Age of acquisition and semantic typicality effects:

Evidences for distinct processing origins from behavioural and ERP data in healthy and impaired semantic processing

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AOA	age of acquisition
CONGR	congruity
df	degrees of freedom
EC	elderly controls
EEG	electroencephalography
EOG	electro-occulogram
ERP	even-related potentials
ISI	inter-stimulus interval
IWA	individual with aphasia
M	mean
ROI	region of interest
RT	reaction times
SD	standard deviation
SE	standard error
SOA	stimulus-onset asynchrony
TYP	semantic typicality

List of original journal articles

The present dissertation is based on the following three empirical studies:

Study I:

Räling, R., Holzgrefe-Lang, J., Schröder, A., & Wartenburger, I. (2015). On the influence of typicality and age of acquisition on semantic processing: Diverging evidence from behavioural and ERP responses. *Neuropsychologia*, *75*, 186–200. doi:10.1016/j.neuropsychologia.2015.05.031

Study II:

Räling, R., Hanne, S., Schröder, A., Keßler, C., & Wartenburger, I. (2016). Judging the animacy of words - The influence of typicality and age of acquisition in a semantic decision task. *The Quarterly Journal of Experimental Psychology*, 1–21. doi:10.1080/17470218.2016.1223704

Study III:

Räling, R., Schröder A., & Wartenburger, I. (2016). The origins of age of acquisition and typicality effects: Semantic processing in aphasia and the ageing brain. *Neuropsychologia*, 86, 80-92. doi: 10.1016/ j.neuropsychologia.2016.04.019

I. SYNOPSIS

1. General introduction

The investigation of linguistic variables has a long tradition in psycholinguistic research. Numerous studies in the past decades identified a wide range of linguistic variables that significantly influence the processing of words in healthy speakers and individuals with a language impairment (e.g., Barry, Morrison, & Ellis, 1997a; Brown & Watson, 1987; Coltheart, 2007; Friendly, Franklin, Hoffman, & Rubin, 1982; Hampton & Gardiner, 1983; Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012; Rubin, 1980). Some of these parameters are intrinsic and can be objectively specified from a words' surface (e.g., word length in phonemes, characters, or syllables; number of morphemes) or by counts of spoken or written language corpora (word frequency, orthographical or phonological neighbourhood density). Others need to be determined empirically in terms of ratings or estimates (e.g., imageability, familiarity, age of acquisition, or semantic typicality; e.g., Brysbaert, Stevens, De Deyne, Voorspoels, & Storms, 2014; Dell'Acqua, Lotto, & Job, 2000; Moreno-Martínez, Montoro, & Rodríguez-Rojo, 2014; Schröder, Gemballa, Ruppin, & Wartenburger, 2012). The influence of linguistic variables on word processing has mainly been studied with behavioural measures recording response times or accuracy rates while conducting language related tasks.

Numerous models of language processing seek to describe mental processes of word processing. Hierarchical-serial models of word and sentence processing are assumed to consist of a concatenation of different, highly specialised, modularised processes, which succeed serially and are organized in a hierarchical manner (see section 1.1.1, e.g., Garrett, 1980; Levelt, 1989; Patterson & Shewell, 1987). Most of the linguistic variables are attributed to have an effect at a specific level of language processing. Consequently, the effects become visible as soon as the stimulus is processed at the associated processing level. Variables that are assigned to originate at the lexical (word form) level are for instance word frequency or phonological neighbourhood density (Garlock, Walley, & Metsala, 2001; Jescheniak & Levelt, 1994; Levelt, Roelofs, & Meyer, 1999; Sommers, 1996; Vitevitch & Luce, 1999), while concreteness, imageability, animacy, or semantic typicality have been ascribed to the semantic level (Bird, Howard, & Franklin, 2000; Gelman, 1990; Mervis, Catlin, & Rosch, 1976; Moss, Tyler, Durrant-Peatfield, & Bunn, 1998; Rosch, 1973b, 1975; Strain, Patterson, & Seidenberg, 1995).

According to the critical-variable approach by Shallice (1988), effects of linguistic variables are enhanced in impaired language processing (e.g., aphasia) and therefore can be taken into account to specify the underlying functional deficit of language impairment. For example, while enhanced concreteness effects in aphasia point to a semantic impairment, enhanced word frequency effects refer to deficits at the word form level (e.g., Nickels, 1997). Hence, investigations of aphasic language processing enable conclusions on the origin of linguistic variables that have not yet been clearly specified in existing cognitive models of language processing. One variable, whose origin is still under debate, is the age of acquisition (AOA).

The present dissertation project aims at investigating the interdependence between the linguistic variables AOA and semantic typicality (TYP) in order to assess a semantic origin of AOA effects in cognitive models of language processing that have been proposed for AOA in the past (see section 1.1.2.3). For that purpose, I conducted three studies (see chapters 5 to 7) in which I collected behavioural and electrophysiological measures in healthy young and elderly participants and in individuals with a semantic deficit suffering from aphasia.

The dissertation is divided into two parts: Part one contains the synopsis of the publication-based dissertation including reviews on the theoretical and methodological backgrounds, the main research questions, a summary of the major findings and the major conclusions. Part two comprises the original peer-reviewed articles that have been published in or submitted to international journals.

1.1 Theoretical background

1.1.1 Cognitive models of word processing

Cognitive models of word processing have been established on the basis of healthy and impaired language processing data. Existing models in psycholinguistics can be divided into connectionist and hierarchical-serial models. Connectionist models assume levels of language processing to be organised within a neural network in form of nodes and links between the nodes. The activation of information occurs via *spreading activation* (Collins & Loftus, 1975; Dell, 1986; Dell & O'Seaghdha, 1992; McClelland & Rogers, 2003; Rogers et al., 2004). Connectionist models are characterised by the simultaneous processing of language levels and their mutual interference. They are primarily used to explain the underlying mechanisms of the variables AOA and TYP (see sections 1.1.2.3 and 1.1.3.3; e.g., Ellis & Lambon Ralph, 2000; McClelland & Rogers, 2003; McRae, Cree, Westmacott, & De Sa, 1999; Monaghan & Ellis, 2010; Rogers et al., 2004).

Hierarchical-serial models, however, are organised in independent and highly specialised modules (see also, *The Modularity of Mind*, Fodor, 1983), whose activation occurs serially and unidirectionally. The current dissertation primarily takes the *Logogen Model* as a basis*:* One of the most important serial models of single word processing that models the perception, production, reading, and writing of mono-morphemic words and non-words (e.g., Morton, 1970, 1979; Patterson, 1988; Patterson & Shewell, 1987). The *Logogen Model* comprises specific and functionally independent components and links between different components (see Figure 1). It distinguishes input and output lexica, which contain word forms of spoken (phonological) and written (graphemic) words, respectively. It also includes a central, amodal semantic system in which the corresponding meanings are stored. In addition, input analyses components (visual and auditory analysis), short-time buffer components, as well as modality specific segmental routes (to process non-words) are assumed in the model (see also, De Bleser et al., 1997). Words are stored as so-called *Logogens*, which specifically characterise the lexical information of a certain word. Activation of a word takes place as soon as a logogen-specific threshold at each task-required processing level is reached. Serial models are used to specify the functional origins of AOA and TYP effects (see sections 1.1.2.3 and 1.1.3.3).

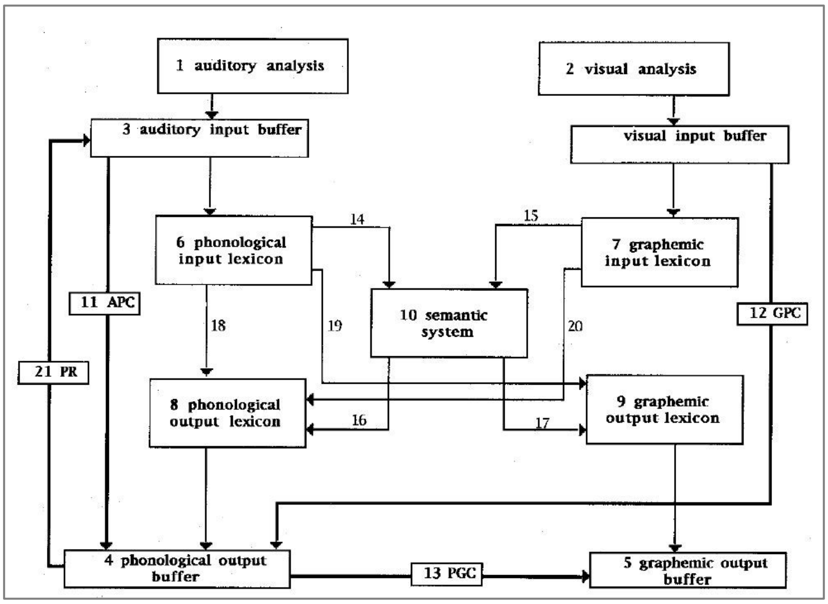

Figure 1 The *Logogen Model* (extracted from De Bleser, Cholewa, & Tabatabaie, 1997, p. 344, after Patterson, 1988). Auditory category-member verification as conducted in studies I and III requires access to the components (1) auditory analysis, (3) auditory input buffer, (6) phonological input lexicon (PIL), (14) link between PIL and semantic system, and (10) semantic system. In study II, animacy decision requires access to equivalent components and routes within the visual modality (i.e., 2, 7, 15, 10).

1.1.2 Age of acquisition (AOA)

Age of acquisition (AOA) constitutes one of the most important variables in psycholinguistic research. It has been defined as the point in time at which a lexical item has been learned and produced in language acquisition (for reviews, see: Johnston & Barry, 2006; Juhasz, 2005). The influence of AOA on healthy speech production and its independence from word frequency has first been emphasised in the seminal study of Carroll and White (1973) who investigated object naming latencies. Over the past 40 years, numerous studies in different languages replicated these pioneering findings and presented so-called AOA effects for a huge variety of psycholinguistic tasks indicating that early acquired words lead to reduced response times and error rates compared to late acquired words. Controlling for AOA in psycholinguistic tasks is challenging because estimates of AOA are often accessible for only a small number of words (Kuperman et al., 2012). The psycholinguistic literature describes two procedures to obtain AOA estimates for words: There are subjective ratings of adults estimating the age at which a word was learned usually at a 7-point-scale (after Gilhooly & Logie, 1980; see Schröder et al., 2012, for German norms on AOA). More objective measures are obtained from object picture naming in children (e.g., Carroll & White, 1973). Since subjective and objective measures are highly correlated, both measures can be reliably used (e.g., Morrison, Chappell, & Ellis, 1997; Pind, Jonsdottir, Gissurardottir, & Jonsson, 2000;

Schröder, Kauschke, & De Bleser, 2003). In the following, I will give an overview of previous behavioural and electrophysiological studies on the AOA variable, existing models to explain AOA effects, and the impact of AOA on language processing in individuals with aphasia.

