications of shared stems of inflectional variants of these forms. We are therefore not convinced about this form of representation. Alternatively, one could account for the results by reconsidering the characteristics of access-level full-form representations. The results could be taken to indicate that *-n* participles without stem change are mentally represented with their internal morphological structure. Importantly, this internal morphological structure would be relevant in processing. We introduced a proposal by Clahsen et al. (2003), who suggested a similar concept, combinatorial lexical entries, for transparently derived words. One could argue that *-n* participles without stem change are ‘transparently inflected words’ because their infinitival stem is maintained (in contrast to the stem in *-n* participles without stem change). The morphological structure of *-n* participles without stem change might be encoded in combinatorial lexical entries. In this case, the word *geschlafen* 'slept' would be mentally represented as [ge-[schlaf]-en] on the access level. Combinatorial lexical entries could explain the full picture of the current and previous evidence: indications of morphological structure in the current study and indications of full-form processing in previous research. Indications for full-form representations of *-n* participles without stem change have also been found in the current study: the negative effect of frequency on production latencies in 9–11-year-olds for *-n* participles without stem change. An anti-frequency effect in 9–11-year-olds was found for *-t* participles. This effect is discussed in the next section.

Participles without stem change yield an anti-frequency effect

In a subgroup of low working memory 9–11-year-olds, high-frequency items elicited longer production latencies than low-frequency items in *-t* participles and *-n* participles without stem change. This phenomenon is not predicted by any of the current morphological processing models, because high frequency should always lead to shorter production latencies. Our result of a disadvantage for high- over low-frequency items in production is, however, known from the literature and replicates results from previous speeded production studies by Prasada et al. (1990), Beck (1997) and Clahsen et al. (2004). Pinker (1999) and Beck (1997) have proposed two different accounts for the anti-frequency effect. As discussed in section 4.2, Beck proposed that the higher proportion of irregular than regular forms within a single experimental session would bias participants towards whole-word form processing. The current study presented words in rule-based processed sentence contexts, as did Clahsen et al. (2004). It is therefore unlikely that anti-frequency effects are due to a full-form processing bias. Pinker (1999), by contrast, attributes the anti-frequency effect to memory traces which high-frequency *-t* participles leave behind in memory. It may be that the observed relation between working memory and anti-frequency effects in the group of 9- to 11-year-olds in the current study is in line with this suggestion: perhaps the anti-frequency effect only occurs in low working memory groups because the parallel activation of *two* mental representations requires participants to hold considerably more information in the working memory than the activation of *one* mental representation. Since participants with relatively high working memory capacities might be able to retain the two representations simultaneously without much effort, the full-form access-level representation does not greatly inhibit the rule-based processing of *-t* participles, and the speaker does not produce anti-frequency effects. In contrast, holding the two mental representations in working memory may more seriously strain processing in participants with relatively low working memory capacities, with the result that high-frequency *-t* participles with full-form representations are more likely to lead to longer production latencies than low-frequency *-t* participles without additional full-form representations. However, this suggestion remains purely speculative at this point. We note that production latencies were affected by working memory capacity only in one subgroup of children. Production latencies in younger children, with even lower working memory scores than 9- to 11-year-olds, are not affected by working memory capacity. In addition, working memory capacity, measured by an auditory digit-span test, is highly correlated with a number of cognitive abilities which may affect morphological processing. Based on the current data set we are not able to disentangle effects of working memory capacity from effects from effects of other cognitive abilities on production latencies. Nevertheless, these observations motivate further investigation into whether working memory affects children's word-production processing.

Regarding the representation of *-n* participles without stem change, the results leave room for different interpretations. On the one hand, previous studies have consistently reported indications of full-form representations for *-n* participles without stem change, and the anti-frequency effect in 9–11-year-olds indicates that full-form properties affect the processing of *-n* participles without stem change. On the other, the lack of frequency effects in 6–8-year-olds and adults indicates the relevance of morphological structure in processing. We have argued above that these combined results might suggest that *-n* participles without stem change are represented in combinatorial entries. However, the account for anti-frequency effects given by Pinker crucially relies on the interaction between *rules* and full-form representations. It seems difficult to reconcile the full set of findings for *-n* participles without stem change reviewed so far in one processing theory. In any case, previous priming studies have only tested adults, and it might very well be that children do represent the morphological structure of *-n* participles differently from adults, as mentioned above. We need empirical evidence using other experimental techniques to more thoroughly investigate children's representation of *-n* participles without stem change on the access level as well as the central level. We therefore use the lexical decision task to test for access-level representation of *-n* participles without stem change in the visual modality. If *-n* participles without stem change are accessed on the basis of their full-form properties, we expect full-form frequency effects. If they are accessed on the basis of their morphological components, we expect no effect of form frequency on reaction times. Our next study, a cross-modal priming experiment, tests for morphological components on central level in the mental lexicon. If *-n* participles without stem change are represented at the central level according to their morphemic constituents, in addition to their full-form representation, we expect to find full priming effects. If the morphological structure of *-n* participles without stem change is encoded in the full-form entry, it should yield only partial priming.

Developmental aspects in younger children and older children

The results of the speeded production study reveal two main developmental findings. First, children produce generally more errors and longer production latencies than adults. Second, the effect of frequency on production latencies is similar in 6–8-year-olds and adults, but is different in 9–11-year-olds.

We have seen that children produce more errors and respond more slowly than adults. This finding is in line with results from experimental studies on child morphological processing reviewed in section 4.4.2. Marcus et al. (1992) have suggested that overregularisation occurs when word forms are not successfully retrieved from the mental lexicon. They suggested that failure in lexical retrieval is more frequent in children than in adults because children's mental lexicon is not as elaborated as that of adults. As a consequence, children's lexical representations may contain less information about form and meaning and may be less well associated with other lexical representations. The overall higher error rate and slower reaction times in the current data may therefore be the result of slower lexical retrieval and a lexicon that is not yet fully elaborated (cf. Clahsen et al. 2004).

Secondly, we have seen that the results for *-t* participles are similar in younger children and adults and that they are different from those obtained from older children. However, it is a frequent observation in language acquisition that younger children superficially behave like adults, but that their adult-like behaviour does not reflect adult-like representation of inflected forms. At the same time, older children are sometimes found to show non-adult-like behaviour, but their behaviour reflects a more advanced stage of language development than the adult-like behaviour of younger children. We outlined this phenomenon for inflectional acquisition in Chapter 3. We have argued that two factors explain older children's deviance from adult production patterns: additional full-form representations for *-t* participles and lower working memory capacities. If 9–11-year-old children have an additional full-form representation for *-t* participles, it seems likely that adults also have such representations for *-t* participles. But because of adults' generally higher working memory capacities, among other things, these do not interfere with the rule-based processing of *-t* participles or cause anti-frequency effects. In this view, relatively strong working memory capacities are necessary to handle the parallel processing routines for *-t* participles. Six–eight-year-olds have lower working memory capacities than 9–11-year-olds. If 6–8-year-olds also had full-form representations for *-t* participles, like adults, they would be expected to show even stronger anti-frequency effects than 9–11-year-olds. The most natural reason to explain the fact 6–8-year-olds do not show such an effect for *-t* participles would be that they have not yet built full-form representations of *-t* participles. We have no independent evidence for the suggestion that young children have fewer representations of *-t* participles than younger children. However, we know that the number of entries in children's lexicon grows with age (e.g. Kauschke 2000, Rothweiler & Kauschke 2007). If we assume that learning of *-t* participles follows the same general order as word-learning, young children are likely to have fewer (additional) full-form lexical entries of *-t* participles than older children. If this is correct, 6–8-year-olds, unlike adults, process *-t* participles in a purely rule-based way. In contrast, 9–11-year-olds, like adults, process *-t* participles via both the full-form and the rule-based processing route. In addition, adults have generally higher working memory capacities than 9–11-year-old children.

7 Cross-Modal Priming

In this chapter, we introduce the cross-modal priming experiment that we used to investigate the central-level representation of participles. As discussed in section 5.1.2, the results from cross-modal priming will allow us to assess the central-level representation of participles and how they are processed within the real-time constraints of word recognition. The results will indicate, in particular, whether inflected forms have a decomposed representation or a full-form lexical entry at the central level.

We reviewed studies relying on the cross-modal priming technique with adults and children in section 4.4; these showed that cross-modal priming experiments have consistently produced full priming effects for *-t* participles and partial priming for *-n* participles. These differences between *-t* and *-n* participles have been interpreted in a variety of ways. Neubauer & Clahsen (2009) and Sonnenstuhl et al. (1999) interpreted them in terms of a dual-system account. Smolka et al. (2007) found no substantial difference between *-t* and *-n* forms and explained their findings in a single-system account. However, their study was hard to interpret because of a number of methodological issues.

The literature review of priming studies with children has revealed that children seem sensitive to morphological structure, at least to derived forms and on a modality-specific access level. These studies do not allow us to draw conclusions about the central-level representation of German past participles; in particular, because semantic relatedness was not controlled for in some of the studies. Quémart et al. (2011) addressed this concern and found stronger priming effects for pseudo-derived and derived prime–target pairs than in orthographic or phonological control conditions, indicating morphological decomposition effects, but only for derived forms, so this interpretation cannot be directly extended to inflected forms.

We will extend previous studies on children (and adults) in several ways. First, one difficulty in most previous cross-modal priming experiments on adults has been to identify the source of the priming effects. This concern also applies to the majority of priming studies in children. It may be that the reported priming effects in priming studies on children are not (only) morphological in nature but are (also) due to the semantic relatedness between primes and targets. Past-participle formation in German in the current experiment allows us to identify the source of the priming effect. Priming effects for *-t* participles and *-n* participles without stem change are compared. While the prime words of these forms are morphologically different, they are exactly parallel in terms of their orthographic, phonological and semantic overlap with the target words. In addition, priming effects for *-n* participles with and without stem changes are compared to assess the role of formal (orthographic/phonological) prime–target overlap. With these comparisons, it should be possible to decide whether any priming effects for *-t* and/or *-n* forms are morphological in nature. Second, most previous cross-modal priming studies on children have examined their primed recognition of derived words, and we do not know if the interpretation of the results holds equally for inflected forms. Third, because previous studies with children used largely uni-modal designs with visual stimuli, the reported priming effects might be specific to the written modality and may not extend to a more abstract level of lexical representation. Finally, little is known about developmental changes in central-level representations of inflected forms. A potential relationship between children's working memory capacities on the processing and representation of past participles, as suggested for the production of inflected forms, has not been addressed in any previous priming study on children. The present study tackles the concerns raised by the literature review, complementing the results from the speeded production study described in the preceding chapter by explicitly testing for children's decomposed representations of past participles on a central level.

7.1 Methods

7.1.1 Participants

One hundred and eight German-speaking monolingual children in two age groups (7-9-year-olds: range 7;3–9;1, mean age 8;4, S.D.: .57, 29 girls; 9-11-year-olds: range 9;1–10;7, mean age 9;9, S.D.: .293, 32 girls) and the ages were tested in the experiment. The children were recruited from an after-school programme and a primary school in the region of Braunschweig/Salzgitter, Northern Germany. Parents or legal guardians provided consent in writing on behalf of their children. Children were at least in 2nd grade and thus had at least one year of reading experience; this was important because the visual representation of inflected forms, which we wanted to investigate, is not present from the beginning of reading development but develops and grows stronger with reading experience (cf. Ziegler & Goswami 2005; Acha & Perea 2008). Children were less than 11 years old: this allows us to differentiate clearly between child language processing (<11 years) and adult language processing (>18 years). As far as their age is concerned, the children in the cross-modal priming experiment are therefore comparable to those tested in the speeded production experiment. The youngest children in the cross-modal priming experiment (7;3 years) were older than the youngest in the speeded production experiment (6;3 years), because of task demands. The children were performing typically in school for their age with respect to reading, language and general learning abilities. We also tested a control group of 72 adult native speakers of Standard German (mean age: 37.65, range: 20;0–60;0, 41 female). The adult participants were asked for their written consent prior to testing. All participants had normal or corrected-to-normal vision, and none of them had any history of language or hearing impairment.

All the child and adult participants took part in an auditory digit-span test, since the main experiment involved testing listening to words (HAWIK Tewes 1983; HAWIE, Tewes 1991). The same test had been used in the speeded production experiment, and described in section 6.1

The results shown in Table 22 revealed similar mean digit spans for the two age groups of children (7–9-year-olds: 10.81, S.D.: 2.34; 9–11-year-olds: 11.06, S.D.: 2.03), both of which are shorter than that of the adult group (12.90, S.D.: 2.53). These observations were confirmed statistically. A one-way ANOVA on these scores revealed a significant effect of group ($F_1(2)=15.51$, $p<.001$), with significantly higher working memory ('WM') scores for the adult group than for both younger children ($t_1(124)=4.79$, $p<.001$) and older children ($t_1(124)=4.54$, $p<.001$), and no reliable WM score difference between the two age groups of children (all *ts* < 1).

	Children 7–9 (n=54)	**Children 9–11 (n=54)**	**Adults (n=72)**
Mean WM score	10.81 (2.34)	11.06 (2.03)	12.90 (2.53)

Table 22: Mean short-term memory scores (S.D.) per participant group

The strongest child readers were selected from a larger pool of 230 children based on their scores in a standardised test of single-word reading, the *Würzburger Leise Leseprobe* (WLLP) (*Würzburg Silent Reading Test*) (Küspert & Schneider 1998). Ninety-two children with relatively low overall reading scores (63 out of 140 points) did not take part in the cross-modal priming experiment. Another 30 children took part in the experiment but were excluded from the analysis of the cross-modal priming data as they exhibited characteristics of reading by grapheme–phoneme correspondence rules, which implied that they did not directly recognise stimuli via their visual lexical representation, and it was lexical representations that we wanted to test in the study. Children were therefore excluded if they overapplied the grapheme–phoneme correspondence rule in more than three cases.

7.1.2 Materials

As illustrated in Table 23, materials were designed for nine experimental conditions covering the three-level factor participle type (*-t* participles *vs.* *-n* participles with stem change *vs.* *-n* participles without stem change) in three priming conditions (identical *vs.* morphological *vs.* unrelated). In the morphological priming condition, primes were the participle and targets were the 1st singular present-tense forms of the same verbs (e.g. *geliehen – leihe* 'borrowed$_{[part]}$– borrow$_{[1ps]}$'). In the identical priming condition, a 1st singular present-tense form of the same verb was presented as prime and target (e.g. *leihe – leihe* 'borrow$_{[1ps]}$– borrow$_{[1ps]}$'). In the unrelated priming condition, the infinitive prime word was not related to the1st singular present-tense target (e.g. *schwören – leihe* 'to swear – borrow$_{[1ps]}$'). Infinitive forms of semantically unrelated forms were used as primes in the unrelated condition, because they contain an affix (the infinitive *-n*) that was not contained in the target. Hence, unrelated prime–target pairs were comparable to the critical pairs in terms of their morphological structure. There were nine critical prime–target pairs per condition, yielding a total of 81 prime–target pairs. A complete list of critical primes and targets is shown in Appendix 5.

Participle Type	**Prime Type**			**Target**
	Morphological	**Identity**	**Unrelated**	
-t participle	*gedruckt*	*drucke*	*schlendern*	*drucke*
	'printed'	'printed$_{[1ps]}$'	'(to) stroll'	'printed$_{[1ps]}$'
-n, no stem change	*gebacken*	*backe*	*hüpfen*	*backe*
	'baked'	'bake$_{[1ps]}$'	'(to) jump'	'bake$_{[1ps]}$'
-n, stem change	*geliehen*	*leihe*	*greifen*	*leihe*
	'borrowed'	'borrow$_{[1ps]}$'	'(to) grab'	'borrow$_{[1ps]}$'

Table 23: Example prime and target participles for the experimental conditions

We matched the materials for a number of criteria, such as lemma frequency and word-form frequency, word length and lexical neighbourhood, as well as (formal and semantic) prime–target overlap. Word-form properties per item and per experimental condition are summarised in Appendix 6. We matched prime words in the unrelated and morphological prime types with regard to lemma frequency, word-form frequency and number of letters, based on data from the CELEX corpus (Baayen, Piepenbrock & Gulikers 1995), to allow for comparisons between the types (all $ts < 1$). We further matched the three participle types for mean lemma frequency, mean word-form frequency, and mean number of letters (all $Fs<1$), to allow for comparisons between the three types of participle primes. We also matched the target words for the three critical prime types for lemma frequency, word-form frequency and number of letters. Furthermore, mean neighbourhood size was held constant in the target words of the three participle types (*-t*: 11.8; *-n/with*: 11.0; *-n/without*: 12.3) (all $Fs<1$).

In addition, the conditions did not differ with respect to formal overlap, neither for the morphologically related prime–target pairs (-t: .23, *-n/without*: .11, *-n/with*: .16, Fs<1) nor the morphologically unrelated prime–target pairs (-t: .26, *-n/without*: .29, *-n/with*: .24, Fs<1) (both Fs<1). Formal overlap was assessed with the Match Calculator of Davis & Bowers (2006)[21].

Semantic overlap was assessed in a group of 34 adult native speakers of German who estimated the semantic overlap between all three types of prime–target pairs (identity, morphological, unrelated) on a five-point scale (1 = semantically identical, 5 = no semantic overlap). All identical and morphological prime–target pairs (e.g. *geschlafen – schlafe* 'slept – sleep') for the three participle types were rated as 1, i.e. semantically identical. Unrelated control prime–target pairs in all participle types were rated as having no semantic overlap on average (means: *-t* : 4.95, *-n/without*: 4.98; *-n/with*: 4.95, $Fs<1.0$).

As we tested children, the experimental items also need to be matched for *age of acquisition*. For German child language, however, there are no sufficiently large corpora of children's productions that would provide a reliable basis for calculating the ages of acquisition of the experimental items used. However, several studies have found that estimated age of acquisition is highly

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[21] We employed the 'vowel-centric (R-L)' overlap measure, assuming that vowels are the main source of variability in this domain; see, for example, Harm & Seidenberg (1999: 493). If two words are identical, the overlap ratio is 1. If two words have no letter in the same position, the overlap ratio is 0.

correlated with objectively assessed age of acquisition for English nouns (e.g. Carroll & White 1973; Morrison, Chappell & Ellis 1997) and German nouns (Schröder, Gemballa, Ruppin & Wartenburger 2012). We therefore performed a pre-test with 34 adult native speakers of German (age 18–72) in which all critical primes and targets were visually presented as a randomised word list and participants were asked to estimate the age of acquisition for these words on a 10-point scale (1 = year 1, 2= year 2, 3= year 3, 4= year 4 etc. 10 = year 10). Estimated mean ages of acquisition did not significantly differ between participle types (means, *-t*: 3.92, S.D.: .967, *-n* without stem change: 3.65, S.D.: 1.17, *-n* with stem change: 3.54, S.D.: 1.18; $F<1$). These results suggest that the experimental items were properly matched with respect to (estimated) age of acquisition.

The *-t* and *-n* forms occur not only as participles but also as nominalisations (*das Gedruckte* 'the printed (matter)'), and can feed the formation of attributive adjectives (e.g. *das gedruckte Buch* 'the printed book', see section 2.1.2). If such forms were common for particular items, this could lead to competition for the recognition of the participle forms of these items. However, a search in the CELEX data basis revealed that such forms were extremely rare among the critical items of our experiment. There was only one item among the critical *-n* participles without stem changes and one among those with stem changes with a word-form frequency for an attributive adjective or nominalised form that was different from 0, namely the nominalisations *Gefangen(er)*, *Gefangen(e), Gefangen(en)* 'prisoner', and the attributive adjective *gebogen(en)* 'bent'. Secondly, a one-way ANOVA was performed to ensure that the three prime types (*-t* forms, *-n* forms with stem changes, *-n* forms without stem changes) did not significantly differ with respect to their mean frequencies of attributive adjective and/or nominalised forms ($F<1$). Thirdly, adjective and nominalised forms are not fully homophonous with participles, as the former always require an additional ending, at least a *schwa* (e.g. *das Gedruckt*e 'printed (matter)', *gebacken*e *Kartoffeln* 'baked potatoes'), whereas this is not allowed for participles (e.g. *gebacken*). For these reasons, it is unlikely that our participants misperceived our prime words as nominalisations or attributive adjectives.

Furthermore, *-t* and *-n* forms are also are used in predicative adjective contexts (*Das Brot ist gebacken* 'The bread is baked', *Die Sauce ist gerührt* 'The sauce is stirred'). It is true that the predicative adjective and the auxiliary + participle context are different in terms of their syntactic and semantic properties. However, as outlined in Chapter 2, linguistic theories assume that the different syntactic construction types in which *-t* and *-n* forms occur do not affect their internal structure as isolated words. As we are testing *-t* and *-n* forms as isolated words, the different construction types in which these forms appear are unlikely to affect the internal structure of these word forms. Nevertheless, the experimental items should be controlled for whether or not they are commonly used as homophonous adjective forms. Since the CELEX lexical database does not provide this information, we relied on four standard German dictionaries (Grimm & Grimm, 1991; Wahrig, 1997; Drasdowski, 1993; Paul, 1992) to determine whether the critical items used in the present experiment were listed as adjectives in any of them. There were four items within each of the three participle types that (in addition to a participle) had an adjective entry in at least one of these four dictionaries: *-t* participles (*gedruckt* 'printed', *gesteckt* 'stuck', *gesprengt* 'blasted', *gerührt* 'stirred'), *-n/*without stem change (*gesalzen* 'salted', *gewachsen* 'grown, *gewaschen* 'washed', *gefangen* 'caught), *-n/*with stem change (*gebogen* 'bent', *gestohlen*' stolen, *gesunken* 'sunk', *gerissen* 'ripped). Hence, item sets for the three participle types were parallel in this respect.

Three different experimental lists were created to ensure that each participant saw each target word only once. For each participle type, items were divided into three groups matched as closely as possible in terms of mean frequencies. On one list, a target such as *leihe* 'borrowed' was preceded by the identical prime *leihe*, on another list by the morphological prime *geliehen* and on the third list by an unrelated prime *schwöre*. Across all lists all targets appeared with the three different primes.

It was also important to ensure that participants did not develop expectations about the relations between primes and targets, as these could lead them to develop response strategies (cf. Becker 1980; Neely & Keefe 1989; cf. Veríssimo 2010). We therefore added 81 unrelated filler prime–target pairs, so that the number of related prime–target pairs in each experimental list was below 17%. The set of filler items included different verb forms as primes and targets (e.g. bare stem forms, participles, 1st singular present-tense forms and infinitives).

The 108 prime–target pairs in each list were pseudo-randomised to eliminate undesired priming or inhibition effects across items. No more than two items of the same prime–target type occurred in sequence, and each prime or target word had a different onset from the subsequent word. For each list, an additional list was created which was exactly the reverse of the original. To ensure that participants had understood and practised the task, an additional set of eight filler prime–target pairs (consisting of participle forms, infinitives, bare stem forms and 1^{st} singular present-tense forms) was used as practice items.

7.1.3 Procedure

Participants were tested individually in a quiet room. Before the experiment, they took part in the digit-span test. They were informed about their task in the main experiment: they should listen to auditory words and read out aloud visually presented words as quickly and as accurately as possible. To ensure that participants listened carefully to the primes, they were told that ten of the prime words throughout the experiment would be followed by a request from the experimenter to repeat the prime word after they had produced the target word. The requested words were filler trials randomly distributed over each experimental list.

The main experiment started with the eight practice items. After these, the participants had the opportunity to ask questions. They were asked if they could clearly understand the spoken words, and if necessary, the loudspeaker volume was adjusted.

The visual target words were presented in a 36-point font in white letters on a black background. The prime words were spoken by a female German native speaker and digitally recorded in a single session using Audacity® (http://audacity.sourceforge.net). Each word was cut at the onset and offset and stored in a separate *.wav* file. The experiment was controlled by the DMDX experiment software (Forster & Forster 2003) and presented on a 17-inch screen. Each experimental list was divided into nine blocks of 12 prime–target pairs with a short break after each block. After the main experiment, the child participants were tested on a visual word/non-word decision task using experimental items from the main experiment plus corresponding nonce words that differed in not more than one phoneme from the target words. All the children scored the maximum, indicating that they were familiar with the target words tested. Each experimental session took approximately 25 minutes for the children and 20 minutes for the adult participants.

Each trial followed the same sequence. An attention cross was presented for 800ms in the middle of the screen and was immediately followed by an auditory attention tone presented for 200ms. Immediately after the tone, the auditory prime word was presented. At the offset of the auditory prime word, the visual target word was displayed, which stayed on the centre of the laptop screen until the participant had read it aloud. The next trial was initiated by the experimenter. The participants' spoken responses were recorded using a digital audio recorder and processed with the *praat* sound file editor (Boersma & Weenink 2011) after the experiment to obtain response latencies. To make the task more appealing to children, the experiment was introduced along with a board game on which they could mark their progress after each block of 12 trials.

7.1.4 Data Analysis

Error rates and response latencies were analysed separately. The number of unexpected responses over the number of all responses yielded the overall error rate. Unexpected responses included productions of another inflected form of the targeted verb, e.g. *stop* instead of the target word form *stoppe*, or the targeted inflected form of a different lexeme, e.g. *stecke* 'stick$_{[1ps]}$' instead of the target *strecke* 'stretch$_{[1ps]}$'. Trials containing unexpected responses were not analysed in the reaction time analysis.

Participants' response latencies were measured from the offset of the prime word to the onset of their spoken response. Pause boundaries (<45Hz) in the audio files were marked by a pause detection script in *praat*, marked and subsequently double-checked by two transcribers. The data-cleaning procedure for the reaction time analysis was carried out as follows. We removed incorrect responses (adults: 0.6%, children: 3.3%) and mispronunciations of the target words due to hesitations or syllable repetitions (adults: 0.1%, children: 0.6%) and outliers of more than 2.5 standard deviations from the group mean (adults: 1.5%, children 1.3%).

We converted log-transformed raw response latencies to *z*-scores on the basis of individual participants' mean and standard deviations before any statistical analyses, as in the speeded production experiment.

7.2 Results

This section presents an analysis of error rates and response latencies, focussing first on the comparison of morphological priming effects in the three participle types (*-t* participles, *-n/without*, *-n/with*). Full morphological priming effects indicate that prime and target are represented in terms of their morphological constituents in the mental lexicon; partial priming effects indicate that they are represented as full forms. The prime indirectly facilitates response to the target via phonological, orthographic and semantic overlap. A full morphological priming effect is observed if response latencies in the morphological test condition are similar to those in the identity condition but significantly shorter than those in the control condition. A partial priming effect is observed when response latencies in the morphological test condition are significantly longer than those in the identity condition but significantly shorter than those in the control condition. No priming effect is detected when response latencies in the morphological test condition are significantly longer than those in the identity condition but not significantly different from those in the control condition.

Next, we compared priming effects in the three age groups (7–9-year olds, 9–11-year-olds, adults) to investigate developmental changes in the central representation of complex forms. The representation of morphologically complex forms may fundamentally change in the course of language development. For example, children could tend to store morphological constituents of forms rather than full-form representations, perhaps because decomposed representation would require fewer lexical entries than full-form representations of complex word forms. If this is the case, we would expect stronger priming effects in younger children than in older children or adults. Children might also initially tend to store morphologically complex forms as full forms: for instance, if they have not yet discovered the internal morphological structure in complex forms, and only store them as their morphological constituents once they have analysed their morphological structure. If this is the case, we would expect weaker priming effects in younger children than in older children and adults. It could be the case that semantic and form associations between lexical entries in the mental lexicon, which is the source of partial priming, could change in the course of language development. Associations between lexical entries may only be established and strengthen with more incoming language experience. In this case, one would expect weaker indirect priming between full-form representations in younger children compared to older children and adults.

Thirdly, we wanted to find out whether any morphological priming effect obtained in the overall analysis could be replicated without including the Identity condition, as suggested by Smolka et al. (2007: 328). And finally, we were also interested to see whether WM capacity is related to priming effects, as was found to be the case in the speeded production experiment.

We investigated these questions through a statistical analysis of our data in four steps. To investigate priming differences in the three age groups and the three participle types, we first conducted 3x3x3 repeated-measures ANOVAs with the variables participle type (*-t* participle *vs.* *-n* participle without stem changes *vs.* *-n* participles with stem changes), prime type (identical *vs.* morphological *vs.* unrelated) and group (7–9-year-olds *vs.* 9–11-year-olds *vs.* adults). In the by-subject analysis (F_1), prime type and participle type were treated as within-subject factors, and group as a between-subjects factor. In the analysis by items (F_2), group and prime type were treated as within-items factors and participle type as a between-items factor. Secondly, main effects and interactions were further examined in post-hoc comparisons using paired *t*-tests. Thirdly, we tested for a relationship between WM and response latencies in participant groups by including a two-level between-subject factor 'WM' in 3x3x2 repeated-measures ANOVAs with the variables participle type (*-t* participle *vs.* *-n* participle without stem changes *vs.* *-n* participles with stem changes), prime type (identical *vs.* morphological *vs.* unrelated). Finally, two sets of mixed 2x2 ANOVAs were performed for each participant group with the two-level variable prime type (unrelated *vs.* morphological) and the two-level variable participle type (Set 1: '*-t* participle versus *-n* participle without stem changes', set 2: '*-n* participle without stem changes versus *-n* participles with stem changes'). The two-level factor participle type was included specifically to examine the role of the two participle endings (set 1) and the role of stem changes (set 2) independently of each other. For the variable prime type, these analyses only included two levels (unrelated *vs.* morphological), to determine whether any morphological priming effect obtained in the overall analysis could be replicated without including the Identity condition; see Smolka et al. (2007: 328) for discussion. The significance of all effects was assessed using $\alpha=0.05$ and all *p*-values are reported as two-tailed.

7.2.1 Error Analysis

This section presents an error analysis for the child data. We analysed error rates per experimental condition to see whether error rates in the age groups differed according to participle type and prime type. Table 24 displays error rates and standard deviations per experimental condition in the two child groups. We first describe error rates per prime type, then consider if error patterns of prime types differ in the three participle types and, finally, compare these error patterns in the two child groups. Regarding prime types, we see that error rates tended to be highest in the unrelated condition, lower in the morphological test condition and lowest in the identity condition. These error distributions across prime types seem similar in the three participle types. The error distribution across prime types was also similar in the two age groups.

There were only two cases in which error rates across prime type deviate from this pattern. We see the same error rate in unrelated compared to morphological prime type in *-t* participles for the younger child groups (both 5.45%). We also see the same error rate in the morphological test condition and the identity condition for *-n* participles with stem change in older children (both 1.92%). This specific distribution can tell us two things. First, participants actually listened to the prime words, so primes could have a systematic influence on error rates. Secondly, reading a word can be facilitated by prior presentation of auditory stimuli. Specifically, reading the target word was facilitated by listening to an inflected form of the target (morphological prime type) compared to listening to an unrelated form (unrelated prime type) and is, at least in our data, maximally facilitated by listening to the same form as the target word. Whether these observed differences between prime types are meaningful is investigated in the statistical analysis below.

	7–9-year-olds			**9–11-year-olds**		
	Identity	**Morph.**	**Unrelated**	**Identity**	**Morph.**	**Unrelated**
-t	1.82 (13.40)	5.45 (22.78)	5.45 (22.78)	0.63 (7.93)	1.89 (13.65)	5.03 (21.93)
-n/without	0.61 (7.78)	2.42 (15.43)	10.24 (30.4)	0.63 (7.93)	1.89 (13.65)	3.80 (19.17)
-n/with	0.60 (7.71)	2.38 (15.29)	11.90 (32.48)	1.92 (13.78)	1.92 (13.78)	11.54 (32.05)

Table 24: Error rates (S.D.) per age group and experimental condition

A Kolmogorov-Smirnov test showed a significant deviance from normal distribution (p<.001 in all conditions) and calls for non-parametric tests. Wilcoxon-Tests compared error rates between the unrelated and morphological conditions and morphological and identity condition for each group separately, to test whether the differences between prime types were meaningful. The results showed no significant difference between the morphological and identity conditions for any participle type (all Zs>1.00, all ps>.100). Differences in error rates became significant in the comparison between the unrelated and morphological conditions for *-n* participles with stem change in both child groups (7–9-year-olds: Z=3.014, p=.003; 9–11-year-olds: Z=3.441, p=.001) and for *-n* participles without stem change in the younger child group (7–9-year-olds: Z=3.357, p=.001; 9–11-year-olds: Z=1.000, p=.317).

The statistical analysis confirms a meaningful difference only in error rates between the morphological and unrelated conditions, and not in all participle types. The difference in error rates between the identity and morphological conditions was purely numerical in nature in all participle types. We can conclude from this statistical analysis only that some facilitation from prime to target is detected in the error rate. The analysis of error rates may suggest that differences between the morphological and identity conditions are smaller than those between the morphological and unrelated conditions. The error rates, however, did not indicate meaningful differences between participle types and age groups in the amount of facilitation. We must therefore rely on the response-time analysis, described next, to detect differences between participle types and age group in the amount of facilitation from prime to target.

7.2.2 Response Latencies

The results of a one-sample Kolmogorov-Smirnov test revealed normal distribution in all conditions (p>.05) allowing for parametric ANOVAs and t-tests. Mean target response latencies (as well as standard deviations) in the three prime conditions for both *-t* and *-n* participles with and without stem changes are displayed in Table 25 separately for the three participant groups. We can tell from the data that mean response latencies become shorter with age: they were shortest in adults (537ms), who responded more quickly than older children (656ms), who in turn responded more quickly than younger children (717ms). These differences are statistically reliable, as was confirmed by a one-way ANOVA on the log-transformed overall response latencies ($F_1(2,179)=50.249$, $p<.001$, $F_2(2,52)=473.583$, $p<.001$). Regarding prime types, response latencies in the identity condition are shortest across all participle types and groups, followed by those in the morphological test condition and, again, followed by response latencies in the unrelated condition. This staircase pattern for response latencies mirrors the staircase pattern of error rates. Participle types do not seem to reveal systematic differences. The longest response latencies were elicited by *-n* participles with stem change in adults (543ms) and in 7–9-year-olds (731ms) and by *-n* participles without stem change in 9–11-year-olds (662ms). The shortest response latencies were elicited by *-t* participles in adults (527ms) and 9–11-year-olds (645ms) and by *-n* participles without stem change in 7–9-year-olds (708ms). It seems that adults and 9–11-year-olds patterned alike and differently from 7–9-year-olds with respect to the mean response latency per participle type. It should be noted, however, that the mean differences between participle types are very small. The difference between, for example, the fastest and the second fastest participle type is 3ms in adults, 13ms in 9–11-year-olds and 3ms in 7–9-year-olds.

Prime Type	7–9-year-olds (n=54)			9–11-year-olds (n=54)			Adults (n=72)		
	-t	*-n* /without	*-n/with*	*-t*	*-n* /without	*-n/with*	*-t*	*-n* /without	*-n/with*
Iden-tity	664 (163)	628 (120)	623 (101)	609 (131)	619 (130)	595 (109)	505 (82)	496 (80)	519 (90)
Test	665 (104)	729 (146)	778 (131)	611 (84)	666 (127)	665 (128)	505 (62)	549 (80)	546 (98)
Unre-lated	803 (168)	767 (173)	793 (197)	717 (168)	701 (122)	715 (147)	572 (111)	574 (88)	564 (81)
Mean	**711 (130)**	**708 (119)**	**731 (122)**	**645 (124)**	**662 (98)**	**658 (111)**	**527 (83)**	**540 (72)**	**543 (84)**

Table 25: Mean response latencies in ms (S.D.) per age group

In order to assess these observations statistically, we analysed response latencies in overall 3x3x3 ANOVAs with the factors GROUP (7–9-year-olds *vs.* 9–11-year-olds *vs.* adults), PARTICIPLE TYPE (*-t* participle *vs.* *-n* participle without stem changes *vs.* *-n* participles with stem changes) and PRIME TYPE (identical *vs.* morphological *vs.* unrelated). The results revealed significant main effects of prime type (F_1(2, 342)=467.14, p<.001, F_2(2,36)=29.65, p<.001), group (F_1(2,171)=4.71, p=.010, F_2(2,36)<1) and participle type (F_1(2,171)=16.56, p<.001, F_2(2,18)<1), the last two in the participant analysis only. In addition, there were significant interactions of prime type and group (F_1(4,342)=5.65, p<.001, F_2(4,72)=3.27, p=.023), as well as of participle type and prime type (F_1(4,342)=20.83, p<.001, F_2(4,36)=1.46, p=.25) and of participle type and group (F_1(4,171)=2.98, p=.021, F_2 (4,36)=1.08, p=.38), the last two of which were reliable in the participant analysis only. Most importantly, we found a three-way interaction of participle type, prime type and group in both the participant analysis and the item analysis (F_1(8,342)= 4.31, p<.001, F_2 (8,72)=2.59, p=.022). This three-way interaction suggests that response latencies to the three participle types are differently affected by prime type and that the strength of the differences varies between the three age groups.