1.1.2.1 Behavioural studies

The majority of studies investigating AOA collected behavioural data using regression as well as factorial designs (for reviews, see Johnston & Barry, 2006; Juhasz, 2005). The most reliable effects on AOA with the largest effect sizes have been presented in tasks requiring speech production subsequent to a semantic analysis (i.e., spoken picture naming): Early acquired objects were named more quickly and/or more accurate than late acquired words (e.g., Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Catling & Johnston, 2006a, 2009; Chalard & Bonin, 2006; Cuetos, Ellis, & Alvarez, 1999; Holmes & Ellis, 2006; Vitkovitch & Tyrrell, 1995). Moreover, AOA was a significant predictor in written picture naming and spelling to dictation (e.g., Bonin, Malardier, Méot, & Fayol, 2006; Bonin & Méot, 2002), word reading (e.g., Bonin, Barry, Méot, & Chalard, 2004; Gerhand & Barry, 1998; Morrison & Ellis, 2000), category-fluency (Hernández-Muñoz, Izura, & Ellis, 2006) and naming to definition (Navarrete, Pastore, Valentini, & Peressotti, 2015).

In addition, AOA effects, with faster reaction times for early vs. late acquired words, have also been reported for tasks that do not require speech production, as for instance for lexical decision tasks (e.g., De Deyne & Storms, 2007; Ghyselinck, Lewis, & Brysbaert, 2004; Menenti & Burani, 2007; Smith, Turner, Brown, & Henry, 2006; Turner, Valentine, & Ellis, 1998) and semantic processing tasks (e.g., Brysbaert, van Wijnendaele, & De Deyne, 2000; Catling, Dent, Johnston, & Balding, 2010; Catling & Johnston, 2009; Ghyselinck, Custers, & Brysbaert, 2004; Holmes & Ellis, 2006). However, one study by Morrison, Ellis, and Quinlan (1992) reported that AOA had no effect on participants' semantic decision on whether an object was living or non-living in a speeded picture categorisation task. Among others, Brysbaert and Ghyselinck (2006; see also Johnston & Barry, 2005) argued that the null effects in Morrison et al. (1992) might have had methodological reasons because the authors did not distinguish between yes and no responses in their analyses and the solution of the task was possible without access to the entire semantic concept (objects with round forms are rather natural than objects with straight lines). In contrast to Morrison et al. (1992), Catling and Johnston (2006a) reported AOA effects using an animacy decision task with pictures. Further studies investigating semantic processing provide evidence that AOA effects also occur in animacy decision tasks using printed words (De Deyne & Storms, 2007; Menenti & Burani, 2007; Morrison & Gibbons, 2006) and in semantic categorisation tasks (Brysbaert et al., 2000; Ghyselinck et al., 2004). However, in a series of experiments Holmes and Ellis (2006) reported that AOA effects disappeared as soon as the stimuli have been controlled for semantic typicality.

In sum, while lexical decisions and semantic tasks generally show equal effect sizes of AOA (Menenti & Burani, 2007), increased AOA effect sizes have been described for tasks requiring deep semantic processing followed by speech production (Catling & Johnston, 2006a, 2009). Conclusions on the functional origin of AOA effects are hardly possible on the basis of only behavioural data in healthy language processing because reaction time and accuracy measures depict the final output of language processing, but do not allow for mappings of sub-processes (e.g., semantic vs. word form level processing). Since AOA effects have been shown to occur in a large variety of linguistic tasks, the application of electrophysiological methods during online language processing seems useful in disentangling sub-processes from which AOA effects might originate.

1.1.2.2 Event-related studies

To my knowledge, only a few studies examined effects of AOA by means of electroencephalography (EEG) in order to pinpoint their origin in cognitive models of language processing. The existing studies do not report conclusive results on the AOA origin: They are scarcely comparable because of their large diversity of study designs and used electrophysiological measures (topographical mappings vs. different event-related potential (ERP) components, see section 1.2.2).

Tainturier, Tamminen, and Thierry (2005) were the first investigating AOA by means of ERPs using an auditory lexical decision oddball paradigm. In their paradigm, 25 % of the stimuli were words that differed with respect to AOA (in contrast to 75 % non-words). Tainturier et al. report an influence of AOA on the

P300 component, with more positive amplitudes for early vs. late acquired words[1]. However, the authors failed to obtain differences on the N400 amplitude between early and late acquired words (which is not unusual with regard to lexical decisions and the oddball-paradigm, see e.g., Duncan et al., 2009).

Analysing the topographical distribution and the timing of ERP responses in high density EEG, Adorni, Manfredi, and Proverbio (2013) obtained a neuro-functional dissociation between the variables AOA and word frequency in an orthographic detection paradigm. Here, AOA modulated amplitudes in left inferior-temporal brain regions that are preliminarily associated with early lexical-orthographical processing, while word frequency affected left inferior-frontal brain regions.

Assessing the time course of electrophysiological activation in silent word reading provides evidence for a significant influence of AOA on a semantically associated ERP-response only in the time interval 400 to 610 ms post word onset (comparable to the N400 ERP component, with late acquired words resulting in a more negative amplitude than early acquired words; Cuetos, Barbon, Urrutia, & Dominguez, 2009). According to the authors, these data support hypotheses on a semantic origin of AOA effects. In contrast, word frequency affected silent word reading only in an early time window (175 to 360 ms) and thus pointing to an influence of word frequency on lexical-orthographical processing and an independence from AOA.

Laganaro and colleagues present ERP data in overt written and spoken picture naming (Laganaro & Perret, 2011; Perret, Bonin, & Laganaro, 2014). Waveform analyses revealed that during naming AOA effects occur in comparatively late time windows (around 350 ms) after stimulus onset. According to Laganaro and Perret, these late effects are associated with phonological encoding processes and thus evidence against a semantic origin of AOA effects. Prior to this dissertation project, studies examining AOA effects on the N400 ERP component in tasks that demand semantic categorisation had not yet been published.

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[1] Note that a larger effect on the P300 component for early vs. late acquired words constitutes an inverse effect, because, in general, larger effects on the P300 component are expected for words with a lower probability of occurrence (e.g., Duncan et al. , 2009). However, Tainturier et al. (2005) do not refer to this inversion in their discussion.

1.1.2.3 Theories of AOA

In the past, numerous theoretical accounts have been proposed to specify (a) the functional levels in language processing at which AOA effects originate and (b) the underlying mechanisms that lead to AOA effects (Barry et al., 1997a; for reviews, see also: Johnston & Barry, 2006; Juhasz, 2005).

In the current dissertation, I focus more on the functional levels in language processing at which AOA effects originate. Existing accounts can be divided into single-locus and multiple-loci theories. Single-locus theories seek to pinpoint AOA effects at a discrete stage of language processing such as the word form processing level (i.e., phonological/graphemic output lexicon; Brown & Watson, 1987; Gerhand & Barry, 1998; Gilhooly & Watson, 1981; Laganaro & Perret, 2011; Perret et al., 2014), or the semantic processing level (Brysbaert et al., 2000; Ghyselinck et al., 2004; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). However, these accounts are restricted in their predictions since they do not allow for concurrent AOA effects in lexical perception (e.g., lexical decisions), speech production (e.g., picture naming, reading), or semantic processing (e.g., animacy decisions), respectively, which is not in line with the broad range of AOA effects in behavioural tasks that require various language processing levels (as summarised in section 1.1.2.1).

Therefore, multiple-loci theories seem to be more promising in explaining AOA effects in a large variety of psycholinguistic tasks: A representative of multiple-loci theories is the *Accumulative Hypothesis* of Catling and Johnston (2006a, 2009). Catling and Johnston assume that the increase of AOA effect sizes in speech production tasks is due to the involvement of phonological processing in addition to task-related perceptual/structural or semantic analysis (e.g., picture naming vs. lexical decision or semantic categorisation). They further postulate that effects of AOA always become visible as soon as access to stored material is obligatory. Hence, Catling and Johnston set the loci of AOA effects first on perceptual/structural stages and second on phonological processing stages (i.e., at the word form level or at the links between semantics and phonology). In line with the *Accumulative Hypothesis* is the *Lexical-Semantic Competition Hypothesis* of Brysbaert and Ghyselinck (2006; see also: Belke et al., 2005). These authors propose a distinction between frequency-related and frequency-independent effects. Frequency-related AOA effects are assumed to be strongly related to (cumulative) word frequency effects (Ghyselinck et al., 2004; Lewis, 1999), such that AOA highly correlates with the cumulative count on how often a word has been presented across life and for how long an item is known. According to Brysbaert and Ghyselinck, these frequency-related effects generally arise in tasks that demand access to stored lexical information since word frequency and AOA rely on the same learning mechanisms (as proposed by Ellis & Lambon Ralph, 2000, in connectionist models). However, the assumption of frequency-related AOA effects alone is not sufficient to explain increased effect sizes in tasks involving speech production subsequent to a deep semantic analysis (e.g., Catling & Johnston, 2006a; Navarrete et al., 2015). Those speech production tasks show substantially larger AOA effects in naming tasks as they can be explained in the frame of word frequency effects. To account for these phenomena, Brysbaert and Ghyselinck propose the existence of frequency-independent effects, which they pinpoint either at the semantic level itself or, more likely, at the interface between semantics and phonology (the authors refer to the lemma-level, within the model of speech production by Levelt, 1989; see also Levelt et al., 1999). Brysbaert and Ghyselinck assume frequency-independent AOA effects to arise as soon as possible candidates compete during the response selection process. Since early acquired words have stronger competitors at the semantic and/or the lemma level, according to the authors, the co-activation of competitors facilitates the access to early acquired words, which are thus faster processed than late acquired words[2]. Yet, the *Lexical-Semantic Competition Hypothesis* only refers to speech production processes and does not make assumptions on frequency-independent effects that require semantic analysis without speech production.

In order to explain the underlying mechanisms of AOA effects, different attempts have been made to model AOA effects in *Connectionist Neural-Network Simulations* (e.g., Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Monaghan & Ellis, 2002; Monaghan & Ellis, 2010; Zevin & Seidenberg, 2002, 2004). One of the first were Ellis and Lambon Ralph (2000) who simulated AOA effects by setting out a

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[2] Some authors, however, argue that the existence of competitors at the same processing level might rather lead to an increase of inhibition effects instead of facilitation (see further Howard, Nickels, Coltheart, and Cole-Virtue, 2006).

cumulative, interleaved training on input-output associations within an artificial network that gradually loses its plasticity over the time of training. In this simulation, early acquired patterns are established more robustly than late acquired patterns as the former lead to stronger connections between levels of representations resulting in a substantial processing benefit. In this model, AOA has an impact particularly on input-output structures that are unpredictable and hence arbitrary (in comparison to more consistent or regular mappings, i.e., reading regular words; see also: Zevin & Seidenberg, 2002, 2004). According to these models, AOA effects originate in the transitions between lexical word form representations and their corresponding semantic concepts, since these transitions are naturally arbitrary. In contrast, AOA effects in rather consistent mappings (as it is for instance the case in orthography-to-phonology mappings in English) might occur less likely (Monaghan & Ellis, 2010).

In sum, frequency-related AOA effects seem to originate at the perceptual or productive word form level (i.e., phonological/graphemic input lexicon or the lexeme level), while frequency-independent AOA effects rather originate at the link between phonology and semantics or at the semantic level itself.

1.1.2.4 AOA in aphasia

The systematic investigation of error patterns in language impaired individuals provides significant insights into the organisation of the language processing system (e.g., Morton, 1985; Nickels & Howard, 1995). The enhanced influence of stimulus specific linguistic variables is generally assumed to be due to a specific deficit at the processing level at which a certain psycholinguistic variable originates (Shallice, 1988). Therefore, investigations of impaired language processing might provide important information to better understand at which level of language processing AOA effects originate.

The influence of AOA on impaired language processing has been examined in various studies, whereby the majority has been done with patients suffering from Alzheimer's disease or semantic dementia (e.g., Cuetos, Herrera, & Ellis, 2010; Cuetos, Rodriguez-Ferreiro, Sage, & Ellis, 2012; Hirsh & Funnell, 1995; Woollams, Cooper-Pye, Hodges, & Patterson, 2008). The results primarily revealed AOA as a significant predictor of picture naming accuracy in neurodegenerative disorders (for a review, see Ellis, 2011). In contrast, studies on AOA in individuals with aphasia (IWA) are quite sparse. AOA effects have been observed in the framework of acquired dyslexia (in particular in individuals with a deep dyslexia; e.g., Barry & Gerhand, 2003; Gerhand & Barry, 2000; Law & Yeung, 2010). The majority of studies in IWA, however, focused not on reading but solely on speech production during picture naming (for review, see Brysbaert & Ellis, 2015). A potential influence of AOA on naming performance in aphasia has first been described by Rochford and Williams (1962) – long before Carroll and White (1973) first reported AOA as a reliable linguistic variable. Rochford and Williams (1962) pointed out to the phenomenon that words that have been learned early in language acquisition are more resistant to aphasic vocabulary loss than late acquired words. Since then, studies with IWA examined either single cases or groups of IWA with a very heterogeneous aphasic profile and provided additional evidence on AOA as an important predictor of picture naming performance in aphasia (Cuetos, Aguado, Izura, & Ellis, 2002; Ellis, Lum, & Lambon Ralph, 1996; Feyereisen, van der Borght, & Seron, 1988; Hirsh & Ellis, 1994; Hirsh & Funnell, 1995; Nickels & Howard, 1995).

However, it is hardly possible to draw conclusions on the origin of AOA effects on the basis of these studies because of two reasons: First, the studies only investigated word production, and hence neglected a possible influence of AOA on the single stages of word perception. Second, the IWA were not diagnosed according to their specific underlying language deficit but showed general word finding difficulties, which might be ascribed to various levels of word production. These flaws in a detailed diagnostic and hence in the inclusion of adequate participants might explain why aphasic error patterns in picture naming are heterogeneous and why AOA effects have been ascribed either to semantic (Cuetos et al., 2002; Nickels & Howard, 1995) or to phonological processing levels (Cuetos et al., 2002; Kittredge, Dell, Verkuilen, & Schwartz, 2008).

Therefore, detailed diagnostics and case descriptions of the language profile of the IWA are necessary to draw any conclusions on the underlying functional deficit and the variables that influence specific levels of (impaired) language processing. According to the above-described theories on the possible origin of particularly frequency-independent AOA effects, the investigation of IWA with an underlying central semantic deficit might help to clearly define their origin (which is assumed either at the semantic level or at the link between phonology and semantics).

1.1.3 Semantic typicality (TYP)

The linguistic variable *semantic typicality* (TYP) refers to the degree on how representative a semantic concept is with respect to its superordinate semantic category (e.g., Hampton, 1995; Rips, Shoben, & Smith, 1973; Rosch, 1973a, 1975; Rosch & Mervis, 1975). Traditionally, the semantic category BIRDS is used to illustrate the TYP of category members: A *robin*[3] is a better and thus more typical example of the category BIRDS than it is the case for the semantic concept *ostrich* (Armstrong, Gleitman, & Gleitman, 1983; McCloskey & Glucksberg, 1979; Smith, Shoben, & Rips, 1974).

Since Posner and Keele (1968) first used the term *Prototypicality* to classify visual patterns according to a prototypical pattern in a perceptual learning experiment, numerous studies examined the linguistic variable TYP and thus the internal structure of categories and representations. The seminal work of Rosch and her colleagues (e.g., Mervis & Rosch, 1981; Rosch, 1973a, 1973b, 1975; Rosch & Mervis, 1975) evinced that category members are not equally ranked within semantic categories but are organised in a graded structure. The TYP of category members emerges particularly in semantic tasks as typical members are processed more quickly and less error-prone than atypical members (so-called TYP effects; e.g., Casey, 1992; Hampton, 1997; McCloskey & Glucksberg, 1979). The conception of TYP has been shown to be applicable not only to natural taxonomic categories (e.g., BIRDS, FRUITS, CLOTHING, or FURNITURE; e.g., Larochelle & Pineau, 1994; Rosch, 1975), but also to colours and geometrical forms (Rosch, 1973a; Rosch & Mervis, 1975), to well-defined categories (e.g., FEMALE, ODD NUMBERS; Armstrong et al., 1983; Larochelle, Richard, & Soulieres, 2000; Sandberg, Sebastian, & Kiran, 2012), and to ad-hoc categories (e.g., “things to take to a camping trip”; Barsalou, 1983, 1985; Sandberg et al., 2012).

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[3] The example of BIRD and *robin* (German *Rotkehlchen*; not to be confused with the German translation *Wanderdrossel*) is frequently used in the early literature of TYP.

A common procedure to obtain norms for TYP is to conduct ratings on the goodness-of-representativeness of category members with respect to a certain semantic category usually on a 7-point-scale (e.g., Hampton & Gardiner, 1983; Hernández-Muñoz et al., 2006; Moreno-Martínez et al., 2014; Rosch, 1975; see Schröder et al., 2012, for German norms for TYP). In the following, I will provide an overview of previous behavioural as well as electrophysiological studies on TYP, before summarising studies investigating TYP effects in aphasia.

1.1.3.1 Behavioural studies

Similar to AOA, the majority of experiments used behavioural measures (response times or accuracy rates) in healthy language processing in order to investigate the influence of TYP. TYP effects (i.e., faster response times for typical than atypical words) have most frequently been found in tasks in which participants verified a semantic relationship of a semantic category and a category member in form of visually presented sentences (e.g., "A ROBIN is a BIRD", Armstrong et al., 1983; McCloskey & Glucksberg, 1979; Mervis & Rosch, 1981; Rips et al., 1973; Rosch, 1975; Smith et al., 1974) or word pairs (e.g., "BIRD – OSTRICH"; Casey, 1992; Hampton, 1997; Holmes & Ellis, 2006; Larochelle & Pineau, 1994). TYP effects have also been reported in animacy decision tasks using printed words (Morrison & Gibbons, 2006) and in a number of tasks that required speech production, such as reading (Garrod & Sanford, 1977), category naming (Casey, 1992; Hampton, 1995), picture naming (Dell'Acqua et al., 2000; Holmes & Ellis, 2006), category-member-generation (Hernández-Muñoz et al., 2006; Mervis et al., 1976; Storms, Boeck, & Ruts, 2000), and sentence production (Kelly, Bock, & Keil, 1986; Onishi, Murphy, & Bock, 2008). Moreover, TYP effects have been found in the context of category-based induction (Osherson, Smith, Wilkie, Lopez, & Shafir, 2008; Rein, Goldwater, & Markman, 2010; Rips, 1975) and deduction (Lei et al., 2010).

1.1.3.2 Event-related studies

ERP studies investigating effects of TYP in younger healthy individuals observed a larger negativity of the N400 component (see section 1.2.2) for atypical in comparison to typical words in visual and auditory category-member verification tasks using word pairs (Fujihara, Nageishi, Koyama, & Nakajima, 1998; Heinze, Muente, & Kutas, 1998; Pritchard, Shappell, & Brandt, 1991; Stuss, Picton, & Cerri, 1988). Moreover, Núñez-Peña and Honrubia-Serrano (2005) presented a series of six members to define a semantic category, while the seventh word differed with respect to their TYP (typical/atypical) or displayed a non-member. Similar to the category-member verification studies, the last word of the list evoked significant N400 effects according to their differences in TYP. In addition, investigating the influence of ageing on judging category membership, revealed N400 differences manipulated by TYP in the younger, but not the elderly group (Federmeier, Kutas, & Schul, 2010).

1.1.3.3 Theories of TYP

In contrast to AOA, for TYP, there is no debate on its origin per se. Existing models of TYP agree in the assumption that TYP originates at the semantic level. The most important questions regarding TYP are, however, (a) how is the semantic system itself organised to account for TYP effects, and (b) what are the mechanisms that underlie semantic categorisation? In the following, I will provide an overview of theories that seek to explain TYP effects with respect to both aspects.

According to the organisation of the semantic system, the *Classical View* is based on the all-or-none principle (Komatsu, 1992; Mervis & Rosch, 1981; Smith & Medin, 1981). Within this assumption, semantic categories possess exact boundaries between different categories, which are each clearly defined by a set of semantic features. For example, the category BIRDS would be defined by the features “can fly”, “has wings”, “has feathers”, “sings”, or “lays eggs”, that are equally shared by each member belonging to the category. However, this view is not able to explain gradation between concepts as has first been described for colours and geometric figures, and was later extended to natural semantic categories by Rosch and colleagues within the *Theory of Prototypes* (Mervis et al., 1976; Osherson & Smith, 1981; Rosch, 1973a, 1973b, 1975; Rosch & Mervis, 1975). In the frame of the *Theory of Prototypes*, a prototype is assumed to constitute a central idealised image, which represents the most typical features of a category and has the greatest family resemblance to other members of that category (Rosch & Mervis, 1975). A category member is considered as typical, the more features it shares with the prototype (Rosch, 1975, 1978). Hence, various authors demonstrated that members of a semantic category are not equally ranked and that the borderlines between categories are rather vague than well-defined (Hampton, 1995).