To identify the source of the three-way interaction, we examined response latencies in planned comparisons using paired *t*-tests for each group separately[22]. Table 26 shows paired t-tests in the adult control group. Response latencies to *-t* participles in the morphological condition are

[22] Although in the by-item analyses, *p*-values were often lower than in the corresponding by-participant analyses, the effect size estimates (Cohen's d, Table 26-28) were similar in both analyses and sometimes even larger in the by-item analyses; see Table 26-28. The latter is due to smaller standard deviations amongst items than amongst participants. We attribute the contrast in the *p*-values to the smaller number of items than participants, which was unavoidable given the limited number of *-n* participles with the required properties in the German language.

significantly shorter than in the unrelated condition and as short as in the identity condition (in the participant analysis only). According to our definition above, *-t* participles produced a full priming effect, that is, significantly shorter target response latencies after participle primes than after unrelated prime words, and no difference between identity and participle primes. In contrast to *-t* participles, *-n* participles (with and without stem changes) elicited significantly shorter response latencies in the morphological condition than after unrelated prime words but longer ones in the morphological condition than after identity prime words. The former differences were significant in the participant analysis only. It follows that *-n* participles (with and without stem changes) yielded a partial priming effect.

	-t	***-n/without***	***-n/with***
Morphological–Identity	$t_1(71)= 1.11$, $p=.269$, $d=.00$ $t_2(8)<1$, $d=.02$	$t_1(71)=13.39$, $p<.001$, $d=.66$ $t_2(8)=3.68$, $p=.006$, $d=1.27$	$t_1(71)= 4.12$, $p<.001$, $d=.29$ $t_2(8)= 2.33$, $p=.048$, $d=.60$
Morphological–Unrelated	$t_1(71)=7.85$, $p<.001$, $d=.75$ $t_2(8)=2.28$, $p=.052$, $d=1.04$	$t_1(71)=2.59$, $p=.012$, $d=.31$ $t_2(8)<1$, $d=.46$	$t_1(71)=2.9$, $p=.005$, $d=.21$ $t_2(8)<1$, $d=.39$

Table 26: Planned comparisons of mean response latencies for the adult group

Table 27 shows that 9–11-year-olds produced the same priming patterns as adults. A full priming effect for *-t* participles with similar response latencies for the target after a morphological prime compared to those after the identity prime, but significantly shorter response latencies than after the unrelated prime. In addition, we see partial priming effects for *-n* participles with and without stem changes, that is, response latencies in the morphological condition were significantly shorter than after the unrelated prime but significantly longer than after the identity prime.

	-t	***-n/without***	***-n/with***
Morphological–Identity	$t_1(53)=1.81$, $p=.076$, $d=.02$ $t_2(8)<1$, $d=.04$	$t_1(53)=3.49$, $p=.001$, $d=.37$ $t_2(8)=3.1$, $p=.015$, $d=.89$	$t_1(53)= 7.50$, $p<.001$, $d=.60$ $t_2(8)=6.18$, $p<.001$, $d=1.08$
Morphological–Unrelated	$t_1(53)= 7.50$, $p<.001$, $d=.80$ $t_2(8)=2.94$, $p=.019$, $d=1.65$	$t_1(53)=2.06$, $p=.045$, $d=.29$ $t_2(8)<1$, $d=.53$	$t_1(53)=2.82$, $p=.007$, $d=.36$ $t_2(8)=2.87$, $p=.021$, $d=1.32$

Table 27: Planned comparisons of mean response latencies for 9–11-year-olds

By contrast, we see in Table 28 that 7–9-year-old children showed different priming effects for *-n* participles with and without stem change from adults and older children. While they showed an adult-like full priming effect for *-t* participles, *-n* participles with and without stem changes did not yield any priming effect. In other words, response latencies for *-n* participles were of similar length in the morphological condition and the unrelated condition but were significantly longer than in the identity condition. The results for *-t* participles in all age groups indicate that children in the age range 7–9 have adult-like priming patterns for *-t* participles. The results for *-n* participles indicate developmental changes in the priming patterns for *-n* participles.

	-t	***-n/without***	***-n/with***
Morphological–Identity	$t_1(53)=1.11$, $p=.273$, $d=.01$ $t_2(8)=1.28$, $p=.24$, $d=.22$	$t_1(53)=5.33$, $p<.001$, $d=.76$ $t_2(8)=5.57$, $p=.001$, $d=2.52$	$t_1(53)=10.73$, $p<.001$, $d=1.33$ $t_2(8)=8.05$, $p<.001$, $d=2.93$
Morphological–Unrelated	$t_1(53)=8.16$, $p<.001$, $d=1.00$ $t_2(8)=2.39$, $p=.044$, $d=1.36$	$t_1(53)=1.31$, $p=.196$, $d=.23$ $t_2(8)<1$, $d=.43$	$t_1(53)<1$, $d=.36$ $t_2(8)=<1$, $d=1.32$

Table 28: Planned comparisons of the mean response latencies for 7–9-year-olds

The following analysis checks whether the morphological priming effects revealed in the overall analysis can be replicated without including the identity condition (cf. Smolka et al. 2007: 328). We also use this analysis to examine more closely the role of the participle endings and the role of the stem changes. To this end, we ran two 2x2 analyses with the factors prime type and participle type for each participant group separately. The factor prime type includes the morphological and unrelated prime type. The factor participle type includes the level *-t* participles and *-n* participles (both) without stem change in the first analysis and the level *-n* participles with stem change and *-n* participles without stem change in the second analysis.

The first analysis with the factors prime type (morphological *vs.* unrelated) and participle type (*-t vs. -n/without*) revealed main effects of participle type for the adult group ($F_1(1,69)=58.56$, $p<.001$, $F_2(1,12)=2.32$, $p=.15$) and for older children ($F_1(1,51)=25.65$, $p<.001$, $F_2(1,12)=2.82$, $p=.12$), significant for participants only. There was also a main effect of prime type for the three participant groups (adults: $F_1(1,69)=136.87$, $p<.001$, $F_2(1,12)=6.86$, $p=.022$; 9–11-year-olds: $F_1(1,51)=210.31$, $p<.001$, $F_2(1,12)=7.36$, $p=.019$; 7–9-year-olds: $F_1(1,51)=46.37$, $p<.001$, $F_2(1,12)=5.43$, $p=.038$) and interactions of participle type and prime type that were significant in the participant analyses of the three groups (adults: $F_1(1,69)=12.31$, $p=.001$, $F_2(1,12)<1$; 9–11-year-olds: $F_1(1,51)=10.90$, $p=.002$, $F_2(1,12)=1.60$, $p=.229$; 7–9-year-olds: $F_1(1,51)=15.60$, $p<.001$, $F_2(1,12)= 2.28$, $p=.16$). These interactions show that *-t* and *-n* participles differ in their degree of priming, i.e. response latency differences between the unrelated and the morphological condition. Referring back to Table 25, we can determine the direction of this interaction: the degree of priming is larger for *-t* participles than for *-n* participles without stem change in all three participant groups (adults: 67ms *vs.* 18ms; 9–11-year-olds: 106ms *vs.* 35ms; 7–9-year-olds: 138ms *vs.* 38ms).

The second analysis with the factors prime type (morphological *vs.* unrelated) and participle type (*-n/with vs. -n/without*) yielded main effects of participle type for the adult group ($F_1(1,69)=58.56$, $p<.001$, $F_2(1,12)=2.32$, $p=.15$) and for the younger child group ($F_1(1,51)=11.45$, $p=.001$, $F_2(1,12)=3.11$, $p=.103$), significant in the participant analysis only. This effect was due to longer overall response latencies for *-n* participles with stem changes than for those without. The analysis also revealed main effects of prime type for the adult group ($F_1(1,69)=51.85$, $p<.001$, $F_2(1,24)=2.26$, $p=.16$) and for older children ($F_1(1,51)=15.52$, $p<.001$, $F_2(1,24)=5.74$, $p=.034$). This effect can be explained by shorter response latencies for the morphological than for the unrelated condition in these participant groups. By contrast, there was no statistically reliable interaction between participle type and prime type in any participant group (all $F_1s<2$, all $F_2s<1$). These comparisons confirm that *-n* participles with and without stem changes do not differ in their degree of priming within each of the three participant groups: there is a partial priming effect in the adult group and in 9–11-year-olds and no priming in 7–9-year-olds.

Finally, we assessed statistically whether WM was related to priming effects, as found for frequency effects in *-t* participles in the 9–11-year-olds' speeded production of participles without stem change. We divided each participant group on the basis of their median WM scores. For each group, we ran separate 3x3x2 ANOVAs with the factors participle type (*-t* participles, *-n/with vs. -n/without*), prime type (identity *vs.* morphological *vs.* unrelated) and WM (high *vs.* low). We wanted to find out whether WM was related to response latencies and whether it affected response latencies differently in participle types and age groups. The analysis did not reveal any significant effects or interactions with WM in any age group (7–9-year-olds: Fs<3.20, *ps*>.05; 9–11-year-olds: *F*s<2.60, *ps*>.05; adults: *F*s<3.00, *ps*>.05). The results indicate no relationship between WM and response latencies in these groups.

With regard to the questions asked at the beginning of this section, we can say that, first, participle types show different morphological priming effects: partial priming for both *-n* participles and full priming for *-t* participles. Secondly, we saw developmental changes in the two child groups. Older, unlike younger, children showed adult-like partial priming patterns for *-n* participles. Thirdly, we showed that the morphological priming effects obtained in the overall analysis could be replicated in an analysis without the identity condition. Finally, we saw that WM was not related to priming effects in any age group, unlike what we found in the speeded production experiment for 9–11-year-olds' production of participles without stem change.

7.3 Discussion

The cross-modal priming study investigated central-level representation of German past participles in children and in an adult control group. We will now discuss our results relating to morphological priming effects in different participle types (*-t* participles, *-n/without*, *-n/with*) and in different age groups (7–9-year-olds, 9–11-year-olds, adults). Specifically, we will discuss what results suggest about (i) the central representation of participle types and (ii) how that representation develops in children to become adult-like.

Central representation of participle types

For adults, *-t* participles yielded full stem-priming effects. This finding suggests that the *-t* participle form of a given verb facilitates response to the corresponding 1st singular form as much as this target form itself. This finding replicates previous results for *-t* participles by Sonnenstuhl et al. (1999) from a cross-modal priming task and by Neubauer & Clahsen (2009) from a masked priming experiment. By contrast, *-n* participles (with and without stem change) did not facilitate adults' responses to the target word as much as did an identical prime word, yielding partial priming effects. The findings for *-n* participles replicate earlier findings on adults from a cross-modal priming experiment by Sonnenstuhl et al. (1999) and (only for *-n* participles) by Smolka et al. (2007), and a masked priming experiment by Neubauer & Clahsen (2009). In both experiments, *-t* participles yielded full priming and *-n* participles without stem changes yielded partial priming effects (*-n* participles with stem changes were not tested in these studies).

In children, *-t* participles yielded full stem-priming effects, as they did for adults. In line with our argumentation for adults, this finding shows that *-t* participles facilitate response to the corresponding 1st singular form as much as the target form. By contrast, *-n* participles elicited different priming effects in the two child groups. In older children, as with adults, *-n* participles with and without stem change yielded partial priming effects. In younger children, *-n* participles yielded only numerical facilitation, which did not reach significance in the statistical analysis. The current results from priming in children are consistent with previous results, indicating that primary-school children are already sensitive to morphological structure in word recognition (Feldman, Rueckl, DiLiberto, Pastizzo & Vellutino 2002; Rabin & Deacon 2008; Schiff, Raveh & Kahta 2008; Casalis, Dusautoir, Colé & Ducrot 2009; Deacon, Campbell & Tamminga 2010; Quémart, Casalis & Colé, 2011; Ravid 2011). Comparing our results from cross-modal priming with previous results from purely visual online priming, we suggest that decomposition also takes place on a central abstract level of lexical representation and does not only apply to the written modality. Also, our findings for inflected forms are parallel to findings for derived words, so we suggest that children are also sensitive to morphological structure in the domain of inflectional morphology, not only in that of derivational morphology. We first consider how we can interpret the observed priming effects before discussing developmental differences for *-n* participles between younger and older children below.

Seidenberg & Gonnerman (2000) and Gonnerman et al. (2007), proponents of connectionist approaches, suggested that the source of priming lies in shared semantics or phonological and orthographic form overlap. As discussed in section 5.1.2, morphologically related forms are often orthographically or semantically related, so the various possible sources of priming can be difficult to tease apart. However, as described above, our material was controlled for phonological and orthographic form overlap and semantic relation between primes and targets. Participles with *-t* or *-n* suffix, but without stem change, share the same amount of orthographic overlap with target words. If shared surface forms were responsible for priming, *-t* participles and *-n* participles should have produced the same priming patterns. This was not confirmed in the data, as became particularly clear in our third analysis with participle type level *-t* participle *vs.* *-n* participles without stem change. Also, all participles had the same semantic overlap between prime and target. If shared semantics had been the determining factor, we should have found the same amount of facilitation for all participles. This priming pattern was not observed either, as was statistically confirmed by a three-way interaction in our overall ANOVA. We conclude that the observed dissociation between *-t* participles and *-n* participles cannot be explained by differences in shared semantics or form overlap. Our pattern of results suggests two different systems for *-t* participles and *-n* participles. As we saw in the literature review in section 4.4, the dual approach has explained a large range of masked priming results. In this dual view, the finding of full-form priming effects for *-t* past participles is taken to indicate that *-t* participles are represented according to their morphological components in the mental lexicon, with the result that the recognition of *-t* participles activates the same stem representation as the target form. By contrast, partial priming effects in *-n* participles are taken to indicate that *-n* participles activate their own lexical entries, which are only indirectly related to the lexical entries of the target. In this view, the preactivation of the target word cannot be as strong as the preactivation by the target form. This explanation is located in a dual morpheme-based theory on the representation of word structure, as proposed by Wunderlich & Fabri (1995) and introduced in section 2.2.1. In this view, *-t* and *-n* participles have different morpho-lexical representations. Morphologically structured forms are derived by affixation for *-t* participles and lexical (sub)entries for *-n* participles. Thus, despite similar surface-form and semantic overlap with their targets, *-t* and *-n* participle primes produce different priming patterns, which can explain our findings.

Previous literature and current findings show that morphological structure affects word recognition by adults and children in both overt cross-modal priming experiments and masked priming experiments. We suggest that these findings can usefully complement each other to yield a more complete picture of the processing involved in word recognition. In masked priming experiments, the time between the onset of the prime and the onset of the target is very brief (about 30–60ms), which reduces the possibility that there are episodic memory effects and that participants realise that primes and targets are sometimes related (cf. Silva & Clahsen 2008: 8). Marslen-Wilson (2007) argued that masked priming provides response latency measures that tap into early automatic processes in word recognition and are sensitive to early form-level access. However, masked priming experiments only involve visual stimuli. At the same time, cross-modal priming experiments present overt stimuli, so participants have more time to process the stimuli and to access lemma-level information relating to prime and target. A full priming effect in a cross-modal priming experiment is supposed to result from repeated activation of the same representation in prime and target, and a partial priming effect from the activation of distinct, but related, representations. The cross-modal priming technique hence taps into later stages of word recognition. The findings from the current and previous studies suggest that *-t* participles activate the same representation as the corresponding target. Previous masked priming experiments (Neubauer & Clahsen 2009) and cross-modal priming experiments (Sonnenstuhl et al. 1999) on adults have consistently found that *-t* and *-n* participles and, similarly, regular and irregular English past-tense forms (Rastle, Davis, Marslen-Wilson & Tyler 2000; Rodriguez-Fornells, Münte & Clahsen 2002; Silva & Clahsen 2008) are processed differently, *-t* participles showing full decomposition effects while the results for *-n* participles indicate full-form representation. For adults we can conclude that *-t* participles are decomposed into stem and affix and *-n* participles are processed as whole forms at early and later stages of word recognition.

The current experiment has shown that children access representations of *-t* participle stems but full-form representations of *-n* participles. This result is consistent with previous studies showing that children are sensitive to word structure, such as a masked priming study by Schiff et al. (2008) investigating early form-level access of derived words.

Development

Children performed largely similarly to adults, but we also found developmental differences between younger and older children and adults. Younger children had generally longer response latencies than older ones who exhibited longer overall response latencies than adults. As in our explanation of the speeded production experiment, we suggest that generally longer response latencies for children than for adults can be explained by slower lexical access to lexical entries. Interestingly, longer response latencies were particularly pronounced in younger children compared to older children for *-n* participles with stem change, e.g. *geliehen* ‘borrowed’. In the younger child group, response latencies for *-n* participles with stem change were significantly longer than those for *-n* participle primes without stem changes (778 *vs.* 729ms, $t_1(53)=3.49$, $p=.001$, $t_2(16)=2.30$, $p=.035$). By contrast, adults and older children performed alike, showing similar response latencies for these two types of *-n* participles (adults: 549 *vs.* 546ms; 9–11-year-olds: 665 *vs.* 666ms, all $t_s<1$). This difference is unlikely to be due to properties of the target words, as these were closely matched across conditions. Instead, it seems that stem changes in *-n* participles such as *gesunken* slows down lexical retrieval, particularly in younger children.

Most interestingly, we found developmental changes for *-n* participles (with and without stem change) but not for *-t* participles. For *-n* participles, the older group of children produced an adult-like partial priming effect. The younger child group showed no reliable priming effect for *-n* participles. We attribute the developmental changes for *-n* (but not for *-t*) participles to their distinct lexical representations. While *-n* participles constitute (sub)entries stored in lexical memory, *-t* participles are thought to be combinatorial word–forms, generated from stems and affixes that do not require any kind of lexical storage. Memory storage and retrieval are dependent on experience and are likely to become more stable and reliable as children get older. This applies to the subentries for *-n* participles, which need time to be properly integrated into complex lexical entries. We have further argued that semantic and form associations between lexical entries are thought to be the source of partial priming. The lack of priming in younger children could thus indicate that lexical entries in young children's mental lexicon are not sufficiently associated via their semantic and form properties. One could suggest that associations between lexical entries are not present from an early age but are established later, possibly once semantic and form relationships between entries are discovered. The partial priming effect in older children suggests that associations between lexical entries grow stronger in the course of language development and are similar to those of adults by the age of 9 to 11.