Besides the *Theory of Prototypes*, there are further accounts explaining TYP effects. For instance, *Exemplar Models* assume a collection of features instead of a central prototype representation. These features are calculated on the basis of already stored examples of a category. Thus, semantic categorisation of a concept occurs as calculating the maximum average similarity of stored features within a category (McClelland, 1981; Medin & Schaffer, 1978; Nosofsky, 1988a, 1988b; Smith & Medin, 1981). *Feature-Comparison Models* do neither assume exemplar nor prototypical representatives, but describe TYP effects on features compiling semantic categories (McCloskey & Glucksberg, 1979; Smith et al., 1974).

With regard to the underlying mechanisms of TYP effects, early *Network Models* explained TYP effects as arising from different strengths of links between semantic concepts that are represented in separate nodes within a semantic network that bases on spreading activation (Collins & Loftus, 1975; Glass & Holyoak, 1974). More recent accounts seek to concatenate aspects from feature-comparison and network models in *Computational Connectionist Models* in order to explain TYP effects in terms of semantic features that are highly overlapping and shared in typical items and idiosyncratic and distinct in atypical items (McClelland & Rogers, 2003; Plaut, 1996; Rogers et al., 2004). In contrast, McRae et al. (1999) argue against a typicality of concepts but propose a typicality of features, in which typical items are characterised by highly intercorrelated typical features, while the features of atypical items are less intercorrelated.

1.1.3.4 TYP in aphasia

Since TYP originates at the semantic processing level, specific impairments of the semantic system should result in enhanced effects on the variable TYP (Shallice, 1988). TYP is considered to significantly predict vocabulary loss not only in aphasia but also in neurodegenerative disorders such as semantic dementia (Woollams, 2012; Woollams et al., 2008). However, similar to AOA studies on impaired language processing, the majority of studies did not investigate specific underlying deficits (such as semantic deficits) while studying the influence of TYP. An influence of TYP on language processing in IWA has primarily been studied in category-member verification tasks (Grober, Perecman, Kellar, & Brown, 1980; Kiran, Ntourou, & Eubank, 2007; Kiran & Thompson, 2003; Riley & Thompson, 2010; Sandberg et al., 2012) – a paradigm that is directly related to deep semantic processing (see section 1.2.1.2). Besides, tasks that demand speech production such as picture naming (Rossiter & Best, 2013) and category-exemplar generation (Grossman, 1981; Hough, 1993) have also been shown to reveal effects of TYP on impaired language processing.

However, depending on the aphasic syndrome, studies reported rather inconsistent results on the occurrence of TYP effects: Hough and Pierce (1989; see also Hough, 1993) reported similar TYP effects for both fluent and non-fluent IWA on reaction times and accuracy rates in category-member verifications. In addition, Hough (1993) showed enhanced difficulties in accessing atypical members in a category exemplar generation task for both groups of IWA. In contrast, Grossman (1981) found that non-fluent IWA produced mainly typical items, while fluent IWA produced a broader range on non-appropriate exemplars during generating category members. Grober et al. (1980) presented TYP effects in reaction times and accuracy rates for IWA with anterior and posterior lesions, whereby IWA with a posterior lesion performed significantly worse than anterior lesioned IWA. Moreover, Kiran and Thompson (2003) conducted a category-member verification task with animate category members and revealed similar TYP effects in terms of accuracy and reaction times for young and older healthy participants as well as IWA with Broca's aphasia. However, IWA with Wernicke's aphasia showed significantly higher error rates, but did not show different reaction times for typical vs. atypical category members.

Hence, the studies mentioned above are very inconsistent in drawing conclusions on TYP and its influence on semantic processing. Very carefully summarised, the data point to larger difficulties in processing atypical words for IWA with a semantic deficit, as associated with fluent, posterior, or Wernicke's aphasia in comparison to individuals with other aphasic syndromes and healthy individuals. Semantic deficits are particularly prominent in acquired deep dyslexia. Therefore, Riley and Thompson (2010) investigated this specific syndrome in an auditory and visual category-verification task. The data revealed absent TYP effects in both modalities in individuals with deep dyslexia, while TYP effects were obtained for healthy controls and individuals with phonological dyslexia. Nevertheless, it has to be noted, that the diagnosis of deep dyslexia was grounded only on semantic errors in reading (which are not necessarily due to semantic deficits, e.g., Gainotti, Silveri, Villa, & Miceli, 1986; Nickels, 1997), while the functioning of the semantic system was not fully tested.

Kiran et al. (2007) conducted a category-member verification of inanimate concepts and were the only that included IWA with respect to their specific underlying language deficit as evaluated by the PALPA (Psycholinguistic Assessment of Language Processing Abilities in Aphasia, Kay, Coltheart, & Lesser, 1992). IWA with a primary semantic deficit produced more errors than the non-semantically impaired IWA. Similarly, young and older healthy adults, semantically impaired and unimpaired aphasic participants) showed significant TYP effects on accuracy and reaction times.

To conclude, the above-summarised studies on TYP in IWA demonstrated a huge inconsistency in the obtained results, which are due to partly missing or limited individual diagnostics of the specific impairment in IWA. A detailed diagnostic of the underlying aphasic impairment as conducted in Kiran et al. (2007) should be obligatory for examining linguistic variables and their influence on language processing. The diagnosis of aphasic syndromes in the former studies is not sufficient because of the high heterogeneity of symptoms and error patterns within the single syndromes (e.g., Badecker & Caramazza, 1985; Caramazza, 1984; Schwartz, 1984).

1.2 Methodological background

In the current dissertation, I used different methodologies to evaluate the influence of the variables AOA and TYP on semantic processing in different populations. Hence, I acquired offline behavioural data (studies I to III) and online electrophysiological data (studies I and III). In the following, I am going to introduce the experimental psycholinguistic paradigms that have been selected in order to particularly investigate the access to the semantic processing level. Moreover, I will provide an overview of the neuroscientific method event-related potentials (ERP) acquired by means of the electroencephalography (EEG) and the electrophysiological correlate that is associated with semantic processing.

1.2.1 Behavioural measures and semantic processing paradigms

Models of language processing in psycholinguistics are mainly based on experiments that investigate the behaviour in terms of measuring the response times or error rates while the participants perform a language-related task. There is a huge variety of paradigms that have been used to study the different processing levels involved in speech perception and production, reading, writing, or semantic processing (e.g., Garrod, 2006; Gonzalez-Marquez, Mittelberg, Coulson, & Spivey, 2007; Grosjean & Frauenfelder, 1997). It is assumed that the implementation of specific tasks reflects the structure of the language system, in that the more complex a mental process is, the longer it takes to process the stimuli (as reflected in reaction times) and the more errors are made. In the present project, I focused on semantic processing. For that reason, two different paradigms have been chosen that require deep semantic analysis (without speech production) to solve the tasks and thus reflect access to the semantic processing level. Study II uses a semantic categorisation task in form of animacy decisions, while the studies I and III are based on semantic category-member verifications. Both paradigms are summarised below.

1.2.1.1 Animacy decisions

In the literature, animacy decision tasks are often referred to as semantic categorisations and have mainly been studied in the frame of category-specific deficits in aphasia (e.g., Warrington, 1975; Warrington & Shallice, 1984). In animacy decisions, participants are requested to judge the animacy (i.e., living vs. non-living, natural vs. man-made, or animate vs. inanimate) of presented words or pictures. This task requires deep semantic analysis processes and the retrieval to semantic concepts and their semantic features (Allen, Goldstein, Madden, & Mitchell, 1997). Some authors combine animacy decisions with semantic priming (Allen et al., 1997; Pecher & Raaijmakers, 2004), while others just present single items that have to be judged with respect to their animacy (Andrews & Heathcote, 2001; Menenti & Burani, 2007). To study TYP and AOA, animacy decisions have been conducted by presenting stimuli as pictures (Catling & Johnston, 2006a; Morrison et al., 1992; Morrison & Gibbons, 2006) or as written words (De Deyne & Storms, 2007; Ghyselinck et al., 2004; Menenti & Burani, 2007).

1.2.1.2 Semantic priming and category-member verifications

Similar to animacy decisions, category-member verifications constitute a task that demands deep semantic analysis. It is based on the semantic priming principle (for reviews on semantic priming, see McNamara, 2005; Neely, 1991), which has first been reported by Meyer and Schvaneveldt (1971). Semantic priming represents a cognitive process that shows processing facilitation (in form of faster response times and fewer errors) in target stimuli that have been preceded by a semantically related stimulus. Various forms of this paradigm have repeatedly been used to study cognition and language processing in an enormous quantity of experiments. The majority of studies used semantic priming in combination with lexical decisions or naming, but it has also been used with semantic processing tasks (McNamara, 2005). In category-member verifications, the participants are presented with a semantic category (superordinate) that is followed by a member or non-member of the preceding category. Processing time is reduced if the member belongs to the category in contrast to a false pairing of a category and the target member. This paradigm also constitutes the classical task to obtain TYP effects. The first studies investigating TYP presented pairings of a category and a (non-)member in form of a sentence verification task (e.g., “A bird is an animal”, Rips et al., 1973; “All robins are birds”, McCloskey & Glucksberg, 1979). Later on, only word pairs have been used in the order category-member (Fujihara et al., 1998; Holmes & Ellis, 2006; Kiran et al., 2007; Larochelle & Pineau, 1994) or member-category (Casey, 1992; Larochelle et al., 2000). With respect to AOA, only Holmes and Ellis (2006) conducted a category-member verification so far. However, these authors revealed no effects of AOA as soon as the items were controlled for TYP.

1.2.2 Event-related potentials (ERPs) and the N400 component

While behavioural measures represent the offline outcome of a mental process and are not able to disentangle sub-processes of language processing, electrophysiological methods are able to display the precise online processing time course (in milliseconds) of cognitive operations such as language processing (for reviews, see Duncan et al., 2009; Friederici, 2004; Kutas & Van Petten, 1994; Kutas, Van Petten, & Kluender, 2006; Luck, 2005). Electrophysiological activation of the human brain is measured by means of the electroencephalogram (EEG), which has been discovered by Berger, who published his seminal work in 1929. A number of electrodes applied along the human scalp record the sum of synchronous activation potential shifts (measured in voltage) of large populations of neurons that occur during the perception of a sensory stimulus or higher levels of cognitive processing (e.g., access to meanings, memory processes, attention, motor activity). Different averaging procedures of electrophysiological activity that are time-locked to the onset of experimental stimuli result in event-related potentials (ERPs). It is assumed that sub-processes of the complex language processing system highly correlate with the voltage amplitude of certain ERP components. ERP components are defined by their polarity (positive [P] or negative [N]), their latency from the onset of the stimulus event to the amplitude peak (in ms, e.g., 200, 400, or 600), the size of the amplitude relative to a pre-stimulus baseline and a reference electrode (in µV), and their topographical occurrence (e.g., frontal, central, parietal, occipital; right, left). Conclusions on the actual origin of the neuronal source of activation, however, are not possible on the basis of the topographical occurrence of ERP responses because only activity from neurons that are radially oriented to the scull are measured and activity in deeper brain regions do not adequately contribute to the final signal (Luck, 2005).