8 Unprimed Visual Lexical Decision

This chapter tackles the question of whether full-form frequency of *-t* participles inhibits production but enhances recognition. We therefore tested the items from the speeded production experiment in a visual lexical decision experiment. Specifically, we tested for full-form frequency effects of *-t* and *-n* past participles with and without stem change in children and adult controls. The results offer insight into the nature of the access-level representations which children consult to *recognise* participles. Any effect observed in the recognition experiment can then be compared to effects found in the speeded *production* experiment. This comparison allows us to decide, at least for the set of stimuli we tested, whether full-form frequency of *-t* participles leads to different effects in production from in recognition.

The results of visual lexical decision studies on inflected words in adults have shown contrasts between *-t* and *-n* participles. Inflected non-default forms, such as *-n* participles, have consistently produced frequency effects, with high-frequency *-n* participles showing shorter reaction times (RTs) than low-frequency *-n* participles. This robust finding has been interpreted as evidence for the full-form representation of inflected non-default forms and is in line with morphological processing theories which assume such representations. Lexical decision experiments with adults have produced less consistent results for default *-t* participles, reporting no full-form frequency effect for default forms (e.g. Clahsen et al. 1997; Neubauer & Clahsen 2009) or frequency advantage for inflected default forms (Baayen et al. 1997; Alegre & Gordon 1999). Clahsen et al. (1997) reported a slight disadvantage for high-frequency over low-frequency forms. Neubauer & Clahsen (2009) found a slight advantage for high-frequency over low-frequency forms, though this was not statistically reliable. Studies of other inflectional phenomena – English past-tense forms (Alegre & Gordon 1999) and Dutch plural forms (Baayen et al. 2003) – have shown advantages for high-frequency over low-frequency default forms. Evidence from lexical decision experiments on the representation of inflected words in children is sparse. As described in section 4.4.2, Burani, Marcolini & Stella (2002) used the visual lexical decision task with Italian children as young as eight and found shorter reaction times for high-frequency than for low-frequency existing words and a higher rate of false correct decisions for morphological pseudowords than for non-morphological pseudowords. These results show that the visual lexical decision task can be used to reveal sensitivity to inflection structures.

For children, no results from visual lexical decisions have been compared to results from production. The current visual lexical decision experiment tests for frequency effects in children's recognition of German past participles, comparing results from the visual lexical decision task to effects found for children's production of German past participles.

8.1 Methods

8.1.1 Participants

The visual lexical decision experiment was conducted with two participant groups, a child group of 41 children in two age groups (20 7–8-year-olds: mean age 8;6, S.D.= .337; 21 9–11-year-olds: mean age 10;2, S.D.=.612, 23 girls). The children were similar in age to those in the cross-modal priming and speeded production experiments. They had at least one year of reading experience: enough to develop visual representations of inflected forms (cf. Goswami & Ziegler 2005; Acha & Perea 2008). Again, the experiment was restricted to children younger than eleven in order to have a clear age difference between children (<11 years) and adults (>18 years). Participants were recruited from the Potsdam/Berlin area. Parental consent for child participants was obtained prior to testing. We also tested a control group of 34 adults (age range 20–38 years, mean=25.26, S.D.=4.52, 23 female) from the region of Berlin and Potsdam.

All participants were monolingual native speakers of German, none with a history of language, hearing, motor function or vision impairment. They were asked to provide their date of birth and, for adults, years of education and profession. The testing session took place at the reaction-time laboratory at the University of Potsdam. Ethical approval was attained through the University of Potsdam ethics committee. The participants underwent the auditory digit-span test (Tewes 1983, 1991) as described in section 6.1 for the speeded production experiment.

Table 29 presents mean WM scores as measured by the HAWIK-Test in the child group and the HAWIE-Test in the adult group. The mean WM score of the child group is smaller than that of the adult group. Independent-samples t-tests confirmed that the differences in WM scores vary, between younger and older children ($t_1(39)=3.926$, $p<.001$), between younger children and the adult group ($t_1(52)=6.802$, $p<.001$) and between older children and adults ($t_1(53)=3.879$, $p<.001$). The results show that auditory WM capacities are smaller in children than in adults and suggest that they gradually develop over time until they become adult-like.

	7–8 years	9–11 years	Adults
Mean WM score (S.D.)	12.35 (2.10)	14.95 (2.13)	18.26 (3.52)

Table 29: Mean short-term memory scores (S.D.) per participant group

8.1.2 Materials

In order to compare frequency effects in recognition to those in production, the same materials were tested as in the speeded production task. We added eight *-t* participles so that the group size of *-t* participles in the current study would be comparable to that of *-t* participles in previous studies (Clahsen et al. 1997; Neubauer & Clahsen 2009)[23]. A list of stimuli, written frequencies[24] and word form properties are presented in Appendix 7. The *-n* participles with/without stem change and *-t* participles were further divided into subgroups of relatively high and low word-form frequency, exemplified in Table 30.They differed significantly in terms of written word form frequency (*-t* high *vs.* low $t(16)=3.614$, $p=.002$; *-n/with* high *vs.* low $t(8)=4.006$, $p=.004$; *-n/without* high *vs.* low $t(8)=3.468$, $p=.008$). The written lemma frequency was held constant between the groups of high- and low-frequency groups (*-t* high *vs.* low t(16)=.031, $p=.976$; *-n/with* high *vs.* low $t(8)=.142$, $p=.890$, *-n/without* high *vs.* low $t(8)=.081$, $p=.937$). The participle forms in the high- and low-frequency groups were matched for formal length in terms of letters (*-t* high *vs.* low t(16)=.603, $p=.555$; *-n/with* high *vs.* low $t(8)=.001$, $p=1.0$; *-n/without* high *vs.* low $t(8)=.667$, $p=.524$), phonemes (*-t* high *vs.* low $t(16)=.001$, $p=1.00$; *-n/with* high *vs.* low $t(16)=.354$, $p=.733$; *-n/without* high *vs.* low $t(8)=1.265$, $p=.242$) and syllables (*-t* high *vs.* low identical number of syllables; *-n/with* high *vs.* low $t(8)=1.000$, $p=.437$; *-n/without* high *vs.* low $t(8)=1.633$, $p=.141$).

[23] This concern equally applies to the materials in the speeded production experiment.
[24] In contrast to the speeded production task, which involves *spoken* stimuli and responses and whose material was matched for spoken frequencies, the visual lexical decision task requires participants to read written stimuli and its material is matched for *written* freuqencies.

Participle Type	Frequency	Verb Stimulus
-t	high	*gespart* 'saved'
-t	low	*gelacht* 'laught'
-n/with	high	*geblieben* 'stayed'
-n/with	low	*geschrien* 'screamed'
-n/without	high	*gefallen* 'fallen'
-n/without	low	*gestoßen* 'pushed'

Table 30: Example stimulus set for each experimental condition

To avoid strategies, 262 fillers were added to the 38 experimental items. Fillers included 112 words (four *-t* participles and eight *-n* participles, 50 inflected nouns, 50 inflected adjectives) and 150 nonce words (50 participles, 50 nouns, 50 adjectives), derived from existing words by changing two letters (e.g. *Schule* 'school' – Schipe). The whole stimulus set consisted of 300 items, half nonce words and half real words. The items were pseudo-randomised, with no more than two items of the same experimental condition appearing in a row, no more than four words or nonce words appearing in a row and no semantic relation between subsequent items. A reverse-order list was created, identical to the original list except for the order of items.

8.1.3 Procedure

Each experimental session consisted of two parts. In the first part, the experimenter administered an auditory digit-span test to the participants, which took about five minutes. In the second part, the main experiment was conducted, which took about 20 minutes. Participants read detailed written instructions and had time to ask questions. They were told that they would see strings of letters and would be asked to decide as quickly and as correctly as possible whether the string presented was an existing word of the German language (by pressing Yes or No). To avoid a potential right-hand bias, for half the participants the Yes button was on the right-hand side and for the other half it was on the left. The experiment started with a practice session of six items. After this, the participants again had an opportunity to ask questions.

Only children who correctly identified four out of six items proceeded to the main experiment, to ensure that they had understood and practised the task sufficiently. In fact, all the children successfully passed the practice session.

The lexical decision procedure was adopted from Clahsen et al. (1997). The main part of the experiment consisted of 300 trials. Each trial consisted of a fixation point (hash sign '#'), centred on the screen for 600ms, followed by the stimulus, also centred on the screen. The stimulus remained on screen until the participant had indicated his/her response, but disappeared after 4000ms if no response was given. The stimuli were presented in white letters on a black background in 26-point characters. The next trial started automatically 1200ms after response or time-out. Four breaks were inserted during the experiment, one after the practice session and the others after each 75 items. The breaks were ended by the participant. This presentation mode incorporates three modifications with respect to the procedure used by Clahsen et al. (1997). First, they presented the stimuli beginning at the same point as the fixation point, while we centred both fixation point and stimulus. Second, they inserted only three breaks while we inserted four, to give the children more time to recover. Third, Clahsen et al. introduced a time-out after 2000ms to speed up participants' responses. We inserted it after 4000ms to prevent children from feeling they had to rush, which might have increased the number of incorrect responses. The presentation of the stimuli and reaction time measurement was controlled by the software package DMDX (Forster & Forster 2003). The entire duration of the testing session was about half an hour for children and twenty minutes for adults.

8.1.4 Data Analysis

Error rates and reaction times were analysed separately. To determine the overall error rate, the number of all incorrect cases was divided by the total number of cases. Incorrect cases were non-word responses to existing words ('incorrect false') and word responses to non-words ('incorrect true'). To determine the error rate in the experimental items, the number of incorrect false cases was divided by the total number of experimental items.

The data cleaning procedure for the reaction time analysis was as follows. Incorrect responses, extreme reaction times (>3000ms) and outliers (>2.5 SDs from a subject's mean reaction time) were removed from the data set. This led to a total exclusion rate of 4.97% for 7–8-year-olds, 6.51% for 9–11-year-olds and 3.44% for adults. Before any statistical analyses were conducted, the raw reaction times were log-transformed and converted to *z*-scores on the basis of individual participants' mean and standard deviations.

8.2 Results

This section presents the statistical analysis of error rate and reaction times. We wanted to investigate the access-level representations which children consult in the recognition of the three participle types (*-t* participles, *-n/without*, *-n/with*). Full-form frequency effects are defined as significantly shorter reaction times for high-frequency than for low-frequency items of one participle type. In line with previous studies, we will take a frequency effect to indicate that full-form representations are accessed during recognition. We further want to compare frequency effects in the three age groups, to investigate how representations of participles types develop over time. Children may begin by storing the morphological constituents of written and spoken complex forms, full-form representations developing over time. Alternatively, and in analogy to early developmental stages in the acquisition of inflection (see section 3.1), one could hypothesise that young children store all words as full forms and only later, having analysed their internal morphological structure, represent their morphological constituents. We also want to find out whether the effects observed in the recognition of participles differ from those observed in their production. To this end, we compare the effects observed in the lexical decision experiment to those of the speeded production experiment. Finally, we investigate whether WM capacities and speed of lexical access, which, it has been suggested, influence the production of inflected forms, also influence their recognition.

To address these questions, the reaction time data and error rates were analysed using repeated-measures analyses of variance. In the by-subject analysis (F_1), participle type and word frequency were treated as within-subject factors and group as a between-subject factor. In the by-item analysis (F_2), participle type and frequency were treated as between-items factors and group as a within-items factor. Significant interactions or main effects were explored in pairwise comparisons using *t*-tests. The significance of all effects was assessed on a 5% level. All *p*-values were reported as two-tailed.

8.2.1 Error Analysis

The overall error rates per age group are shown in Table 31. We observe that error rates for words and non-words were similar in all age groups, indicating that participants did not have a pronounced bias towards Yes or No. We further observe that adults produced the fewest errors, followed by the 7–8-year-olds. The 9–11-year-olds produced most errors. It seems surprising that older children produced more errors when making a word/non-word decision. However, their reaction times were considerably shorter than those of younger children, so their higher error rate could be due to a 'speed–accuracy trade-off' effect (e.g. Latash, Sun, Latash & Mikaelian 2011; Yamaguchi, Crump & Logan 2013): a participant produces more errors when giving quick answers than when taking more time to respond. The task for the participants was to respond as quickly and as accurately as possible. Older children might have focused more on giving quick responses, risking more errors, rather than producing slower but more correct responses. The younger children's priorities might have been different, meaning that they produced more correct responses, but more slowly, rather than producing quick responses with more errors.

	Adults		**Children 7–8**		**Children 9–11**	
	Correct	**Incorrect**	**Correct**	**Incorrect**	**Correct**	**Incorrect**
Words	47.48%	2.52%	45.35%	4.65%	43.71%	6.29%
Non-words	47.74%	2.26%	45.51%	4.48%	42.90%	7.10%

Table 31: Correct and incorrect responses per age group as percentages

Table 32 shows the percentages and standard deviations of error rates by experimental condition. We will first consider participle types with respect to differences between high- and low-frequency items and, second, compare the error patterns in the two groups of children. Regarding participle types, *-t* participles showed a smaller error rate for high-frequency than for low-frequency items, consistently across age groups. Participles with *-n* suffix without stem change had a slightly smaller error rate for high-frequency (3.81%) than for low-frequency items (6.67) in the older child group. Participles with *-n* suffix and stem change showed considerably fewer errors for high-frequency than for low-frequency items in younger children (high: 1.00% *vs.* low: 9.00%) and subtle frequency differences in adults (high: 2.35% *vs.* low: 3.53%). When comparing differences between high- and low-frequency items per age group, we see that adults and older children showed more pronounced frequency differences for *-t* participles (adults: .09 *vs.* 4.25%; 9–11-year-olds: 2.65% *vs.* 6.35%) than younger children (1.67% *vs.* 3.33%). Younger children showed more pronounced frequency differences than older children and adults for *-n* participles with stem change participles (1.00% *vs.* 9.00%). Older children showed more pronounced frequency differences than younger children and adults for *-n* participles without stem change (3.81% *vs.* 6.67%).

With regard to the questions at the beginning of this section, the error distribution across frequency conditions and age groups does not indicate distinctive patterns according to participle types or age groups. Rather, all groups show fewer errors in high-frequency than low-frequency items, but to different extents for each participle type in the age groups.

	Adults		**Children 7–8**		**Children 9–11**	
	High	**Low**	**High**	**Low**	**High**	**Low**
-t	.09% (.10)	4.25% (.20)	1.67% (.12)	3.33% (.18)	2.65% (.16)	6.35% (.24)
-n/without	11.8% (.10)	11.8% (.10)	4.00% (.19)	4.00% (.19)	3.81% (.19)	6.67% (.25)
-n/with	2.35% (.15)	3.53% (.18)	1.00% (.10)	9.00% (.28)	6.67% (.25)	6.67% (.25)

Table 32: Error rates (S.D.) by age group and experimental condition

These observations were statistically examined. Kolmogorov-Smirnov tests on the participant file and item file revealed $p<.05$ in all conditions, indicating significant deviance from normal distribution and prescribing non-parametric tests. For the adult group, the Wilcoxon test revealed significant differences between error rates in high- and low-frequency *-t* participles ($Z=2.486$, $p=.013$), but not for the child groups (7–8-year-olds: $Z=1.342$, $p=.180$; 9–11-year-olds: $Z=1.807$, $p=.071$). Differences between high- and low-frequency *-n* participles without stem change were not statistically reliable in any group (adults: $Z<.001$, $p=1.00$; 7–8-year-olds: $Z<.001$, $p=1.00$; 9–11-year-olds: $Z=.905$, $p=.366$). For *-n* participles with stem change differences between high- and low-frequency forms reached statistical significance in the older children ($Z=1.994$, $p=.046$), but not in adults or younger children (adults: $Z=.632$, $p=.527$, 7–8-year-olds: $Z<.001$, $p=1.00$).

In sum, differences between high- and low frequency items between participle types reached significance only for *-t* participles in the adult group and *-n* participles with stem change in the older child group. We can only conclude from the error analysis that all participle types in all age groups tend to show lower error rates in high-frequency than low-frequency items. The statistical significance for *-t* participles in adults and *-n* participles with stem change in older children may be a first indication of full-form representation of these forms on an access level. Note, however, that error rates were numerically very small and the results were not clear-cut.

8.2.2 Reaction Times

This section presents an analysis of reaction times with the factors GROUP (7–8-year olds *vs.* 9–11-year-olds *vs.* adults), PARTICIPLE TYPE (*-t* participles *vs.* *-n/without* participles *vs.* *-n/with* participles) and FREQUENCY (high *vs.* low). The analysis focused on the influence of frequency on reaction times in the three participle types and in the three age groups. Following our definition above, frequency effects were defined as significantly shorter reaction times to high-frequency items than to low-frequency items. An 'anti-frequency effect' refers to significantly shorter reaction times to low-frequency items than to high-frequency items. No frequency effect is detected when reaction times for high-frequency and low-frequency items do not differ significantly. The significance of all effects was assessed on a 5% level (α=.05) and *p*-values were reported as two-tailed.

A one-sample Kolmogorov-Smirnov test revealed normal distributions on the participant file and the item file in all conditions ($p>.05$) allowing for parametric ANOVAs and t-tests. Table 33 displays mean reaction times and standard deviations per condition. Overall, we observe that adults (588ms) responded more quickly than children. The 9–11-year-olds (927ms) responded more quickly than the 7–8-year-olds (1089ms). A one-way ANOVA on the log-transformed reaction times confirmed that differences in reaction times between groups are significant ($F_1(2,72)=60.92$, $p<.001$, $F_2(2,74)=315.01$, $p<.001$). Table 33 shows that high-frequency items elicited shorter reaction times than low-frequency items in all participle types and age groups. Difference between high-frequency and low-frequency items were most pronounced for *-t* participles in 9–11-year-olds (233ms) and least pronounced for *-t* participles in 7–8-year-olds (21ms).

	8–9-year-olds	9–11-year-olds	Adults
***-t* high**	1133 (367)	902 (457)	549 (109)
***-t* low**	1154 (380)	1135 (578)	619 (163)
***-n/with* high**	1051 (483)	818 (576)	591 (134)
***-n/with* low**	1176 (389)	988 (373)	628 (151)
***-n/without* high**	889 (328)	726 (372)	564 (130)
***-n/without* low**	1046 (265)	860 (335)	592 (132)
Overall Means	1089 (384)	927 (490)	588 (140)

Table 33: Mean production latencies (S.D.) per condition in ms

In order to assess these observations statistically, a 3x3x2 repeated-measures ANOVA was conducted with the factors group (8–9-year olds *vs.* 9–11-year-olds *vs.* adults), participle type (*-t* participles *vs.* *-n/without* participles *vs.* *-n/with* participles) and frequency (high, low). The by-participant analysis, but not the by-items analysis, yielded a main effect of participle type (F_1(2,144)=33.702, p<.001, F_2(2,32)=.867, p=.430), a main effect of group (F_1(2,72)=11.315, p<.001, F_2(2,64)=.569, p=.533) and a main effect of frequency (F_1(1,72)=118.545, p<.001, F_2(1,32)=.025, p=.877). We also see an interaction of participle type and group (F_1 (4,144)=7.344, p<.001, F_2 (4,64)=8.189, p<.001), an interaction of group and frequency (F_1 (2,72)=5.243, p=.007, F_2 (2,64)=5.694, p=.01) and a three-way interaction of participle type, frequency and group (F_1 (4,144)=5.380, p=.001, F_2 (4,64)=3.528, p=.019). These interactions reveal that reaction times to participle types were differently affected by frequency and that the differences vary in the three age groups. To statistically disentangle the influence of frequency on participle types in the three age groups, 3x2 ANOVAs were performed for each participant group separately.

In the adult participant group, there was a main effect of frequency (F_1(1,33)=38.604, p<.001, n_p^2=.539*,* F_2(1,32)=.345, p=.561, n_p^2=.011), a main effect of participle type (F_1(2,66)=11.046, p<.001, n_p^2=.349, F_2(2,32)=2.639, p=.087, n_p^2=.142) and an interaction of participle type and frequency (F_1(2,66)=3.580, p=.033, n_p^2=.192, F_2(2,32)=1.710, p=.197, n_p^2=.097), all for participants only. Subsequent planned comparisons on mean reaction times between high-frequency and low-frequency items per participle type showed that responses were significantly faster for high-frequency items than for low-frequency items in all participle types (*-t* participles:

$t_1(33)=10.047$, $p<.001$, $d=2.21$, $t_2(16)=1.325$, $p=.204$, $d=.66$, *-n/without* participles: $t_1(33)=2.440$, $p=.02$, $d=.65$, $t_2(8)=.692$, $p=.509$, $d=.044$, *-n/with* participles: $t_1(33)=2.590$, $p=.014$, $d=.70$, $t_2(8)=1.232$, $p=.253$, $d=.79$), again in the participant analysis only. We see that effects in the three participle types go in the same direction and cannot explain the interaction between participle type and frequency. Going back to Table 33 above, however, we see that the interaction arises from a significantly bigger difference between high- and low-frequency items in *-t* participles (70ms) than in *-n* participles with stem change (37ms) or *-n* participles without stem change (28ms).

The analysis has shown significant effects, but only in the by-participant analysis. One reason that the by-item analysis did not yield *p*-values below .05 might lie in the smaller number of items (n=34 for adults) per condition than the number of participants per condition (n=18 for *-t* participles). We have added effect size measures, partial eta squared ($n_p^{2)}$ for the ANOVAs and Cohen's *d* for t-tests, because effect sizes are less affected than *p*-values by small item numbers. The results show for all ANOVAs that effect sizes for items are negligible in contrast to large effect sizes for participants. For *t*-tests, however, Cohen's *d* indicates a medium effect size for *-t* participles ($d=.66$) and a large effect size for *-n* participles with stem change ($d=.79$). The F_1 and t_1 analysis indicates whether the results generalise over the participant group to other members of the same population. The F_2 and t_2 analysis indicates whether results generalise over the item group to other past participles. The $p<.05$ and the high effect sizes in the F_1 analysis indicate that the current results can be generalised to adults other than those tested in the current participant group. By contrast, the $p>.05$ in the F_2 analysis show that the current results for items cannot be generalised to past participles beyond those tested in the current setting. The effect sizes for *-t* participles and *-n* participles with stem change, but not for *-n* participles with stem change, suggest that the non-significant results might be due to small item numbers. Future research will be required to show whether the current patterns extend to more than the past participles used in this study.

For the older child group of 9–11-year-olds, the 3x2 ANOVA revealed in the by-participant analysis a main effect of participle type ($F_1(2,40)=24.472$, $p=.001$, $n_p^2=.550$, $F_2(2,32)=2.218$, $p=.125$, $n_p^2=.122$), a main effect of frequency ($F_1(1,20)=107.798$, $p<.001$, $n_p^2=.844$, $F_2(1,32)=1.005$, $p=.324$, $n_p^2=.030$) but no interaction of participle type and frequency ($F_1(2,40)=2.489$, $p=.108$, $n_p^2=.11$, $F_2(2,32)=.682$, $p=.513$, $n_p^2=.041$). The main effect of participle type shows that 9–11-year-olds respond generally faster to *-n* participles without stem change (mean 793ms) than to *-n* participles with stem change (mean 903ms) and *-t* participles (mean 1,019ms). In accordance with our observations, the main effect of frequency indicates for all participle types that 9–11-year-olds respond faster to high-frequency (mean 815ms) than to low-frequency items (mean 994ms). Considering the non-significant *p*-values and small effect sizes in the by-item analysis, we can only suggest that the results generalise to the participant population of 9–11-year-olds but not to past participles beyond those tested in the current experiment.

For the younger child groups, the 3x2 ANOVA showed in the by-participant analysis a main effect of participle type (F_1(2,38)=10.181, p=.002, n_p^2=.349, F_2(2,32)=1.343, p=.275, n_p^2=.077), a main effect of frequency (F_1(1,19)=13.779, p=.001, n_p^2=.420, F_2(1,32)=1.540, p=.224, n_p^2=.046) and an interaction of the two (F_1(2,38)=4.501, p=.027, n_p^2=.192, F_2(1,32)=3.014, p=.063, n_p^2=.159). As in the adult group, the interaction in the younger child group indicates that word-form frequency affected reaction times differently in the three participle types. Subsequent planned comparisons on the mean reaction times of participle types showed that participants reacted significantly faster to high-frequency than to low-frequency *-n* participles with and without stem change (*-n/with*: t_1(19)=2.730, p=.013, d=.99, t_2(8)=1.601, p=.148, d=1.13, *-n/without*: t_1(19)=-6.877, p<.001, d=1.8, t_2(8)=2.515, p=.036, d=1.78). There was no such difference for reaction times in high- and low-frequency *-t* participles (t_1(19)=.326, p=.748, d=.11, t_2(16)=1.184, p=.254, d=.14).

Our analysis for younger children, like those for adults and older children, has shown significant effects only in the by-participant analysis. The effect-size measurements show negligible effect sizes for items in ANOVAs but large effect sizes for *-n* participles in *t*-tests. These results indicate that *p*-values below .05 for *-n* participles in the t-tests might be due to the small number of *-n* participles.

Taken together, all the groups showed a significant frequency effect for *-n* participles with and without stem change in the by-participant analysis. By contrast, *-t* participles elicited a significant frequency effect in the by-participant analysis only in adults and the 9–11-year-old children. The results for 7–8-year-old children for *-t* participles indicated no statistically reliable influence of frequency on reaction times.

With regard to the questions asked at the beginning of this section, the statistical analysis reveals indications for full-form representation for *-n* participles with and without stem change. The results for *-t* participles also indicate full-form representation but are not stable across age groups. Comparing effects in the three age groups, we find an indication of visual full-form representation of *-t* participles in older children and adults, but not in 7–8-year-olds. The results for *-n* participles indicate that full-form representation is already present in 7–8-year-olds and remains stable in older children and adults.

In the speeded production experiment, we found an influence of WM capacity on participants' production of *-t* participles in 9–11-year-olds. This section investigates whether WM capacity, as measured by the digit-span test, or speed of lexical access, as measured by the individual overall mean reaction times, are also related to the reaction times in the current visual lexical decision experiment. If we find that WM scores and/or speed of lexical access with frequency effects are related to different reaction time patterns in visual lexical decisions, we can infer that WM and/or speed of lexical access capacities influence the recognition of inflected forms. If this is the case, it would be necessary to further assess whether WM capacities and/or speed of lexical access are related to reaction times in the current recognition experiment in the same way as they are related to reaction times in the speeded production experiment described in section 6.2.2.

WM is important in children's learning of words. Only if newly encountered forms are held in WM can they be stored in the mental lexicon (Lauer 2006: 3). One could hypothesise that children with strong WM capacities show a stronger tendency to store forms as full forms, but that children with low WM capacities might be less likely to do this.

We investigated the influence of auditory WM, measured as the score of a digit-span test in children (HAWIK, Tewes 1983) and adults (HAWIE, Tewes 1991), on the reaction times in the experiment. This section considers whether WM was related to reaction times and, if so, whether it affected reaction times differently in the participle types and age groups. We are also interested in whether performance in the digit-span test was related to the speed of lexical access, measured as the individual's average reaction times. As in the procedure used in the speeded production task, the three age groups were divided into subgroups of high and low WM scores on the basis of the median score. For each participant group, WM was then fed as a between-subject factor into repeated-measures ANOVAs with the within-subject factors participle type and frequency.

The analysis did not reveal any significant effects or interactions with WM for 9–11-year-olds (9–11-year-olds: *F*s<1.00, *ps*>.40) nor in the adult group (three-way interaction: $F_1(2,64)=2.053$, $p=.139$, all other *F*s<.1.00, *ps*>.80), indicating no relationship between WM capacities and reaction times in these groups. For 7–8-year-old children, the results showed a three-way interaction of participle type, frequency and WM ($F_1(2,36)=3.848$, $p=.040$), revealing that subgroups of high and low WM differ in the way reaction times to participle types are affected by frequency. The reaction times in 7–8-year-old children per experimental condition are shown in Table 34.

	7–8-year-olds	
	High WM (n=10)	**Low WM (n=10)**
	RT	RT
-*t* high	988 (155)	1290 (255)
-*t* low	1166 (242)	1136 (167)
-*n/with* high	1003 (332)	1097 (421)
-*n/with* low	1059 (220)	1288 (315)
-*n/without* high	803 (165)	976 (297)
-*n/without* low	959 (145)	1127 (187)
Overall	**1012 (163)**	**1176 (205)**

Table 34: Mean production latencies in ms (S.D.) in subgroups of 7–8-year-olds per condition

Table 34 shows that overall reaction times in children with relatively high WM capacity (1012ms) are shorter than those in children with relatively low WM capacity (1176ms). The two groups show similar trends for -*n* participles with and without stem change. The 7–8-year-olds respond faster to high-frequency than to low-frequency -*n* participles with and without stem change. The two groups show opposite trends for -*t* participles. While 7–8-year-olds with relatively high WM capacity exhibit shorter reaction times for high-frequency than for low-frequency -*t* participles, 7–8-year-olds with relatively low WM capacity show longer reaction times for high-frequency than for low-frequency -*t* participles. The difference between high- and low-frequency -*t* participles is more pronounced in the group of high WM children (178ms) than in the group of low WM children (154ms).

Table 34 suggests that differences in WM capacity affect *-t* participles but not *-n* participles. Planned comparisons on the data show that differences between high- and low-frequency *-n* participles without stem change are significant in the by-subject analysis in both 7–8-year-olds with high WM scores (t_1(9)=4.952, p=.001, t_2(8)=1.495, p=.173) and those with low WM scores (t_1(9)=4.754, p=.001, t_2(8)=1.453, p=.184). The difference between high- and low-frequency *-n* participles with stem change reaches significance in the subgroup of low WM (t_1(9)=3.003, p=.015, t_2(8)=2.666, p=.029) but not in the subgroup of high WM (t_1(9)=1.340, p=.213, t_2(8)= 1.465, p=.181). The inverse case applies to *-t* participles: reaction times in high WM children for high-frequency forms are significantly shorter than reaction times for low-frequency forms (t_1(9)=3.058, p=.014, t_2(16)=1.541, p=.143) in the by-subject analysis, but difference in reaction times for *-t* participles in low WM children is not statistically reliable (t_1(9)=1.731, p=.117, t_2(16)=.663, p=.517).

Comparing the findings for WM capacities in the visual lexical decision experiment to those in the speeded production experiment, we can make two observations. First, in both experiments, WM capacities are related to (anti-/)frequency effects observed for *-t* participles but not these of *-n* participles. Second, we observe that high WM subgroups in both experiments show adult-like behaviour while the low WM subgroups show non-adult-like behaviour.

In a second analysis we investigated whether speed of lexical access, measured by individual overall mean production latencies (cf. Clahsen et al. 2004), was related to the recognition of inflected forms. We asked whether and how speed of lexical access was related to reaction times in the experimental conditions; in particular, whether it affected reaction times differently in participle types and age groups. We divided the three age groups into subgroups of relatively fast and relatively slow participants by their median score and entered the two-level factor SPEED (high and low) into a 3x2x2 repeated-measures ANOVA with the factors participle type and frequency separately for each participant group. The analysis yielded no significant interactions with speed, neither in the youngest child group (all Fs<.1.00, all ps>.20) nor the older child group (all Fs<.1.00, ps>.20), nor in the adult group (interaction of participle type and speed F_1(2,64)=1.661, p=.198, all other Fs<.1.00, ps>.70). The 3x2x2 ANOVA provides no indication that frequency affected reaction times differently in the subgroups of slow and fast participants.

8.3 Discussion

The lexical decision experiment investigated access-level representation in the visual recognition of German past participles in children, compared to an adult control group. The main findings of this study are that (i) *-n* participles with and without stem change showed frequency effects in all participant groups, (ii) frequency positively affected reaction times to *-t* participles in all groups, except for younger children with low working memory scores and (iii), developmental changes can be observed from the younger to the older children.

High-frequency *-n* participles (with and without stem change) elicited shorter reaction times than low-frequency *-n* participles (with and without stem change). This finding was consistent across all age groups. We can take the full-form frequency effect as an indication for full-form representations of *-n* participles (with and without stem change) on the access level. This finding can be explained in all current models of word recognition. The frequency effects in the visual lexical decision task are explained similarly to those in the speeded production task (see section 6.3). Yang (2002) explains frequency effects in terms of frequency ranks assigned to items within the same rule class, while models that assume full-form storage for (at least some) inflected forms interpret this finding as a memory effect.

For *-t* participles, we found that high-frequency forms elicited shorter reaction times than low-frequency forms in adults, older children and a subgroup of high-working memory 7–8-year-olds. Similar frequency effects for *-t* and *-n* participles as found for adults, older children and a subgroup of high-working memory younger children were not reported in earlier lexical decision experiments with adults on German past participles by Clahsen et al. (1997) and Neubauer & Clahsen (2009). Clahsen & Neubauer's (2009) result show the same trend in *-t* participles (high 729ms *vs.* low: 746ms) as in *-n* participles (high: 691ms *vs.* low: 748ms), but the difference between *-t* participles (17ms) is much smaller than that between high- and low-frequency *-n* participles (57ms) and is not statistically significant ($t_1(28)= 1.67$, $p = .107$, $t_2(8)= 1.11$, $p = .298$, p. 422). Low working memory 7–8-year-olds behave similarly to participants in previous studies: they do not show a frequency effect for *-t* participles. The lack of frequency effects is usually taken as an indication that forms do not have full-form representations in the mental lexicon. Similar frequency effects for *-t* and *-n* participles, as observed for adults, older children and younger children with high working memory capacity, are compatible with single-system models and with the dual-system model under the assumption that *-t* participles can have additional full-form entries. Single system models can account for results in adults, older children and younger children with high working memory capacity. There is one finding in a subgroup of the current data set that is difficult to explain within a single-system model, namely the dissociation of frequency effects for *-t* and *-n* participles in the subgroup of low working memory children. Single-system theories would predict similar results for all participle types, regardless of working memory capacity (see section 4.3.1). This is only a small aspect of the current data set and one could speculate about how it could be explained within a single-system theory. However, a simple explanation for the dissociation is provided in a dual-processing model. In such a model, *-t* participles are recognised on the basis of their morphological constituents and can have additional full-form entries, while *-n* participles are recognised on the basis of their full-form properties. The results could be taken to indicate that younger children with low working memory capacities have not stored additional full-form representations of *-t* participles on an access level and therefore process them according to their morphological constituents. Younger children with high working memory capacities, as well as older children and adults, have stored additional full-form representations of *-t* participles on an access level. Since lexical decision tasks encourage participants to rely on their memory, these groups recognise *-t* participles through their full-form properties.

Comparing the results from the speeded production experiment and the visual lexical decision experiment on *-t* participles, we can answer the question raised in the introductory remarks to this chapter: full-form representations of *-t* participles do indeed slow down production and speed up recognition. As described in Chapter 4, the dissociation between recognition and production was explained by the fact that the lexical decision task encourages participants to match stimuli against memory and the speeded production task encourages participants to rely on rule-based processing. This interpretation is in line with previous findings from word recognition (e.g. Baayen et al. 1997; Alegre & Gordon 1999) and production (Prasada et al. 1990; Clahsen et al. 2004).

Developmental aspects

The results of the lexical decision experiment discussed above indicate developmental differences between the access-level representation of participles in younger and older children and adults; in consistency with Burani, Marcolini & Stella (2002). First, we observe that young children are generally slower than older children who, in turn, are slower than adults. Second, young children, unlike older children and adults, do not show frequency effects for *-t* participles.

The first of these observations is consistent with the results from the speeded production study and the cross-modal priming study. We attributed these differences to lexical retrieval on the access level in production and on the central level in recognition becoming more efficient as children get older. The current results indicate that this interpretation extends to the retrieval of access-level representations in recognition.

We have argued that frequency effects for *-t* participles, observed in the visual lexical decision experiment, arise from additional full-form representations of *-t* participles on the access level and are in line with a dual-system view. We have seen that younger children with *low* working memory capacity did not show frequency effects in the recognition of *-t* participles, unlike younger children with *high* working memory capacity, older children and adults. The lack of such effects indicates that younger children with low working memory capacity do not access (additional) full-form representations of *-t* participles in word recognition but access decomposed representations of these forms. One suggestion as to why this might be is that they have not yet built additional full-form access-level representations of *-t* participles. One reason may lie in their relatively low working memory capacity, which is known to affect from an early age how children build up their lexicon (e.g. Weinert 2004: 22). Children need to retain the visual or phonological form of a word in working memory to map it onto its meaning and create a new lexical entry (Lauer 2006: 9, 16). Therefore, children with relatively low working memory capacity may store fewer form–meaning mappings in lexical entries than children with relatively high working memory capacity. If some word-forms *can* be represented, but do not *have* to be represented, as full forms, as suggested for regular English past-tense forms by Pinker & Ullman (2002), these, in particular, might be more likely to be represented in children with high working memory capacities but not in children with low working memory capacities.