One of the most important language-related ERP components is the N400 component (for reviews, see Duncan et al., 2009; Federmeier & Laszlo, 2009; Kutas & Federmeier, 2000, 2011). The N400 constitutes a negativity peaking 400 ms subsequent to the onset of a stimulus that is normally disseminated over centro-parietal electrodes. Visually presented stimuli, however, evoke a slight bias to the right hemisphere, while auditory stimuli result in a more symmetrical or left-sided distribution. Moreover, the N400 of auditory stimuli starts earlier and shows a longer duration as of visual stimuli (Friederici, 2004; Hagoort, 2008; Kutas & Federmeier, 2011; Kutas et al., 2006). Most importantly, the N400 component is sensitive to semantic violations of the stimulus, in that target items, which are semantically related to the preceding context, evoke a lower amplitude magnitude than less expected or particularly semantically unrelated items – usually known as the N400 priming effect. Since the discovery of the N400 by Kutas and Hillyard (1980) using an anomalous-sentence paradigm (see also Kutas & Hillyard, 1983, 1984), numerous studies investigated the N400 with a remarkable range of stimuli (auditory, written, pictures, sounds, faces, sign language, etc.) and tasks (Kutas & Federmeier, 2011). In the 1980s and 1990s, the N400 component was assumed to represent an index of expectation and close probability that reflects semantic integration processes (Holcomb, 1993; Kutas & Federmeier, 2011; Kutas & Hillyard, 1984). More recently, it has been shown that the N400 generally reflects a response to meaningful or word-like stimuli presented across modality (Kutas & Federmeier, 2011; Kutas et al., 2006). The N400 component is sensitive to a certain context created via single words (e.g., Bentin, McCarthy, & Wood, 1985; Bermeitinger, Frings, & Wentura, 2010; Chwilla, Brown, & Hagoort, 1995; Holcomb, 1993; Holcomb & Neville, 1990; Kiefer, Weisbrod, Kern, Maier, & Spitzer, 1998), word lists (e.g., Bentin, Kutas, & Hillyard, 1995; Nobre & McCarthy, 1994), sentences or discourses (e.g., Kutas & Hillyard, 1984; Van Berkum, Hagoort, & Brown, 1999; Van Petten, 1993).

Most authors agree that the N400 represents the access to the semantic processing level (e.g., Federmeier & Laszlo, 2009; Kutas & Federmeier, 2000; Lau, Phillips, & Poeppel, 2008). Kutas and Federmeier (2011) extend this assumption by proposing that the N400 constitutes a time interval (circa 200 to 700 ms) that reflects a feedforward convergence of external and internal input streams that have previously been perceived within the first 200 ms post-stimulus onset or are pre-activated by the context. The access to the long-term multimodal memory proceeds dynamically within the interval of the N400 and creates a multi-modal meaning of an item (Laszlo & Federmeier, 2010). The context in which an item is presented has a crucial influence on the baseline processing activity of an item and thus on the N400 amplitude. Pre-activation caused by a prime or context in any sense (linguistic information such as semantic features, phonological neighbours; non-linguistic information such as mood, attentional state, knowledge of the world) leads to a reduction of the baseline N400 and hence a reduction of the target word amplitude. According to Laszlo and Federmeier (2009), the created binding between context and item is temporary, implicit and displays a continuous process that varies across people and their stored experiences as well as their attentional states.

Therefore, the measurement of the N400 is a useful tool to evaluate semantic memory states (compared to a control condition) and to investigate the influence of variables on semantic processing and priming.

2. Aims and research questions

As shown in chapter 1, the functional origin of AOA effects is still under debate (Brysbaert & Ghyselinck, 2006). It is assumed that frequency-independent AOA effects originate either at the semantic processing level or at the transition between semantics and phonology (i.e., lemma-level, according to data primarily involving speech production), while frequency-related AOA effects rather originate at the word form level. The majority of studies investigating the origin of AOA effects collected behavioural data in healthy young individuals. Previous studies regarding AOA effects in aphasic language processing primarily examined speech production.

The aim of the current dissertation project was to examine the influence of AOA on semantic processing without accessing speech production levels with different methodologies and populations in order to evaluate a conceivable semantic origin of frequency-independent AOA effects. For this reason, I considered the variable AOA from different angles.

First, I was interested in the interplay of AOA with a clearly semantic variable - that is semantic typicality (TYP). The objective was to investigate if and how both variables interact as assessed by means of behavioural and electrophysiological data while conducting different semantic processing tasks that used either auditory or visual (written) input modalities in healthy young and older individuals. Hence, I conducted an auditory category-member verification task (studies I and III, see below) and in collaboration with Dr. Astrid Schröder and Steffie Ruppin an animacy decision task by presenting written category members (study II). The target items systematically differed with respect to their AOA (early vs. late acquired) and their TYP (typical vs. atypical). To exclude an influence of frequency-related AOA effects, the target items were controlled for word frequency. Depending on the presentation modality, the items were also controlled for word length (number of phonemes or characters, syllables), duration to the uniqueness point and/or animacy.

Second, I scrutinized whether a specific deficit of the semantic system in individuals with aphasia (IWA) affects the linguistic variables AOA and TYP, if both variables originate at the semantic processing level (with typical and/or early acquired words to be better preserved and thus easier to access than atypical and/or late acquired words).

Third, since aphasia normally occurs in an elderly population (i.e., above 50 years of age) investigating IWA also needs to include elderly age-matched healthy controls. Thus, I was further interested in the question on how semantic processing changes in the ageing brain.

To answer these research questions, we conducted three studies primarily addressing the interplay of AOA and TYP on semantic processing:

- Study I (chapter 5) investigated AOA and TYP effects in healthy young individuals in an auditory category-member verification task while collecting behavioural (reaction times and accuracy rates) and ERP data (Räling, Holzgrefe-Lang, Schröder, & Wartenburger, 2015).
- Study II (chapter 6) collected behavioural data (reaction times and accuracy rates) on AOA and TYP effects from healthy young and elderly individuals[4] performing an animacy decision task. Unlike studies I and III, we included not only AOA and TYP as predictors, but also word frequency and semantic domain (Räling, Hanne, Schröder, Keßler, & Wartenburger, 2016)
- Study III (chapter 7) examined AOA and TYP effects in healthy elderly participants and IWA suffering from a specific semantic deficit in an auditory category-member verification task (see study I) by means of behavioural and ERP data (Räling, Schröder, & Wartenburger, 2016).

The results of the studies are summarised and discussed in the following chapters.

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[4] The final manuscript of study II (Räling, Hanne, Schröder, Keßler, & Wartenburger, 2016) includes data of healthy young participants only, while in former drafts of the manuscript also data from healthy elderly were reported (Räling, Schröder, Keßler, & Wartenburger, under revision).

3. Summary of the major results

3.1 Response times

Study I to III showed main effects of TYP (typical target words have been processed more quickly than atypical target words) and of AOA (early acquired target words have been processed more quickly than late acquired target words). Interactions between TYP and AOA were non-significant in each of the three studies. Moreover, the IWA with a central semantic deficit performed significantly slower in judging atypical vs. typical words than the age-matched control group, while the IWA did not deviate from the controls with regard to the factor AOA.

3.2 Accuracy rates

The accuracy data in study I and III (accuracy data in study II were at ceiling) revealed significant main effects of TYP in each of the groups (healthy young and elderly, and IWA) with typical target words resulting in higher accuracy rates than atypical target words. In contrast, neither main effects of AOA nor significant interactions between TYP and AOA were found. The IWA performed with significantly more errors on atypical words vs. typical words compared to the elderly controls, while AOA did not lead to an increase in errors.

3.3 ERP results

In study I, the variable TYP and the control condition congruity significantly affected the N400 component at centro-parietal electrodes in young healthy participants, while AOA did not influence the amplitude of the N400 component. In study III, the elderly showed a shift of the N400 congruity effect to right frontal electrodes. Group comparisons on the N400 component revealed non-significant differences between the elderly and the IWA with respect to the variables TYP and AOA. However, within-group comparisons showed an inverse N400 effect of AOA in the elderly, with more negative amplitudes for early vs. late acquired words, but none effect of the N400 for TYP. The variables TYP and AOA did not significantly affect the N400 amplitude of the IWA.

4. Conclusion

I collected behavioural (RTs, accuracy rates) as well as electrophysiological data (except for study II) in different populations (healthy young and older individuals, IWA with a semantic deficit) while conducting linguistic tasks that require a deep semantic analysis without speech production. The purpose of the project was to determine the origin of (frequency-independent) AOA effects by investigating the dependence of AOA on the semantic variable TYP.

With regard to the RT results, the analyses across the three studies revealed the most informative and consistent results with respect to the variables AOA and TYP. The RT results revealed in each of the three groups of participants faster RTs for typical and early acquired words compared to atypical and late acquired words, respectively. The RT data replicated the results of previous studies that separately investigated the variables AOA and TYP in lexical and semantic processing (e.g., Johnston & Barry, 2006; Juhasz, 2005; Larochelle & Pineau, 1994; Morrison & Gibbons, 2006). The independence of AOA and TYP was supported by null interactions of both variables in each of the RT analyses in the three studies. The IWA only deviated from the elderly with respect to the variable TYP.

Both tasks (animacy decisions and category-member verifications) that have been conducted in the studies involve processing of various levels of word perception: The task-related processing requires access to the visual or auditory analysis level (depending on the input modality presentation), to the phonological or graphemic input lexicon (lexeme level), to the link between input lexicon and semantics (comparable to lemma-level), and to the semantic (conceptual) level (as proposed for speech production by Levelt, 1989; Levelt et al., 1999; or within the logogen model by Morton, 1969; see also Patterson & Shewell, 1987 and section 1.1.1). The decision or verification necessitated in the task will be taken on the basis of a semantic analysis. The effects obtained for both variables at the RT level may have originated at one of the processed levels, but can be narrowed to the link between input lexicon and semantics or semantic level for frequency-independent AOA effects (Brysbaert & Ghyselinck, 2006; Brysbaert et al., 2000) and the semantic level for TYP effects (McRae et al., 1999; Woollams, 2012). Thus, with respect to the origin of AOA effects, reaction times of healthy language processing alone do not point to a certain processing level. Only the consideration of impaired semantic processing yields new insights: In comparison to the RTs of the elderly controls a semantic impairment led to an enhancement of TYP effects only. This provides evidence for a semantic origin of TYP effects but excludes the same for frequency-independent effects of AOA.