However, again, we should point out that, for a number of reasons, our data may allow for other interpretations. The effect of working memory was only observed in one subgroup of children in the current data set. Also, working memory is correlated with a number of other cognitive factors. For now, this explanation seems consistent with our data and needs to be further investigated in future research.The current working memory measure only captures one out of many cognitive aspects that could possibly affect processing. It should also be kept in mind that the auditory digit-span test primarily measures auditory working memory and does not specifically test visual working memory (but see section 8.1.1). It is not fully clear why older children revealed no effect of working memory capacity, if it is indeed relevant to building access-level representation of *-t* participles.

9 Summary and Discussion

This thesis has investigated morphological processing in 6–11-year-old child native speakers of German and a control group of adult native speakers. Its focus has been on the role of morphological structure in child processing of German past participles. The empirical basis of the thesis consists of three online experiments, described in Chapters 6, 7 and 8, which addressed the question of how child learners of German represent and process inflected forms. In morphological processing, two levels of representation can be distinguished, the modality-specific access representation and the central representation. It is quite possible that the access-level representation and processing of an inflected form is different from its central-level representation and processing. Two ways of processing morphologically complex forms can be distinguished, storage and morphological computation; in the latter, an inflected form is decomposed into its morphological constituents and possible stems and affixes are identified. To investigate access representations in spoken word production, we used a speeded production experiment. To examine access representations in visual word recognition, we employed an unprimed visual lexical decision experiment. And to investigate central-level representations of inflected forms in word recognition, we used a cross-modal priming experiment. In addition, the subject-level factors working memory (WM, measured by a digit-span test, HAWIK, Tewes 1983, HAWIE, Tewes 1991) and speed of lexical access (measured as the mean overall production latencies time per participant, cf. Clahsen et al. 2004) were measured, to determine any effect they may have on children's morphological processing.

A large amount of evidence has shown that morphological decomposition plays an important role in how adult native speakers process inflected forms on the access level and on the central level. The question remains of children make use of the same mechanisms. One possibility is that child learners process inflected forms in exactly the same way as adult speakers. Alternatively, they might rely more on morphological decomposition of inflected forms if they have not yet formed full-form representations, or they might rely on full-form decomposition if they have not yet analysed an inflected form into its morphological constituents. Against this background, the current study contributes new evidence on morphological processing in children, having addressed the following research questions:

- Which mental mechanisms do children use in morphological processing?
- Are these mental mechanisms similar to those observed in adult morphological processing?
- How do children's processing patterns differ from those of adults?

Table 35 provides an overview of the main findings from the current study, showing the different experimental effects (column 3) between the factors representational level (access level vs. central level, column 1), modality (recognition vs. production, column 2), age group (younger children vs. older children vs. adults, column 4) and participle type (-t vs. -n/without vs. -n/with, columns 5–7). In the columns for each participle type, Table 35 indicates whether the effect given in column 3 was obtained. Below the table, the effects are specified for strength (full priming vs. partial priming effect) and direction (anti-frequency effect).

				Participle types		
Level	**Modality**	**Experimental Effects**	**Age Group**	**-t**	***-n/without***	***-n/with***
Central	Recognition	Priming effects (Cross-modal priming)	Younger children	yes***	no	no
			Older children	yes***	yes**	yes**
			Adults	yes***	yes**	yes**
Access	Production	Frequency effect (Speeded production)	Younger children	no	no	yes
			Older children	High WM: no Low WM: no*	High WM: no Low WM: no*	yes
			Adults	no	no	yes
Access	Recognition	Freqeuncy effect (Visual lexical decision)	Younger children	High WM: yes Low WM: no	yes	yes
			Older children	yes	yes	yes
			Adults	yes	yes	yes

Table 35: Summary of observed experimental effects

*** full priming
** partial priming
* anti-frequency effect

9.1 Representation on the Central Level *Versus* the Access Level

As we can see from Table 35, the results for the central-level representation are different for *-t* participles and *-n* participles (with and without stem change), indicating that *-t* participles are represented according to their morphological constituents while *-n* participles are represented as full forms. These results are consistent with the idea, illustrated in (21), that the central level has a two-way system of representation, in which default forms such as *getanzt* 'danced' are decomposed in terms of their morphemes, i.e. [tanz], [t] and [ge], while *-n* participles as *geschlafen* 'slept' and *gebrochen* 'broken' are represented as whole forms [geschlafen] and [gebrochen].

(21) **Suggested representation of past participles on the central level**

Central level	
[tanz]	[geschlafen]
[t] [ge]	[gebrochen]

The results from the two experiments testing access-level representations of *-n* participles with stem change unequivocally indicate that these are represented as full forms. The results on the access-level representations of *-t* participles suggest that they can be accessed *either* on the basis of their morphological constituents (as in adults and young children in the speeded production experiment and for young children with low working memory capacities in lexical decision experiment) *or* on the basis of their full-form properties (in older children in the speeded production experiment and in older children and adults in the lexical decision task). The results for the access-level representations of *-n* participles without stem change similarly indicate that these participles can be accessed either on the basis of their morphological constituents (in adults and young children in the speeded production experiment, in young children with low working memory capacities in lexical decision) or on the basis of their full-form properties (in older children in the speeded production experiment, in all age groups in the lexical decision task). The current results for the access-level representation of *-n* participles without stem change and for *-t* participles seem similar. They show different effects only for the subgroup of young children with low working memory capacity in the lexical decision experiment. The easiest interpretation of the results would be that *-n* participles without stem change and *-t* participles are represented alike. However, similar effect patterns might come from different sources. Significant indications about this possibility come from previous experiments on access-level representations of German past participles. The studies reviewed in chapters 6 and 8 indicated full-form representations for *-n* participles without stem change and decomposed representations of *-t* participles on the access level (e.g. Clahsen et al. 1997; Neubauer & Clahsen 2009). The decompositional effects for *-t* participles in the current study are in line with previous research. Full-form frequency effects for *-t* participles have not been reported before, but they are in line with storage effects reported by Alegre & Gordon (1999) on the English regular past tense, and consistent with Pinker's (1999) theoretical account of full-form effects in default forms. He suggested that the rule-based processing of default forms, such as *-t* participles, leaves memory traces. In this view, the rule-based process for individual default forms is stored. For example, memory traces for a high-frequency form as *getanzt* 'danced' provide the information that the stem *tanz* 'dance' is joined with the *-t* suffix to form the past participle form *getanzt*. A slightly different explanation would be that high-frequency *-t* participles have additional full-form representations on the access level, similar to those of *-n* participles with stem change (cf. Alegre & Gordon 1999). In this case, *getanzt* 'danced' would be stored as [getanzt]. The current data set does not allow us to decide between these two suggestions but, crucially, both scenarios assume that access to *-t* participles involves access to memory.

In line with these suggestions, we found indications that the representation and processing according to the full-form representation of *-t* participles on the access level is related to working memory capacity. Effects of working memory were found in experiments testing access-level representation, but not in the cross-modal priming experiment testing central-level representation. Also, subgroups of high and low working memory children differed in their behaviour towards *-t* participles but not towards *-n* participles. To explain these results, we suggested that children with low working memory capacity build fewer lexical entries than children with high working memory capacity, since children's working memory capacity plays a role in lexical development. We further suggested that working memory might be important during online processing when two representations of a default form need to be held active in parallel, i.e. the decomposed representation and the full form. One should note, however, that the digit-span test is only *one* measure of *one* cognitive feature, and there are many others that play a role in lexical development and language processing. More research on this topic is required before the association between cognitive capacities and language development is clearly understood.

The full-form effects in the visual lexical decision experiment for *-n* participles without stem change are consistent with previous results. However, similar production latencies for low-frequency and high-frequency *-n* participles without stem change in the speeded production task have not been reported before. They are consistent with the suggestion, introduced in section 3.2.1, that the representation of *-n* participles without stem change encodes morphological structure, as suggested by Clahsen et al. (2003) for transparently derived forms. In accordance with this suggestion, the access level hosts the representation of *geschlafen* as a full form and this representation indicates the morphological constituents [ge], [schlaf] and [en], yielding a representation such as [[ge][schlaf][en]].

The suggested interpretation of results for the access level is consistent with the idea that it has a two-way system of representation, as shown in (22) below. In this view, participles with *-t* suffix are decomposed into morphemes and additionally leave memory traces of the full form. Both *-n* participles with and without stem change are represented as whole forms. Meanwhile, *-n* participles without stem change have an encoded morphological structure.

(22) **Suggested representation of past participles on the access level**

Access level	
[t] [tanz] [ge]	[[ge][schlaf] [en]]
(memory traces of) [getanzt]	[gebrochen]

Overall, our results are consistent with the suggestion that the central level and the access level have a two-way system of representation of past participles. Access to memory for high-frequency *-t* participles on the access level affects recognition and production differently, a fact that will be discussed in more detail in the next section.

9.2 Explaining Differences Between Production and Recognition

In the literature review, we observed an asymmetry of experimental effects between previous production experiments and recognition experiments (see section 4.4). High-frequency default forms, such as *-t* participles, elicited longer production latencies in production tasks than low-frequency default forms (e.g. Prasada et al. 1990; Clahsen et al. 2004). In recognition tasks, if a difference is found, it is that high-frequency default forms have shorter reaction times than low-frequency default forms (e.g. frequency effect: Alegre & Gordon 1999; no frequency effect: Neubauer & Clahsen 2009). As explained in section 4.4.1, Pinker suggests that the expected frequency disadvantage arises from an interaction between rule route and memory access in production. In his view, full-form access slows down the rule. High-frequency default forms, whose full-form properties are represented in memory, are slowed down relative to low-frequency default forms, whose full-form properties are not represented in memory. However, in recognition, the two routes do not inhibit each other but work in parallel until the target entry is identified. Following Pinker's (1999) explanation of the anti-frequency effect for regular forms, we hypothesised that high-frequency *-t* participles elicit longer *production* latencies than low-frequency *-t* participles but should elicit shorter *recognition* times than low-frequency *-t* participles in visual lexical decision experiments. Meanwhile, forms which are accessed solely as full forms should show a frequency advantage in both recognition and production.

Our results in the two experiments on access level representations corroborate predictions for *-t* participles and *-n* participles with stem change. The combined results for *-t* participles and *-n* participles with stem change in the lexical decision and speeded production experiments can thus be taken to suggest that Pinker's (1999) hypothesis reflects real aspects of morphological processing in production. However, contradicting that hypothesis, *-n* participles without stem change did not behave similarly in recognition and production. We need to evaluate more thoroughly the methodological aspects of the speeded production task and the visual lexical decision task to investigate the different effects for *-n* participles without stem change in recognition (visual lexical decision) and production (speeded production). The presentation order of the verb stimuli was different in the visual lexical decision experiment and the speeded production experiment, which may explain why *-n* participles without stem change behave differently in those tasks. In speeded production, participants listen to the verb stimulus (containing the unmarked stem) *before* they produce the past participle form. In the visual lexical decision experiment, participants are not presented with a stem before the participle form but *only* process the participle form. The presentation of the stem of *-n* participles without stem change could activate morphological subparts of a combinatorial entry, such as [schlaf] in [ge-[schlaf]-en], thus encouraging combinatorial processing of the target form. In the visual lexical decision task the participle is processed in isolation, so it cannot be affected directly by any prior presentation of the stem. The fact that only *-n* participles without stem change but not those with stem change show different behaviour in recognition and production could also be due to form differences. The stem of the verb stimulus is fully contained in the *-n* participles without stem change but not in those with stem change. Coming back to our suggestion above, the auditory presentation of the verb stimulus activates the stem in structured lexical entries of *-n* participles without stem change, e.g. [schlaf] activates [ge-[schlaf]-en], but the stem of *-n* participles with stem change does not similarly activate the stem of *-n* participles with stem change. If, as our results from the visual lexical decision experiment suggest, *-n* participles with stem change are represented as full forms with no encoded morphological structure, the participle stem is not specifically marked in the lexical entry [geliehen]. The stem is only marked in a structured representation like [ge-$[\text{schlaf}]_V$-en], as we suggested for *-n* participles without stem change. In any case, the stem [leih] 'borrow' activates the participle form [ge-[lieh]-en] 'borrowed' to a lesser extent than [schlaf] 'sleep' activates [ge-[schlaf]-en] 'slept' because the amount of phonological form shared between stem and participle is less in *-n* participles with stem change than in those without. One difficulty with this explanation is that it does not account for the *anti*-frequency effect for *-n* participles without stem change, which was observed in the subgroup of 9–11-year-old children with low WM. A representation like [ge-$[\text{schlaf}]_V$-en] may elicit a reduced frequency effect, but it is not clear why it should elicit an anti-frequency effect. Pinker's explanation of the anti-frequency effect for default forms revolves around the idea that the two processing routes inhibit each other. An alternative way to account for this observed anti-frequency effect in the speeded production task would be to suppose that participants have activated the rule-based route. They may have automatically applied the participle default rule to any auditorily presented stems as if those stems were non-words. In the case of *-n* participles *with* stem change, the stem and suffix of an overregularised form do not match the target, so participants might detect the error at an early stage of production. Rule-based processing is turned off and the full-form entry is accessed. In the case of *-n* participles without stem change, the overregularised, rule-based form and the target form are very similar, differing only in the suffix.

When the rule is active, participants "monitor the internal phonological output and intercept potential errors" (Levelt 1999: 226) to detect the mistake and search for the full-form representation of *-n* participles without stem change. Once the two routes are active, the full-form entry slows down the rule-based process and provides the correct form. The production latencies for high-frequency items may be slowed down more for high- than for low-frequency items because high-frequency representations slow down the rule more than low-frequency representations. This explanation remains purely speculative for now and would have to be more closely examined in future research.

On a methodological note, we have mentioned the potential confounds in testing *-n* participles without stem change and *-n* participles with stem change in a speeded production task. Obviously the same methodological concerns apply to *-t* participles because, like *-n* participles without stem change, *-t* participles fully contain the stem of the verb stimulus. We do not know from our speeded production experiment alone whether the similar behaviour of *-t* participles and *-n* participles without stem change originates from similar representation and processing strategies. It was therefore important that we had considered the behaviour of *-t* participles and *-n* participles without stem change in other experiments and in previous research. We do not know whether the discrepancy between *-n* participles with and without stem change is specific to our speeded production experiment or can also be found in previous such experiments. This is because previous studies have not differentiated between *-n* participles with and without stem change. It is possible that the reported frequency effect for *-n* participles in previous studies was carried by the subgroup of *-n* participles with stem change and that the subgroup of *-n* participles without stem change shows similar patterns as in our experiment. This concern applies even more strongly to previous speeded production tasks of English past-tense forms. In these studies, regular past-tense forms, such as [walk[-ed]], fully contain the verb stimulus [walk], while irregular past-tense forms, such as [brought], do not contain the verb stimulus [bring] and are in most cases not even transparently analysable into stem and affix. Future research should use this particular design of the speeded production method only to compare forms which have the same amount of phonological overlap between stem and inflected target form.

9.3 Representation of Participle Types

The results for *-n* participles with stem change in the three experiments provide consistent evidence of full-form representation and processing on both the access and the central level. We found no indication that morphological structure was relevant in processing or representation of *-n* participles with stem change.

The results for *-t* participles in the three experiments indicated that these participles are processed according to their morphological properties on the central level and that their full-form properties can be represented on the access level in addition to their morphological constituents. These full-form representations inhibited production and speeded up recognition. These results are consistent with the assumption that *-t* participles are directly accessed via their full-form representations in recognition, so full-form frequency positively affects recognition. They are further consistent with the hypothesis that *-t* participles are formed via the default rule in production, and that full-form representations of *-t* participles inhibit the default rule (cf. Pinker 1999).

For *-n* participles without stem change, we suggested that they are represented as full forms on the central level. Their morphological structure may be represented on the access level, like combinatorial lexical entries for transparently derived forms (cf. Clahsen et al. 2003). This, however, raises the question of why *-n* participles without stem change such as *geschlafen* 'slept' elicited anti-frequency effects in the speeded production experiment, at least for one subgroup of older children with low WM. The alternative suggestion, that the anti-frequency effect for *-n* participles without stem change is a task-specific effect, does not require morphological encoding but degrades the anti-frequency effect for *-n* participles without stem change to an experimental artefact of the speeded production task.

9.4 Developmental Aspects of Children's Processing of Inflected Forms

We will now summarise our findings from subgroups of children whose behaviour deviated in specific ways from that of adults. We will then discuss what these results tell us about how morphological processing develops in children. Non-adult-like behaviour was revealed in four instances. First, children responded slower and made more errors in their responses than adults. Second, in the visual lexical decision experiment, 7–9-year-old children with low working memory did not show any influence of full-form frequency on the visual recognition of *-t* participles. Third, 9–11-year-olds with low working memory showed anti-frequency effects for *-t* participles and *-n* participles without stem change. Fourth, 7–9-year-old children showed no priming effect for *-n* participles in the cross-modal priming experiment.

Children produced more errors than adults in all experiments. In the visual lexical decision and cross-modal priming experiments, in which an incorrect response is always an incorrect button press, the speeded production experiment allows the analysis of different types of erroneous responses. In this experiment, children overregularised the *-t* suffix and the unmarked stem to verbs which require the *-n* suffix and marked stems. The contrast found for errors in *-t* and *-n* participles in children's production is consistent with the studies reviewed in section 3.3 testing children's spontaneous and elicited production of German past participles. This contrast also occurs in adults' production of inflected nonce words. In a production experiment by Clahsen (1997), participants were presented with simple past forms or infinitive forms and were asked to fill in a blank with a participle form for each nonce verb. The participants applied the *-t* suffix to nonce 'regular nonce words', which were phonologically similar to existing regular verbs, and to 'irregular nonce words', which were phonologically similar to existing irregular verbs. They rarely applied the *-n* suffix to 'regular nonce words'. Hence, both adults and children use the *-t* suffix but not the *-n* suffix productively. In the current three experiments, children were generally slower to respond than adults but their response patterns exhibited considerable similarities to adults' reaction times in all experiments. As can be seen from Table 35 above, children's reaction times in the visual lexical decision experiment and their production latencies in the speeded production experiment were affected similarly by the factors participle type and frequency as those of adults in the two experiments. As an exception to this picture, one subgroup of 9–11-year-old children with low working memory produced an anti-frequency effect for *-n* participles without stem change and *-t* participles, unlike adults, whose production latencies were not affected by frequency in this condition (see discussion above). The observed similarities between adults and children suggest that generally slower reaction times and higher error rates in children do not indicate fundamental differences between adults and children. Following the suggestion that overregularisation occurs when the irregular word form is not successfully retrieved, the overall higher error rate in the child groups might be a result of less accurate and slower lexical retrieval and a lexicon that has not yet been fully elaborated. The overall slower reaction times of children and their overall higher error rate could be due to their generally less accurate and slower lexical retrieval (cf. Clahsen et al. 2004).