The accuracy rate analyses also revealed very consistent results with respect to studies I and III. Effects of AOA or significant interactions between AOA and TYP were not present in any of the conducted studies within the accuracy data, while TYP effects were always apparent. Thus, it seems that the measurement of accuracy rates provides better insights into access to the semantic processing level than RT data does. Furthermore, the accuracy data showed – similar to the RTs – group differences between elderly controls and the IWA for TYP only (significantly more errors on atypical vs. typical words in IWA compared to the elderly). These results also underline a semantic origin of TYP, while they do not support a semantic origin for AOA.

To summarise, the overall behavioural data from studies I to III rather point to an origin of frequency-independent AOA effects at the link between input lexica and semantics (lemma-level) while the results speak against an origin at the semantic level. A semantic origin can only be supported for the variable TYP.

These findings are also in line with the ERP data from study I in the healthy young participants (N400 effect of TYP only) providing further evidence for a larger influence of the variable TYP on the dynamic compilation of a words' meaning (as assumed in the N400 model of Kutas & Federmeier, 2011) than it is the case for the variable AOA. It seems that frequency-independent AOA effects originating at the lemma-level cannot be captured with the N400 priming effect.

The ERP results from study III, do not fully contribute to the overall conclusion. Firstly, this is because the IWA did not show any differences on the ERP response in general (they did not produce a N400 congruity effect as obtained in the control condition in the healthy young participants) and in particular with respect to the variables AOA and TYP. Similar effects in IWA have already been described in the literature (Hagoort, Brown, & Swaab, 1996; Swaab, Brown, & Hagoort, 1997). Secondly, in consideration of the ERP responses in the elderly controls, absent effects at the ERP level in IWA are not surprising: On the one hand, the elderly showed a rather unusual shift of the N400 congruity effect to right frontal electrodes (in comparison to a more standard centro-parietal distribution of the N400 congruity effect in the young, healthy individuals in study I) and no differences on the N400 amplitude regarding the variable TYP. On the other hand, rather unexpected, the ERP data of the elderly revealed an inverse N400 effect for the variable AOA, with more negative amplitudes for early vs. late acquired words. I explain this unexpected effect of AOA with regard to neuro-functional changes and an increasing inhibition deficit that can be observed in ageing (see section 7.4.4 for a discussion).

Concluding, the data of the current dissertation project support an origin of TYP effects at the semantic level and an origin of frequency-independent AOA effects at the links between the (phonological or graphemic) input lexicon and the semantic system. These findings expand previous assumptions, which proposed an origin of AOA effects at analogous stages for speech production only (Brysbaert & Ghyselinck, 2006; Brysbaert et al., 2000). Assuming the origin of AOA effects at multiple levels, namely at each and every link between the (input or output) lexicon and the semantic level would also explain increasing effect sizes that cumulatively occur in tasks that require speech production (as proposed by Catling & Johnston, 2006a).

II. ORIGINAL JOURNAL ARTICLES

5. On the influence of typicality and age of acquisition on semantic processing: Diverging evidence from behavioural and ERP responses[5]

Abstract

Various behavioural studies show that semantic typicality (TYP) and age of acquisition (AOA) of a specific word influence processing time and accuracy during the performance of lexical-semantic tasks. This study examines the influence of TYP and AOA on semantic processing at behavioural (response times and accuracy data) and electrophysiological levels using an auditory category-member verification task. Reaction time data reveal independent TYP and AOA effects, while in the accuracy data and the event-related potentials predominantly effects of TYP can be found. The present study thus confirms previous findings and extends evidence found in the visual modality to the auditory modality. A modality-independent influence on semantic word processing is manifested. However, with regard to the influence of AOA, the diverging results raise questions on the origin of AOA effects as well as on the interpretation of offline and online data. Hence, results will be discussed against the background of recent theories on N400 correlates in semantic processing. In addition, an argument in favour of a complementary use of research techniques will be made.

5.1 Introduction

Numerous studies provide evidence that psycholinguistic variables influence speed and accuracy during language comprehension and production. Semantic typicality and age of acquisition are two word characteristics, which seem to affect lexical-semantic processing in particular.

Semantic typicality (TYP) is defined as the rated degree to which a semantic concept represents a semantic category. The originally called "Theory of

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[5] This chapter was adapted from the final draft post-refereeing: Räling, R., Holzgrefe-Lang, J., Schröder, A., & Wartenburger, I. (2015). On the influence of typicality and age of acquisition on semantic processing: Diverging evidence from behavioural and ERP responses. *Neuropsychologia*, 75, 186–200. doi:10.1016/j.neuropsychologia.2015.05.031

Prototypicality" assumes that certain members constitute better examples ("goodness-of-example") and are thus more typical than other members of a category (Osherson & Smith, 1981; Rosch, 1975). For instance, for the semantic category BIRD a *sparrow* would be more typical than a *penguin*. The notion of prototypes was first described by Posner and Keele (1968) in a perceptual learning experiment. Rosch and her colleagues (Mervis et al., 1976; Rosch, 1973a, 1973b) used various experimental tasks to investigate the inner structure of semantic concepts and revealed that TYP could also be found in natural categories. They demonstrated that members of a semantic category are not equally ranked and that the borderlines between categories are fuzzy rather than clearly defined (Hampton, 1995; Rosch, 1978).

Differences between typical and atypical members of a category do not only appear in typicality ratings (Rips et al., 1973; Schröder et al., 2012), but also in response latencies obtained from visual semantic categorisation tasks (Holmes & Ellis, 2006; McCloskey & Glucksberg, 1979; Rips et al., 1973), with faster reaction times for typical vs. atypical members. This so called *typicality effect* has repeatedly been demonstrated in written category-member verification tasks where a semantic relation, including a superordinate and a subordinate item, is visually presented in form of a sentence (e.g., "A SPARROW is a BIRD", Mervis & Rosch, 1981; Smith et al., 1974) or as a word pair (e.g., "BIRD – SPARROW"; Hampton, 1997; Kiran et al., 2007; Larochelle & Pineau, 1994). In addition, TYP effects have been found in semantic tasks involving category-based induction and deduction (Lei et al., 2010; Rein et al., 2010), visual living/non-living-decisions (Morrison & Gibbons, 2006), category naming (Casey, 1992; Hampton, 1995), and in tasks involving both lexical and semantic processes like picture naming (Dell'Acqua et al., 2000; Holmes & Ellis, 2006), reading (Garrod & Sanford, 1977), sentence production (Kelly et al., 1986) or category-member-generation (Hernández-Muñoz et al., 2006). Concerning different forms of categories, TYP effects are not restricted to perceptual (e.g., GEOMETRIC FIGURES or COLOURS; Posner & Keele, 1968; Rosch, 1973a) or natural taxonomic categories (e.g., biological: FRUITS, ANIMALS or artifacts: FURNITURE, VEHICLES; Larochelle et al., 2000), but also exist in ad-hoc categories (e.g., "things to buy at the bakery"; Barsalou, 1983; Sandberg et al., 2012) and well-defined categories (e.g., ODD NUMBERS or MALE; Armstrong et al., 1983; Larochelle et al., 2000; Sandberg et al., 2012).

Several semantic representation models seek to implement the underlying mechanisms of the TYP effect. In the framework of the theory of prototypes (Osherson & Smith, 1981; Rosch, 1973b), the prototype of a semantic category has been depicted as a mental idealised image, which is created by a list of the most typical features of a category and the greatest family resemblance to other category members (Rosch & Mervis, 1975). Within this theory a member of a category is considered to be more typical the more features or attributes it has in common with the prototype (Rosch, 1975, 1978). Thus, the more typical an item is, the more features it shares with other category members, which speeds-up the access to typical items, resulting in faster reaction times.

Feature-comparison models do not assume prototypical representatives, but instead describe TYP effects in categorisation tasks based on individual features which comprise semantic categories (McCloskey & Glucksberg, 1979; Smith et al., 1974). TYP effects have also been explained in network models, where categories are displayed as separate nodes within the semantic network and TYP effects result from different strengths of the links between members and categories (Collins & Loftus, 1975; Glass & Holyoak, 1974). Recent accounts of TYP effects combine core characteristics of the above mentioned models, including feature comparisons as well as spreading activation from network models, in computational connectionist models (McClelland & Rogers, 2003; Rogers et al., 2004). In a connectionist framework, McRae et al. (1999) argue against concept typicality and assume rather a typicality of features. Thus, typicality is determined by the intercorrelation of semantic features. Typical items therefore possess features which are highly intercorrelated with other typical members of the category (e.g., sweet and seeds as typical intercorrelated semantic features for FRUITS), while atypical items are represented by less intercorrelated features.

Age of acquisition (AOA) is defined as the age at which the concept of a certain word has been learned and produced for the first time (Ellis, 2011). In their pioneering work, Carroll and White (1973) first described AOA as a critical variable which influences word production regardless of the words' frequency, in that objects with early acquired names are named faster than objects with late acquired names.

Subsequent behavioural studies in different languages and populations replicated this benefit in language processing of words with an early vs. late AOA for numerous lexical and/or semantic tasks (Ellis, 2011; Johnston & Barry, 2006; Juhasz, 2005). AOA effects have been found in visual and auditory lexical decision tasks (Menenti & Burani, 2007; Smith et al., 2006), thus pointing to a potential lexical origin of AOA in language recognition. The influence of AOA on semantic processing is less clear: AOA effects have been found in various visual semantic tasks (e.g., semantic association, categorisation, or living-/non-living-classification tasks; (Brysbaert et al., 2000; Johnston & Barry, 2006) and provide evidence for an influence of AOA on semantic word processing. However, some studies failed to find comparable results in semantic tasks (Holmes & Ellis, 2006; Morrison et al., 1992). Moreover, increased effect sizes for AOA have been reported as soon as semantic and additional lexical output processes were involved (e.g., for word naming and picture naming: Belke et al., 2005; Chalard & Bonin, 2006; for word reading and written word production tasks: Bonin et al., 2006). Based on these contradictory results, numerous proposals on the locus of AOA effects have been discussed (Juhasz, 2005). In sum, single locus theories localize AOA effects on either phonological / lexical processing levels (Brown & Watson, 1987; Laganaro & Perret, 2011; Perret et al., 2014) or semantic processing levels (Brysbaert et al., 2000; Steyvers & Tenenbaum, 2005). In contrast, AOA effects were recently explained within multiple processing level accounts that are mainly based on production data (Brysbaert & Ghyselinck, 2006; Moore, Smith-Spark, & Valentine, 2004). As an example, Catling and Johnston (2009) claim that the AOA effect is additive and increases with the number of involved processing stages. In particular, additional involvement of phonological processes, as is the case in word reading or word production, will enhance the expected effect size (Catling & Johnston, 2006b, 2009). Thus, Catling and Johnston postulate two parallel origins for AOA effects: a first one at early phonological levels and a second one at the link between semantic and phonological representations. As a further example of multiple level theories, recent computational accounts aim at modelling the underlying mechanisms of AOA effects within connectionist models (Ellis & Lambon Ralph, 2000). Within these models the focus is not on specific processing levels, such as phonological or semantic levels, but on the strength of connections between representations affecting the entire cognitive system. Ellis and Lambon Ralph (2000) demonstrated a crucial benefit of early acquired concepts over late acquired concepts in their network model, which is due to the continuing loss of the network's plasticity over life (Mermillod, Bonin, Méot, Ferrand, & Paindavoine, 2012; Zevin & Seidenberg, 2002).