The group of 7–11-year-olds with low working memory showed no frequency advantage for *-t* participles in the visual lexical decision experiment, unlike 7–9-year-old children with high WM. At the same time, all subgroups of 7–9-year-olds showed full-form frequency effects for *-n* participles with and without stem change. The frequency advantage for *-t* participles in 7–9-year-old children with high working memory shows that children of this age *can* access full-form representations in the recognition of *-t* participles, but the lack of full-form frequency effects, we concluded in section 6.3, indicated that younger children did not do so. We attribute this difference to the fact that 7–9-year-old children with low working memory have not yet built visual full-form access representations of *-t* participles but the same age group of children with high working memory have done so. This result might be taken to suggest that working memory is somehow relevant in the development of mental representations of *-t* participles (cf. section 8.38.3). Children with high working memory capacity may be more likely to hold the incoming information sufficiently long in working memory to create access-level representations in the mental lexicon than children with low working memory capacity, who may, instead, use representations of smaller stored entities of the word. The results from speeded production in 6–8-year-olds are in line with this suggestion. We argued that this age group showed no frequency effect for *-t* participles because, unlike adults, they did not have full-form representation of such participles and relied on their morphemic representation in production. In the light of two converging pieces of evidence from production and recognition, we argue that younger children do indeed rely on morphemes in access-level recognition and access-level production of *-t* participles.

9–11-year-old children with low working memory showed a frequency disadvantage for *-t* participles in the speeded production task. We argued in section 6.3 that 9–11-year-olds represent *-t* participles according to their constituents *and* as full forms. We now bring these suggestions from the speeded production experiment together with results from the visual lexical decision experiment. In the visual lexical decision experiment, adults and 9–11-year-olds show a frequency advantage for *-t* participles, indicating that these groups consult full-form access-level representations for *-t* participles. The speeded production experiment and the visual lexical decision experiment therefore indicate that 9–11-year-olds access *-t* participles via their full-form properties on the access level in both production and recognition.

The observed effects in the recognition and production of *-t* participles add to our discussion on how working memory might affect the representation and processing of *-t* participles on access level in 9–11-year-olds. The results from the speeded production experiment indicate that full-form representations of *-t* participles significantly inhibited rule-based production in 9–11-year-old children with low working memory capacity. The results from the visual lexical decision experiment indicate no differences between the number of full-form representations of *-t* participles in 9–11-year-old children with low working memory capacity and children in the same age-group with high working memory capacity. We therefore suggest that low working memory in 9–11-year-olds leads to inhibition of rule-based processing of *-t* participles but is not associated with fewer full-form representations of *-t* participles on the access level (as in 7–8-year-olds' recognition).

7–9-year-old children showed no priming effects for *-n* participles with and without stem change in the cross-modal priming experiment. In connection with this finding, we suggested in section 7.3 that all age groups represent *-n* participles as full forms in the mental lexicon but that the lexicon is continuously elaborated and associations between full-form entries grow stronger in the course of language development. The visual lexical decision and speeded production experiments investigate access-level representations and the results suggest that *-n* participles are already represented as full forms in younger children. Lexical decision reaction times to *-n* participles were generally longer in younger children than in older children, which has been taken to indicate that memory storage and lexical retrieval depend on language experience and become more stable and reliable as children get older. The results from speeded production also support this interpretation in that younger children, like older children, showed clear full-form storage effects, at least for *-n* participles with stem change, but younger children showed generally longer production latencies than older children. Thus, we conclude that *-n* participles are represented as full forms on the central level in all age groups and the lexical representations of *-n* participles become more elaborate over time, leading to faster retrieval. Associations between full-form representations of *-n* participles and other inflected forms on the central level are strengthened by exposure, with the result that activation spreads more explicitly between representations.

Comparing these three conclusions about the processing of *-t* and *-n* participles in younger and older children, we note that these participles show different patterns not only in adult processing but also in how they develop in child processing: the purely rule-based processing of *-t* participles in young children on the access level is increasingly influenced by the representation of full-form properties of *-t* participles. By contrast, *-n* participles are processed from an early age as full forms, as by adults, and only change in the light of a maturing mental lexicon.

9.5 Evaluating Theoretical Approaches to Processing

Different theories have been proposed to account for processing differences between inflectional types. These theories differ in the processing effects they predict for inflectional types, as summarised in Chapter 4. Based on models of full-form representation, connectionist single-system theories have suggested that all inflected forms are processed via the same processing mechanisms. Differences in the processing of inflectional types are explained by differences in form and semantic codes (e.g. Sereno & Jongman 1997, Seidenberg & McDonald 1999, McClelland & Patterson 2002). Our experiments were designed to test these assumptions. Semantic relations were held constant and form differences were incorporated as fixed factors in all the experiments. Although the results for *-n* participles without stem change and *-n* participles with stem change differed in the speeded production experiment (but see comments above), we argued that the full set of results from all three cannot be explained by differences in form. In particular, the results from the cross-modal priming task showed that form differences between *-n* participles with stem change and the inflected forms, compared to those between *-n* participles without stem change and the inflected forms, did not lead to different priming effects. Furthermore, the single-system associative model cannot explain our observation that *-t* and *-n* participles were differently affected by working memory and lexical maturation during processing development. Finally, the discrepancy between the recognition and production of *-t* participles and the observed anti-frequency effect is difficult to explain with a connectionist account, because frequency should always speed up processing. For these reasons, we are not convinced that a connectionist single-system view can best explain the present results.

Similarly, a rule-based single-system model (e.g. Taft & Forster 1975; Halle & Mohanan 1985; Yang 2002; Rastle & Davis 2008) cannot adequately account for the present results. In these models, an automatic parsing process decomposes all word forms into stems (e.g. [mach]) and affixes (e.g. [te]) based on their formal surface properties. A rule-based model predicts parallel behaviour by *-t* and *-n* participles because these participles are acquired and processed via rules. Participles are predicted to show no frequency or full decomposition effects because all inflected forms are decomposed and recognised via their stems. Rule-based decomposed processing was explicitly tested in the cross-modal priming experiment and showed clear dissociations between *-t* and *-n* participles and in the course of development. The rule-based model also predicts that processing development of participles, as a rule-learning task for all participles, should be similarly affected by working memory and lexical maturation. Finally, the rule-based account cannot explain different effects of frequency in recognition and production. In a rule-based single-system view, any factor that affects participles in production should do the same in recognition. The rule-based theory thus cannot fully explain the current data set.

Other researchers have proposed different processing and mental representations for default and non-default forms. The dual-system model of processing as proposed by Pinker (1999) and Clahsen (1999) distinguishes between combinatorial processing and full-form processing, but allows for additional full-form representations of default forms (Pinker 1999; Clahsen et al. 2004). This model holds that the processing of default forms (*-t* participles) and non-default forms (*-n* participle with and without stem change) are fundamentally different, in that only default forms are subject to combinatorial processes, while the processing of *-n* participles, it is suggested, relies on full-form representations. Thus, *-t* participles, but not *-n* participles, should show decompositional effects, while *-n* participles should show full-form processing effects. The observed *-t*/*-n* differences reported for the central-level representations are indeed consistent with this account. Effects consistent with the decomposition of default *-t* participles were observed in all experiments, at least in some groups of participants; the *-t* participles tested showed full priming effects in cross-modal priming in all age groups. They showed no frequency advantage in speeded production in younger children and adults, nor in lexical decisions in a subgroup of low working memory 7–8-year-olds. The full-form processing effects were also found for *-t* participles and were explained by the representation of full-form properties on the access level.

Meanwhile, the results for *-n* participles with and without stem change showed indications of full-form representations, e.g. partial priming effects in recognition and full-form frequency effects in visual recognition and production (at least for *-n* participles with stem change). Influence of morphological structure on the processing of *-n* participles without stem change was found in the speeded production study. We suggested two explanations for this finding, both of them requiring that *-n* participles without stem change are represented as full forms on the access level. It was further argued that *-n* participles were represented as full forms on the central level, because the results of the cross-modal priming experiment showed only a partial priming effect. The results further indicated that the processing of *-t* and of *-n* participles develops differently in children: *-t* participles are processed using rules from an early age and are increasingly influenced by the representation of full-form properties, while-*n* participles are processed as full forms from an early age and associations between full-form representations grow stronger with age.

Taken together, the results reflect a three-way distinction. On the central level, *-t* participles are represented in terms of their morphological constituents while *-n* participles are represented as whole forms. On the access level, *-t* participles are represented in terms of their morphological constituents and, additionally, in terms of their full-form properties. At the same time, *-n* participles without stem change have full-form central and access-level representations, possibly encoding morphological structure, and *-n* participles with stem change have full-form central and access-level representations without morphological structure. Distinct processing patterns for *-t* and *-n* participles in processing and development support the existence of a dual-structure morphological processing system.

9.6 Limitations of the Current Study and Future Research

The current thesis has gathered evidence on children's morphological performance by taking online and offline measures from reaction time experiments. These methods could be supplemented by techniques which take measures other than reaction time and error rate, such as event-related potentials, eye-tracking and brain imaging techniques. They could be further supplemented by offline techniques such as grammaticality judgments and spontaneous speech analysis.

In addition, the current study focused on children of primary school age because the tasks used required the children to read. It would also have been interesting to include preschool and middle-school children; for the former, new methods would have had to be adopted. A broader age range in the child participant group would have enabled the comparison of children at more widely separated developmental stages.

We investigated children's age and full-form frequency, which are continuous in nature. We analysed the factors using analyses of variance which does not allow for analysing continuous variables but requires categorical factors. We therefore dichotomised frequency into groups of high and low frequency forms and children into groups of younger and older children. Using mixed-effects regression models would have enabled us to analyse frequency and age as continuous factors.

Finally, we used the linguistic phenomenon of German past participles to investigate morphological processing. However, morphological processing also includes derivation and compounding. Including other linguistic phenomena – one or both of these morphological domains – would have allowed us to generalise beyond the morphological domain of inflection.

10 References

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11 Appendix

Appendix 1: Speeded Production Experiment: Critical Items

Verb Type	Sentential Context	Verb Stimulus	Target Word
-*t* participle	Die Frau hat Blumen…	schicke	geschickt
-*t* participle	Der Frosch hat die Fliege…	störe	gestört
-*t* participle	Das Schwein hat in den Stall ...	gucke	geguckt
-*t* participle	Die Maus hat die Kekse…	zähle	gezählt
-*t* participle	Das Pferd ist auf der Straße …	stürze	gestürzt
-*t* participle	Der Musiker hat die Gitarre ...	tausche	getauscht
-*t* participle	Das Bonbon hat in der Tasche…	stecke	gesteckt
-*t* participle	Die Kuh hat im Stall…	wohne	gewohnt
-*t* participle	Der Affe hat im Baum …	lache	gelacht
-*t* participle	Das Mädchen hat die Süßigkeiten…	spare	gespart
-*n/without*	Der Jogger ist auf der Bahn…	falle	gefallen
-*n/without*	Der Schüler hat die richtige Antwort…	rate	geraten
-*n/without*	Der Vater hat das Kind …	messe	gemessen
-*n/without*	Der Junge hat die Bonbons …	fangen	gefangen
-*n/without*	Das Eichhörnchen ist im Wald…	wachse	gewachsen
-*n/without*	Die Ente hat das Krokodil ...	stoße	gestoßen
-*n/without*	Das Auto hat die Bälle…	lade	geladen
-*n/without*	Der Roboter hat den Stein…	esse	gegessen
-*n/without*	Das Mädchen hat auf dem Spielplatz…	schlafe	geschlafen
-*n/without*	Der Frosch hat den Löwen…	fresse	gefressen

Appendix 1 (cont.): Speeded Production Experiment: Critical Items

Verb Type	Sentential Context	Verb Stimulus	Target Word
-n/with	Das Baby ist im Bett ...	bleibe	geblieben
-n/with	Der Junge hat den Luftballon…	ziehe	gezogen
-n/with	Der Junge ist in den Kreis…	steige	gestiegen
-n/with	Der Frosch hat die Ente...	treffe	getroffen
-n/with	Der Affe hat den Ball…	schieße	geschossen
-n/with	Der Vater hat das Hemd …	greife	gegriffen
-n/with	Der Koch hat auf dem Brett…	stehe	gestanden
-n/with	Der Matrose hat das Boot…	schiebe	geschoben
-n/with	Das Mädchen hat das Papier ...	reiße	gerissen
-n/with	Die Eule hat im Käfig…	schreie	geschrien

Appendix 2: Speeded Production Experiment: Word Form Properties of Critical Items

Verb Type	Target Word	(Spoken) Word-Form	(Spoken) Verb-Stem	(Spoken) Participle-Stem	Participle letters	Participle syllables	Participle phonemes	Stem letters	Stem syllables
-t	*geschickt* 'sent'	17	29	29	9	2	6	9	2
	gestört 'disturbed'	17	39	39	7	2	7	4	1
	geguckt 'looked'	9	26	26	8	2	7	5	1
	gezählt 'counted'	7	44	44	7	2	6	4	1
	gestürzt 'fallen'	7	22	22	8	2	8	5	1
	high frequency mean	**11.4**	**32**	**32**	**7.8**	**2**	**6.8**	**5.4**	**1.2**
	getauscht 'changed'	7	20	20	9	2	6	6	1
	gesteckt 'stuck'	5	68	68	8	2	7	5	1
	gewohnt 'lived'	5	34	34	7	2	6	4	1
	gelacht 'smiled'	3	61	61	7	2	6	4	1
	gespart 'saved'	3	34	34	7	2	7	4	1
	low frequency mean	**4.6**	**43.4**	**43.4**	**7.6**	**2**	**6.4**	**4.6**	**1**
-n/ without	*gefallen* 'fallen'	34	68	68	8	3	7	6	2
	geraten 'geraten'	26	40	40	7	3	7	5	2
	gemessen 'measured'	24	43	43	8	3	7	3	1
	gefangen 'caught'	20	63	63	8	3	7	4	1
	gewachsen 'grown'	15	27	27	9	3	8	5	1
	high frequency mean	**23.8**	**48.2**	**48.2**	**8**	**3**	**7.2**	**4.6**	**1.4**
	gestoßen 'pushed'	15	27	27	8	3	8	4	1
	geladen 'loaded'	10	24	24	7	3	7	3	1
	gegessen 'eaten'	9	101	101	8	3	7	2	1
	geschlafen 'slept'	7	29	29	10	3	8	6	1
	gefressen 'eaten'	2	9	9	9	3	8	4	1
	low frequency mean	**8.6**	**38**	**38**	**8.4**	**3**	**7.6**	**3.8**	**1**

Appendix 2 (cont.): Speeded Production Experiment: Word Form Properties of Critical Items

Verb Type	**Target Word**	**(Spoken) Word-Form**	**(Spoken) Verb-Stem**	**(Spoken) Participle-Stem**	Participle letters	Participle syllables	Participle phonemes	Stem letters	Stem syllables
-n/ with	*geblieben* 'stayed'	48	534	71	9	3	8	5	1
	gezogen 'drawn'	39	94	60	7	3	7	4	1
	gestiegen 'increased'	36	83	41	9	3	8	5	1
	getroffen 'met'	36	97	36	9	3	8	5	1
	geschossen'shot'	15	52	20	10	3	7	6	1
	high frequency mean	**34.8**	**172**	**45.6**	**8.8**	**3**	**7.6**	**5**	**1**
	gegriffen 'grabed'	12	39	19	9	3	8	5	1
	gestanden 'stood'	10	1048	128	9	3	9	4	1
	geschoben 'push'	9	21	19	9	3	7	6	1
	gerissen 'ripped'	7	19	12	8	3	7	4	1
	geschrien 'cried'	5	20	7	9	2	6	6	1
	low frequency mean	**8.6**	**229.4**	**37**	**8.8**	**2.8**	**7.4**	**5**	**1**

Appendix 3: Speeded Production Experiment: Filler Items

Item Type	Target Sentence + Target Item	Verb Stem
061a	Das Nashorn hat das Gitter verbogen	verberge
062a	Der Löwe hat die Wurst zerbissen	zerbeisse
063a	Die Großmutter hat die Torte eingefroren	einfriere
064a	Das Mädchen hat der Puppe die Augen verbunden	verbinde
065a	Das Eichhörnchen hat die Nuß vergraben	vergrabe
066a	Der Schüler hat die Rechenaufgabe begriffen	begreife
067a	Der Kellner hat die Gläser festgehalten	festhalte
068a	Der Kaspar hat den Clown verhauen	verhaue
069a	Das Flugzeug hat von der Startbahn abgehoben	abhebe
070a	Der Mann hat den LKW beladen	belade
071a	Der Matrose hat das Schiff verlassen	verlasse
072a	Das Schaf hat sich im Wald verlaufen	verlaufe
073a	Der Radfahrer hat einen Unfall erlitten	erleide
074a	Der Arzt hat die Medizin verschrieben	verschreibe
075a	Der Spion hat den König verraten	verrate
076a	Der Koch hat den Käse zerrieben	zerreib
077a	Die Frau hat sich die Haare abgeschnitten	abschneide
078a	Die Sonne hat die Kirche beschienen	bescheine
079a	Der Vater hat den Schrank abgeschliffen	abschleife
080a	Der Bär hat das Würstchen verschlungen	verschlinge
081a	Der Zwerg hat die Goldmünzen eingeschmolzen	einschmelze
082a	Der Wespenstich hat den Arm angeschwollen	anschwelle
083a	Der Dieb ist ins Haus eingebrochen	einbreche

Appendix 3 (cont.): Speeded Production Experiment: Filler Items

Item Type	Target Sentence + Target Item	Verb Stem
084a	Die Oma hat ihrem Enkel Bonbons versprochen	verspreche
085a	Das Mädchen hat den Pulli ausgewrungen	auswringe
086a	Der Verbrecher hat den Richter bestochen	besteche
087a	Der Wanderer hat den Turm bestiegen	besteige
088a	Der Großvater hat das Brötchen mit Honig bestrichen	bestreiche
089a	Der Polizist hat das Auto angeschoben	anschieb
090a	Die Sängerin hat die Liebe besungen	besinge
091a	Der Elefant hat im Dschungel trompetet	trompete
092a	Die Ärztin hat den Kranken besucht	besuche
093a	Der Delphin ist vom Schiff weggetaucht	wegtauche
094a	Der Vogel hat die Flügel ausgebreitet	ausbreite
095a	Der Igel hat sich beim Wettrennen beeilt	beeile
096a	Der Vater hat den Stuhl zusammengeklappt	zusammenklappe
097a	Das Mädchen hat das Fenster beklebt	beklebe
098a	Der Postbote hat bei der Frau angeklopft	anklopfe
099a	Die Großmutter hat die ganze Fußballmannschaft bekocht	bekoche
100a	Der Opa hat das Tanzen verlernt	verlerne
101a	An der Kreuzung ist ein Unfall passiert	passiere
102a	Der Astronaut hat das Raumschiff repariert	repariere
103a	Die Banane ist in dem Rucksack zerquetscht	zerquetsche
104a	Die Mutter hat den Brief verschickt	verschicke
105a	Der Affe hat den Zaun beschmiert	beschmiere
106a	Die Lehrerin hat den Schüler bestraft	bestrafe
107a	Die Oma hat ihre Tasche vertauscht	vertausche

Appendix 3 (cont.): Speeded Production Experiment: Filler Items

Item Type	Target Sentence + Target Item	Verb Stem
108a	Der Magier hat das Königskind verzaubert	verzaubere
109a	Die Mutter hat den Kuchen eingewickelt	einwickele
110a	Der Luftballon ist auf der Herdplatte zerplatzt	zerplatze
111a	Der Weihnachtsmann hat das Geschenk verpackt	verpacke
112a	Die Sekretärin hat den Besucher angemeldet	anmelde
113a	Der Affe ist an der Palme hochgeklettert	hochklettere
114a	Der Großvater hat die Zwillinge verwechselt	verwechsele
115a	Die Katze hat die Wolle abgerollt	abrolle
116a	Der Hase hat die Erdbeeren zermatscht	zermatsche
117a	Der Junge ist die Treppe hochgetrampelt	hochtrampele
118a	Die Wolke hat die Sonne verdeckt	verdecke
119a	Die Lehrerin hat das Verkehrszeichen erklärt	erkläre
120a	Der Pirat ist von der Insel weggerudert	wegrudere

Appendix 4: Speeded Production Experiment: Practice Items

Item Type	Sentential Context + Target Item	Verb Stem
ueb1a	Die Tänzerin ist im Kreis gehüpft	hüpfe
ueb2a	Der Bäcker hat auf den Tisch gekleckert	kleckere
ueb3a	Die Bäuerin hat die Kuh gemolken	melke
ueb4a	Der Mann hat am Fluß geangelt	angele
ueb5a	Der Clown hat ein Buch gelesen	lese
ueb6a	Der Verbrecher hat viel Geld gedruckt	drucke
ueb7a	Der Schiedsrichter hat den Spieler angerufen	anrufe
ueb8a	Der Hase hat die Möhre aufgegessen	aufesse
ueb9a	Der Trainer hat die Mannschaft angeheizt	anheize
ueb10a	Der Mann hat das Auto betankt	betanke

Appendix 5: Cross-Modal Priming Experiment: Critical Items

Condition	Morphological	Identity	Unrelated	Target
-*t* participle	*gedruckt*	*drucke*	*schlendern*	*drucke*
	‘printed’	‘printed$_{[1ps]}$’	‘(to) stroll’	‘printed$_{[1ps]}$’
	gesteckt	*stecke*	*scheitern*	*stecke*
	‘stuck’	‘stick$_{[1ps]}$’	‘(to) fail’	‘stick$_{[1ps]}$’
	gesprengt	*sprenge*	*schleppen*	*sprenge*
	‘blasted’	‘blast$_{[1ps]}$‘	‘(to) carry’	‘blast$_{[1ps]}$’
	gestoppt	*stoppe*	*senden*	*stoppe*
	‘stopped’	‘stopped$_{[1ps]}$’	‘(to) send’	‘stopped$_{[1ps]}$’
	gerührt	*rühre*	*nähern*	*rühre*
	‘stirred’	‘stir$_{[1ps]}$’	‘(to) approach’	‘stir$_{[1ps]}$’
	gepackt	*packe*	*tauchen*	*packe*
	‘packed’	‘pack$_{[1ps]}$’	‘(to) dive’	‘pack$_{[1ps]}$’
	getanzt	*tanze*	*starren*	*tanze*
	‘danced’	‘dance$_{[1ps]}$’	‘(to) stare’	‘dance$_{[1ps]}$’
	gelandet	*lande*	*schildern*	*lande*
	‘landed’	‘land$_{[1ps]}$’	‘(to) describe’	‘land$_{[1ps]}$’
	gehängt	*hänge*	*schütteln*	*hänge*
	‘hung’	‘hang$_{[1ps]}$’	‘(to) shake’	‘hang$_{[1ps]}$’
-*n*, no stem change	*gebacken*	*backe*	*hüpfen*	*backe*
	‘baked’	‘bake$_{[1ps]}$’	‘(to) jump’	‘bake$_{[1ps]}$’
	gesalzen	*salze*	*schaukeln*	*salze*
	‘salted’	‘salt$_{[1ps]}$’	‘(to) swing’	‘salt$_{[1ps]}$’
	gewachsen	*wachse*	*herrschen*	*wachse*
	‘grown’	‘grow$_{[1ps]}$’	‘(to) rule’	‘grow$_{[1ps]}$’
	gebraten	*brate*	*schleudern*	*brate*
	‘roasted’	‘roast$_{[1ps]}$’	‘(to) throw’	‘roast$_{[1ps]}$’
	gegraben	*grabe*	*schwanken*	*grabe*
	‘dug’	‘dig$_{[1ps]}$’	‘(to) dither’	‘dig$_{[1ps]}$’
	gewaschen	*wasche*	*wandern*	*wasche*
	‘washed’	‘wash$_{[1ps]}$’	‘(to) hike’	‘dig$_{[1ps]}$’

Appendix 5 (cont.): Cross-Modal Priming Experiment: Critical Items

Condition	Morphological	Identity	Unrelated	Target
-*n*, no stem change	*geladen*	*lade*	*triefen*	*lade*
	'charged'	'charge$_{[1ps]}$'	'(to) drip'	'charge$_{[1ps]}$'
	geschlafen	*schlafe*	*pflegen*	*schlafe*
	'slept'	'sleep$_{[1ps]}$'	'(to) care'	'sleep$_{[1ps]}$'
	gefangen	*fange*	*schweigen*	*fange*
	'caught'	'catch$_{[1ps]}$'	'(to) keep still'	'catch$_{[1ps]}$'
-*n*, stem change	*geliehen*	*leihe*	*greifen*	*leihe*
	'borrowed'	'borrow$_{[1ps]}$'	'(to) grab'	'borrow$_{[1ps]}$'
	gebogen	*biege*	*schwitzen*	*biege*
	'bent'	'bend$_{[1ps]}$'	'(to) sweat'	'bend$_{[1ps]}$'
	gegossen	*gieße*	*bessern*	*gieße*
	'poured'	'pour$_{[1ps]}$'	'(to) improve'	'pour$_{[1ps]}$'
	geflohen	*fliehe*	*rollen*	*fliehe*
	'fled'	'flee$_{[1ps]}$'	'(to) roll'	'flee$_{[1ps]}$'
	gestohlen	*stehle*	*schimpfen*	*stehle*
	'stolen'	'steal$_{[1ps]}$'	'(to) grumble'	'steal$_{[1ps]}$'
	geschritten	*schreite*	*zögern*	*schreite*
	'paced'	'pace$_{[1ps]}$'	'(to) hesitate'	'pace$_{[1ps]}$'
	geflossen	*fließe*	*schmecken*	*fließe*
	'flowed'	'flow$_{[1ps]}$'	'(to) taste'	'flow$_{[1ps]}$'
	gesunken	*sinke*	*zweifeln*	*sinke*
	'sunk'	'sink$_{[1ps]}$'	'(to) doubt'	'sink$_{[1ps]}$'
	gerissen	*reiße*	*flüstern*	*reiße*
	'ripped'	'rip$_{[1ps]}$'	'(to) whisper'	'rip$_{[1ps]}$'

Appendix 6: Cross-Modal Priming Experiment: Word Form Properties of Critical Items

Participle Type	Word	Lemma Frequency	Word Form Frequency	Letters	Syllables	Neighbor-hood	Formal Overlap	AoA	Semantic Overlap
-t	drucke	11	0	6	2	7	1	4.58	1
Identity	haenge	56	2	5	2	15	1	3.02	1
	lande	34	0	5	2	15	1	4.23	1
	packe	32	0	5	2	26	1	2.94	1
	ruehre	31	1	5	2	8	1	2.47	1
	sprenge	14	0	7	2	8	1	5.00	1
	stecke	67	0	6	2	10	1	2.02	1
	stoppe	20	0	6	2	5	1	4.17	1
	tanze	32	1	5	2	12	1	3.55	1
	Mean	**33**	**.44**	**5.56**	**2**	**11.78**	**1**	**3.55**	**1**
-t	gedruckt	11	7	8	2		.33	4.82	1
Test	gehaengt	56	4	7	2		.40	4.11	1
	gelandet	34	7	8	3		0	3.41	1
	gepackt	32	7	7	2		0	3.47	1
	geruehrt	31	6	7	2		.20	4.76	1
	gespreng	14	4	9	2		.14	4.91	1
	gesteckt	67	9	8	2		.67	2.88	1
	gestoppt	20	5	8	2		.33	4.08	1
	getanzt	32	4	7	2		0	3.02	1
	Mean	**33**	**5.89**	**7.67**	**2.11**		**.23**	**3.94**	**1**
-t	naehern	29	8	6	2		.20	4.52	4.85
Control	scheitern	47	9	9	2		.33	5.05	5
	schildern	45	8	9	2		.20	4.35	5
	schlendern	6	1	10	2		.17	4.97	5
	schleppen	23	7	9	2		.29	3.26	4.91
	schuetten	47	3	9	2		0	1.85	4.91
	senden	28	9	6	2		.17	4.50	4.94
	starren	36	4	7	2		.60	5.14	5
	tauchen	30	6	7	2		.40	4.67	5
	Mean	**32.33**	**6.11**	**8**	**2**		**.2622**	**4.26**	**4.95**

Appendix 6 (cont.): Cross-Modal Priming Experiment: Word Form Properties of Critical Items

Participle Type	Word	Lemma Frequency	Word Form Frequency	Letters	Syllables	Neighbor-hood	Formal Overlap	AoA	Semantic Overlap
-n/without	backe	1	0	5	2	21	1	3.29	1
Identity	brate	2	0	5	2	5	1	3.88	1
	fange	72	2	5	2	14	1	4.14	1
	grabe	9	0	5	2	12	1	4.44	1
	lade	45	1	4	2	15	1	4.58	1
	salze	1	0	5	2	12	1	4.17	1
	schlafe	67	2	7	2	8	1	2.08	1
	wachse	89	1	6	2	13	1	3.23	1
	wasche	20	1	6	2	11	1	1.08	1
	Mean	**34**	**.78**	**5.33**	**2**	**12.33**	**1**	**3.43**	**1**
-n/without	gebacken	1	0	8	3		0	2.26	1
Test	gebraten	2	1	8	3		0	4.38	1
	gefangen	72	11	8	3		0	4.85	1
	gegraben	9	2	8	3		0	3.91	1
	geladen	45	12	7	3		0	4.20	1
	gesalzen	1	0	8	3		0	4.76	1
	geschlafen	67	7	10	3		0	1.94	1
	gewachsen	89	20	9	3		.50	3.41	1
	gewaschen	20	6	9	3		.50	2.26	1
	Mean	**34**	**6.56**	**8.33**	**3**		**.1111**	**3.55**	**1**
-n/without	herrschen	69	10	9	2		.17	5.02	5
Control	huepfen	8	2	6	2		0	2.08	5
	pflegen	43	9	7	2		.29	4.64	4.82
	schaukeln	8	2	9	2		.60	1.73	5
	schleudern	15	1	10	2		.20	4.58	5
	schwankeen	20	4	9	2		.40	4.97	5
	schweigen	57	14	9	2		.20	3.67	5
	triefen	33	0	7	2		.25	5.17	5
	wandern	28	10	7	2		.50	3.82	5
	Mean	**31.22**	**5.78**	**8.11**	**2**		**.29**	**3.**	**4.98**

Appendix 6 (cont.): Cross-Modal Priming Experiment: Word Form Properties of Critical Items

Participle Type	Word	Lemma Frequency	Word Form Frequency	Letters	Syllables	Neighbor-hood	Formal Overlap	AoA	Semantic Overlap
-n/with	biege	10	0	5	2	16	1	2.29	1
Identity	fliehe	23	1	6	2	8	1	3.91	1
	fliesse	32	0	7	2	9	1	1.08	1
	giesse	11	0	6	2	7	1	2.52	1
	leihe	7	0	5	2	17	1	3.38	1
	reisse	72	0	5	2	12	1	2.58	1
	schreite	24	0	8	2	3	1	4.02	1
	sinke	52	1	5	2	16	1	3.41	1
	stehle	24	0	6	2	11	1	4.79	1
	Mean	**28.33**	**.22**	**5.89**	**2**	**11**	**1**	**3.11**	**1**
-n/with	gebogen	10	1	7	3		0	3.11	1
Test	geflohen	23	3	8	3		0	3.88	1
	geflossen	32	2	9	3		0	3.05	1
	gegossen	11	2	8	3		.20	2.23	1
	geliehen	7	2	8	3		.20	4.70	1
	gerissen	72	8	8	3		.40	2.35	1
	geschritten	24	2	11	2		.12	5.23	1
	gestohle	24	14	9	3		.50	4.23	1
	gesunken	52	12	8	3		0	4.17	1
	Mean	**28.33**	**5.11**	**8.44**	**2.89**		**.1**	**3.66**	**1**
-n/with	bessern	27	3	7	2		.17	4.55	5.0
Control	fluestern	29	3	8	2		.20	3.08	5.0
	greifen	104	24	7	2		.60	3.35	5.0
	rollen	33	8	6	2		.17	2.82	4.94
	schimpfen	13	3	9	2		.17	2.20	4.91
	schmecken	13	0	9	2		.17	2.35	5.0
	schwitzen	11	3	9	2		.40	4.58	4.97
	zoegern	32	5	6	2		.12	5.85	5.0
	zweifeln	21	8	8	2		.20	5.61	4.94
	Mean	**31.44**	**6.33**	**7.67**	**2**		**.24**	**3.82**	**4.97**

Appendix 7: Visual Lexical Decision Experiment: Word Form Properties of Critical Items

Participle Type	Word	Word form frequency	Lemma frequency	Part stem frequency	Participle letters	Participle syllables	Participle phonemes
-n/without	gefressen	3	17	10	9	3	8
	gegessen	7	67	45	8	3	7
	geschlafen	7	67	35	10	3	8
	geladen	12	45	24	7	3	7
	gestoßen	14	101	35	8	3	8
	Low mean	**8.6**	**59.4**	**29.8**	**8.4**	**3**	**7.6**
	gefangen	11	72	28	8	3	7
	gewachsen	20	44	34	9	3	8
	gemessen	22	49	41	8	3	7
	geraten	23	66	25	7	3	7
	gefallen	30	60	31	8	3	7
	High mean	**21.2**	**58.2**	**31.8**	**8**	**3**	**7.2**
-n/with	geschrien	2	72	49	9	2	6
	gegriffen	6	104	57	9	3	8
	gerissen	8	72	49	8	3	7
	geschoben	9	62	43	9	3	7
	gestanden	13	1138	344	9	3	9
	Low mean	**7.6**	**289.6**	**108.4**	**8.8**	**2.8**	**7.4**
	geschossen	16	75	41	10	3	7
	getroffen	32	256	32	9	3	8
	gestiegen	49	209	136	9	3	8
	gezogen	51	284	201	7	3	7
	geblieben	66	799	306	9	3	8
	High mean	**42.8**	**324.6**	**143.2**	**8.8**	**3**	**7.6**

Appendix 7 (cont.): Visual Lexical Decision Experiment: Word Form Properties of Critical Items

Participle Type	Word	Word form frequency	Lemma frequency	Part stem frequency	Participle letters	Participle syllables	Participle phonemes
-t	**gekratzt***	**1**	**9**	**9**	**8**	**2**	**7**
	gerutscht*	**2**	**17**	**17**	**9**	**2**	**6**
	gebremst*	**2**	**14**	**14**	**8**	**2**	**8**
	gelenkt*	**8**	**36**	**36**	**7**	**2**	**7**
	getauscht	2	17	17	9	2	6
	gelacht	4	109	109	7	2	6
	gespart	5	36	36	7	2	7
	gesteckt	9	67	67	8	2	7
	gewohnt	9	79	79	7	2	6
	Low mean	**4.66**	**42.66**	**42.66**	**7.77**	**2**	**6.66**
	geknüpft*	**9**	**14**	**14**	**8**	**2**	**7**
	geweckt*	**9**	**19**	**19**	**7**	**2**	**6**
	geräumt*	**9**	**30**	**30**	**7**	**2**	**6**
	geprüft*	**22**	**77**	**77**	**7**	**2**	**7**
	gezählt	10	85	85	7	2	6
	geguckt	11	19	19	8	2	7
	gestürzt	11	59	59	8	2	8
	gestört	14	54	54	7	2	7
	geschickt	20	31	31	9	2	6
	High mean	**12.77**	**43.11**	**43.11**	**7.55**	**2**	**6.66**

* Items added to the speeded production stimuli.

Erklärungen

Gemäß §4 (2) 5. der Promotionsordnung der Humanwissenschaftlichen Fakultät der Universität Potsdam vom 17.10.06

Hiermit erkläre ich, Elisabeth Fleischhauer, geb. 10.02.1983, dass ich an keiner anderen Hochschule ein Promotionsverfahren beantragt oder eröffnet habe.

Gemäß §4 (2) 8. der Promotionsordnung der Humanwissenschaftlichen Fakultät der Universität Potsdam vom 17.10.06

Hiermit erkläre ich, Elisabeth Fleischhauer, geb. 10.02.1983, dass die ich Arbeit selbständig und ohne unzulässige Hilfe Dritter verfasst habe und bei der Abfassung nur die in der Dissertation angegebenen Hilfsmittel benutzt, sowie alle wörtlich oder inhaltlich übernommenen Stellen als solche gekennzeichnet habe.

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Gemäß §4 (2) 7. der Promotionsordnung der humanwissenschaftlichen Fakultät der Universität Potsdam vom 17.10.2006

Hiermit erkläre ich, Elisabeth Fleischhauer, geb. 10.02.1983, mich damit einverstanden, dass die eingereichte Zusammenfassung der Dissertation nach erfolgreicher Beendigung des Verfahrens veröffentlicht werden darf.

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