Considering the studies on TYP and AOA separately, in sum, the majority of the above mentioned studies provide evidence for an influence of both variables on visual semantic processing at a behavioural level. Only few studies have investigated the effects of AOA and TYP within the same experiment, although rating studies have shown that TYP and AOA are substantially correlated (Holmes & Ellis, 2006; Schröder et al., 2012), with early acquired concepts being the more typical members of a category (e.g., bed - FURNITURE) (Holmes & Ellis, 2006; Mervis & Rosch, 1981). To our knowledge, Holmes and Ellis (2006) were the first to directly compare the effect of TYP and AOA in semantic processing. They showed that in a visual category-member verification task, AOA effects disappeared as soon as the items are controlled for TYP. Hence it is important to control for TYP and AOA in order to clarify how the two variables influence word processing, whether effects occur in dependence of each other (as indicated by a possible interaction), and if both arise from the same semantic processing level.

A crucial ERP component that is predominantly assigned to semantic processing and context integration[6] is the N400. The N400 is characterised by a negative amplitude peaking around 400 ms post stimulus onset and is distributed over centro-parietal areas with a slight asymmetry to the right hemisphere for visual stimuli (Federmeier & Laszlo, 2009; Kutas & Federmeier, 2011). Kutas and Hillyard (1980) first reported the N400 component in an anomalous-sentence-paradigm. They discovered a larger negativity for sentence final words which are semantically unrelated (incongruent targets) to the preceding sentence context, in contrast to

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[6] Notably, in addition to the wealth of literature on semantic manipulations modulating the N400, it has also been found to be sensitive to rhyme priming (Praamstra, Meyer, & Levelt, 1994; Rugg, 1984).

semantically related words (congruent targets). Subsequent studies revealed that the N400 is not only influenced by semantic violations but also by the cloze probability, or rather expectancy, of words given in a sentential context (Kutas & Federmeier, 2000). In priming studies, semantically related but rather unexpected words evoke a larger N400 than semantically related but fully expected ones (Federmeier & Kutas, 1999; Kutas & Hillyard, 1984). These so called N400-priming effects have been shown both at sentence level processing and at the word level using word lists (Bentin et al., 1995; Nobre & McCarthy, 1994) or word pairs (Chwilla et al., 1995; Holcomb & Neville, 1990) presented visually and also auditorily (Kutas & Van Petten, 1994; O'Rourke & Holcomb, 2002). In studies directly comparing the presentation of auditory versus visual stimuli, the auditorily evoked N400 usually starts earlier, has a longer duration, and a more symmetric distribution, with an occasional slight asymmetry towards the left hemisphere in comparison to the visually evoked N400 component (Hagoort, 2008; Holcomb & Neville, 1990). Further, modality differences of semantic priming on the N400 amplitude have been observed with respect to different stimulus onset asynchronies (SOAs). Especially, long SOAs (800 ms) result in larger priming effects in auditory processing compared to visual processing (Anderson & Holcomb, 1995). With regard to the tested variables, several ERP studies demonstrated an influence of TYP on the N400 amplitude using visual category-member verification tasks in that atypical items evoke a larger N400 amplitude than typical items (Fujihara et al., 1998; Heinze et al., 1998; Núñez-Peña & Honrubia-Serrano, 2005; Stuss et al., 1988). However, regarding AOA, to our knowledge there is no comparable study that reports an influence of AOA on the N400 component as a result of a semantic task.

In sum, numerous behavioural studies provide evidence that TYP influences word processing at a semantic origin of the underlying effects. However, the underlying mechanisms for AOA effects (being more at the semantic or more at the lexical level) are still under debate. Investigations on the electrophysiological level for TYP and AOA that might shed further insight in the locus of origin are less common. ERP studies investigating the visual modality suggest an influence of TYP on the semantic level, indexed by the modulation of the N400 component. Due to the lack of pertinent ERP literature, comparable conclusions regarding AOA effects are not warranted. Hence to date, it is not clear if both variables function on exactly the same level of word processing. In addition, not much is known about the auditory semantic processing of both variables, because most previous research has been performed in the visual modality. Therefore, the present study systematically investigates the influence of TYP and AOA a) within one experiment to examine whether both variables operate independently or whether they interact, b) on auditory semantic processing to expand findings from the visual modality, and c) by using offline behavioural measures and online ERP data to further determine the origin of both variables within the language processing system. For this purpose, an auditory category-member verification task was carried out. In addition to accuracy and reaction time data, we were especially interested in the underlying semantic processes observable by means of the N400 component. Based on the above cited literature, we hypothesise a semantic origin for both variables in a semantic system. Hence, we expect to find slower reaction times and a higher error rate for atypical and late acquired words in comparison to typical and early acquired words, respectively. Under the assumption that both TYP and AOA effects originate at least in parts at the semantic level, we would further expect a larger N400 amplitude for atypical and late acquired words. On the contrary, differences in the effects of both variables at the behavioural and/or electrophysiological level would point to distinct origins of both variables in the word processing system.

5.2 Material and methods

5.2.1 Participants

Thirty-six healthy native speakers of German took part in the experiment. The participants were recruited within the student population of the University of Potsdam. Every participant was right-handed as evaluated by a German version of the Edinburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal vision. No participant reported a history of neurological, psychiatric, or hearing disorders. Participants gave informed consent and received either course credit or reimbursement for their participation. The experiment was approved by the local ethics committee of the University of Potsdam. Due to technical problems during the experiment, five participants had to be excluded from data analysis. In addition, seven participants were excluded as a result of EEG-artefact rejection (see below). Hence, the data of twenty-three participants (14 female, 9 male) with a mean age of 22.8 years (*SD*: 2.98 years; range: 18 to 29 years) was further analysed for the current purpose.

5.2.2 Stimuli

An auditory category-member verification task was conducted using a 2 × 2 factorial study design with four conditions: typical / early acquired, typical / late acquired, atypical / early acquired, atypical / late acquired. The stimulus material was composed of 240 prime-target word pairs. Nine semantic category names (four natural: FRUITS, VEGETABLES, BIRDS, ANIMALS; five man-made: CLOTHING, FURNITURE, VEHICLES, TOOLS, MUSICAL INSTRUMENTS) served as primes. The target words were selected from a database containing German norms for semantic typicality, age of acquisition, and concept familiarity (Schröder et al., 2012) and were members of one of the nine semantic categories (e.g., pineapple - FRUIT, anorak - CLOTHING, etc.; see Table A 1 in the Appendix). The 240 target words systematically differed with respect to TYP (typical vs. atypical) and AOA (early acquired vs. late acquired). Target words were balanced for animacy (natural or man-made), duration until the uniqueness point, word length (number of phonemes and syllables), and word frequency (logarithmic normalized lemma frequency, as available from the German dlexDB database (www.dlexdb.de, Heister et al., 2011)) with no statistically significant differences for these variables across the four conditions (see Table A.1 in the Appendix).

In two thirds of the word pairs, prime and target were semantically related in that the target belonged to the semantic category (e.g., FRUITS – pineapple) (congruent trials, $n = 160$). In one third of the word pairs, prime and target were not semantically related: the target belonged to one of the other categories (e.g., FRUITS – sock) (incongruent trials, $n = 80$). Effects of TYP and AOA were only analysed on congruent trials, hence we inserted a greater number of them. Four pseudo-randomized lists of the 240 prime-target word pairs (160 congruent, 80 incongruent trials) were created for stimulus presentation. Incongruent trials served as filler trials in which participants had to press the “no”-button as well as a control condition to replicate the known N400 congruity effects, to prove the efficacy of the experimental design.

5.2.3 Procedure

The auditory category-member verification task was carried out in a sound-attenuating chamber while the EEG was recorded. Participants were instructed to listen to the auditory word pairs and to decide intuitively, as fast and as accurately as possible via button press (Cedrus RB-830 Response Pad, http://cedrus.com/) whether the presented second word (target) was a member of the previous presented semantic category (prime) or not (see Figure 2). Response latency was recorded. Participants had to press a green button with their left index finger for congruent word pairs and a red button with their left middle finger for incongruent word pairs. The assignment of the buttons was changed for half of the participants. To ensure that participants were familiar with the experimental task, a practice phase was conducted including four congruent and two incongruent prime-target word pairs that were similar but not identical to the experimental stimuli.

During the experiment, participants listened to one of the four pseudo-randomized lists of word pairs. Each prime-target word pair was presented only once. Stimuli were played binaurally over in-ear-headphones (E-A-RTONE 3A Insert Earphones, Aearo Technologies Auditory Systems, Indianapolis, USA). Stimuli were spoken by a trained female in natural voice with normal speed. The display of the experiment was controlled by Presentation® software (Version 14.1, Neurobehavioral Systems, http://www.neurobs.com/). Each trial started with a white fixation cross in the centre of the black screen while the semantic category prime was presented auditorily with a mean duration of 607.6 ms (*SD*: 126.78 ms; duration range: 369-767 ms). The prime was followed by 300 ms silence (inter-stimulus interval (ISI)), before the target word was played[7]. Therefore, the stimulus-onset-asynchrony (SOA) varied between 669 ms and 967 ms (*M*: 907.6 ms) and can thus be assigned to rather controlled processing (Carter, Hough, Stuart, & Rastatter, 2011; Neely, 1991). The auditory presentation duration of the target words ranged from 393 ms to 1269 ms with a mean duration of 722.2 ms (*SD*: 167.4 ms). The following inter-trial-interval (ITI) was jittered between 4 and 12 s (mean ITI: 6 s) since the overall study design allowed for additional near-infrared spectroscopy (NIRS)

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[7] The best fitting ISI length of 300 ms was computed by taking into account the maximum length of the experiment (max. 30 minutes), a suitable number of items per condition, and the avoidance of acoustic and ERP overlays of the target stimulus and the preceding category prime stimulus.

measurement (NIRS data will not be presented). During the ITI the fixation cross disappeared. A self-paced short pause was implemented every 10 minutes. The experiment lasted about 60 minutes (incl. preparation of the EEG cap).

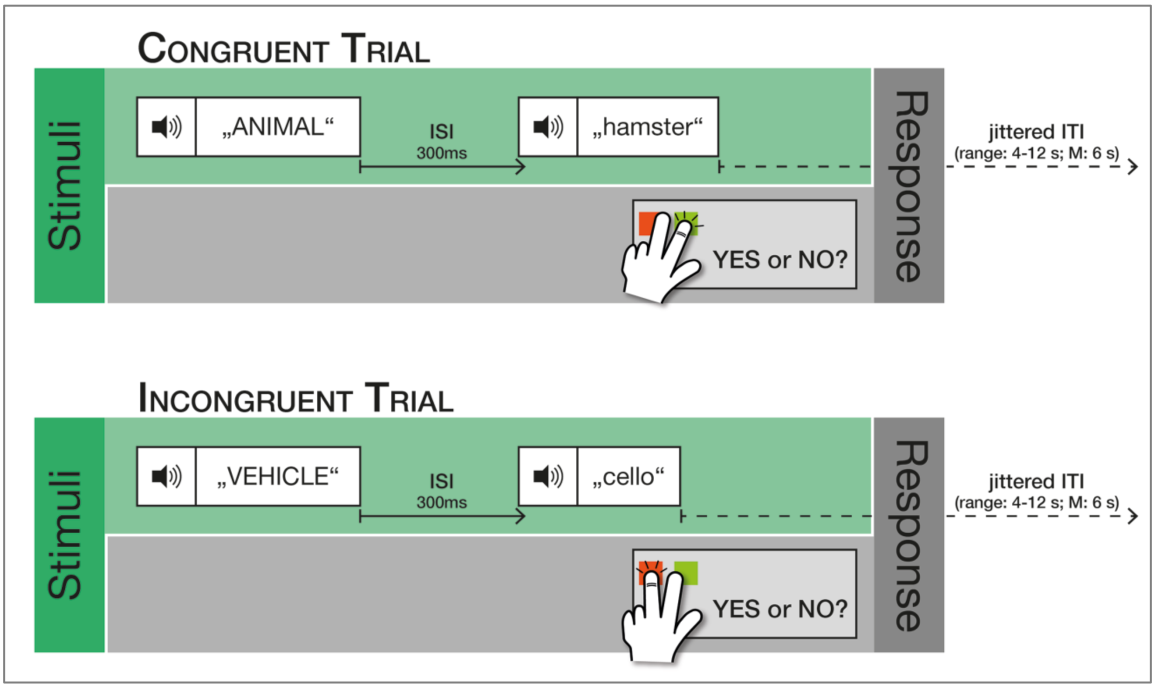

Figure 2 Schematic illustration of the study design.

5.2.4 EEG recording

EEG was recorded at 32 scalp positions with active Ag/AgCl electrodes (actiCAP, Brain Products, Germany) fixed in an elastic EEG cap (EASYCAP) with a sampling rate of 1000 Hz. According to the international 10-10 system (Epstein et al., 2006) the following electrodes were used: Fp2, Fpz, AFz, F3/4, F7/8, Fz, FC3/4, FCz, FT7/8, C3/4, Cz, T7/8, T10, CP3/4, CPz, P3/4, Pz, P7/8, PO3/4, POz, and Oz with Fp1 as ground electrode, an online reference against the left mastoid and an offline re-reference to averaged left and right mastoid. Impedances of the electrodes were kept below 5 kΩ. The electro-occulogram (EOG) was recorded from electrodes placed above (FP2) and below the right eye.

5.2.5 Data analysis

For the analysis of the behavioural data, reaction times (RTs) as well as error rates were analysed using a 2 × 2 repeated measures analyses of variances (ANOVAs) with the factors TYP (typicality: typical vs. atypical) and AOA (age of acquisition: early vs. late acquired). Only correct responses were included in the reaction time analyses. Incongruent trials served as fillers and were also excluded from data analysis. To meet the assumptions of parametric tests, RTs have been log-transformed.

EEG data analysis was performed using the Brain Vision Analyzer Software (Version 2.01; Brain Products, Gilching, Germany). A digital band-pass filter was set from 0.01 to 100 Hz (12 dB) to remove muscle artefacts and slow drifts. A notch filter of 50 Hz was used. Offline ocular correction was carried out using the algorithm of Gratton, Coles, and Donchin (1983) for vertical eye movements. For presentation purposes only, grand average ERPs were filtered offline with an 8 Hz low-pass filter (12 dB).

The continuous EEG signal was segmented into epochs of 1000 ms, relative to the onset of the target stimuli (i.e., the category member; time window: 100 ms prior and 900 ms after target onset), excluding incorrect trials. Trials that were contaminated with artefacts were rejected semi-automatically based on the following rejection criteria: maximal allowed voltage step of 35 µV/ms, maximal allowed difference of values in intervals of 150 µV, lowest allowed activity in intervals of 0.5 µV. Participants with more than 15 % rejected trials were excluded from further analysis. Epochs were baseline corrected using a 100 ms prestimulus interval (-100 ms to stimulus onset). The mean number of averaged trials per participant for the congruent trials was 37.6 for the typical / early acquired targets (*SD* = 1.58; 94.05 %), 36.62 for the typical / late acquired targets (*SD* = 1.65; 91.55 %), 35.55 for the atypical / early acquired targets (*SD* = 2.53; 88.88 %), and 34.97 for the atypical / late acquired targets (*SD* = 3.10; 87.41 %). For the incongruent trials the mean number of averaged trials per participant was 74.2 (*SD* = 2.78; 92.77 %).

ERP mean amplitude values were first analysed on the grounds of visual inspection by using a broad time window of 350 to 750 ms. This window was chosen because it includes the greatest effects for congruity and is also based on the N400 literature in auditory processing (Hagoort, 2008; Mehta, Jerger, Jerger, & Martin, 2009; Van Petten, Coulson, Rubin, Plante, & Parks, 1999). Second, to additionally evaluate the time course of existing effects within the time interval of the N400 component and to increase the statistical power for smaller, but reliable effects (see Anderson & Holcomb, 1995; Chwilla & Kolk, 2005; Chwilla, Kolk, & Mulder, 2000 for comparable analyses) further analyses were performed on five 100 ms time windows starting at 300 ms post onset.

The following six regions of interest (ROIs) were selected by computing the mean amplitudes of the four corresponding electrodes: left anterior (F7, F3, FT7, FC3), left posterior (C3, CP3, P3, PO3), midline anterior (Fpz, AFz, Fz, FCz), midline posterior (Cz, CPz, Pz, POz), right anterior (F4, F8, FC4, FT8), and right posterior (C4, CP4, P4, PO4).

Two different ERP analyses for each time window using repeated measures analysis of variance (ANOVAs) were carried out. Firstly, as a control condition and to replicate congruity effects 2 × 6 ANOVAs with the factors CONGR (congruity: congruent vs. incongruent/filler targets) and ROI (left anterior, left posterior, midline anterior, midline posterior, right anterior, right posterior) were conducted. Secondly, to examine TYP and AOA effects 2 × 2 × 6 ANOVAs were calculated on the congruent and correctly answered trials only with the factors TYP (typicality: typical vs. atypical), AOA (age of acquisition: early vs. late acquired), and ROI. The Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) was applied when appropriate, so that corrected F- and p-values are reported, but with the uncorrected degrees of freedom. Only statistically significant main effects and interactions ($p \leq .05$) for the factors CONGR, TYP, and AOA were included in post-hoc paired t-test comparisons. To analyse the topographical distribution of the effects, significant interactions of CONGR, TYP, and/or AOA with ROI were resolved by computing further paired t-tests within each of the ROIs.

5.3 Results

5.3.1 Reaction times and accuracy rates

Figure 3 depicts the mean reaction time for each condition. The analysis of the congruent mean log RTs revealed significant main effects of TYP ($F(1,22) = 15.15$, $p < .01$) and AOA ($F(1,22) = 29.15$, $p < .001$). As predicted, post-hoc comparisons showed that typical / early acquired targets were processed faster than atypical / late acquired targets. There was no statistically significant interaction of TYP and AOA ($F(1,22) = 1.03$, $p > .05$).

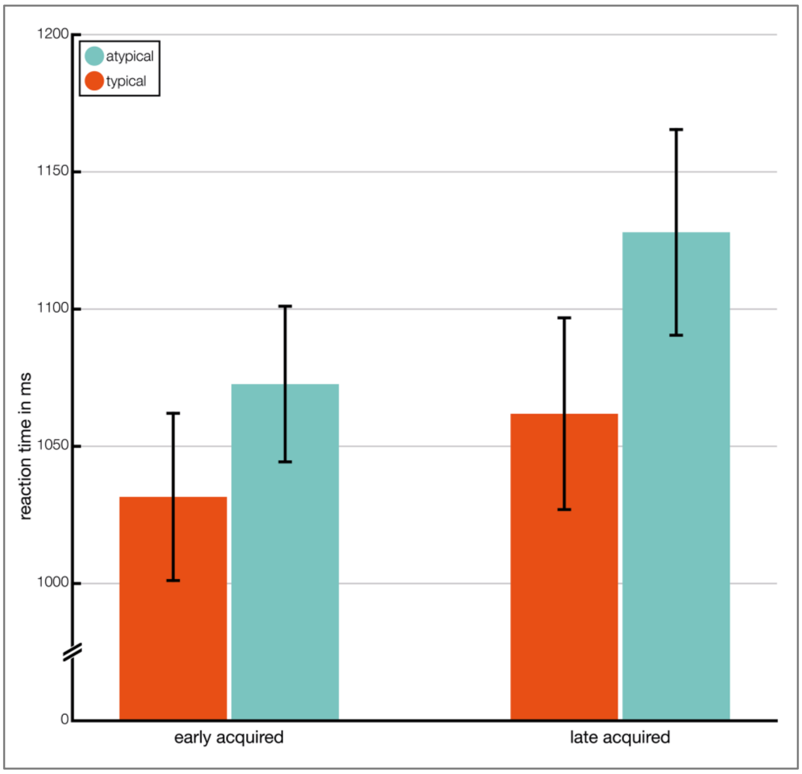

Figure 3 Mean reaction times and standard error bars for the four conditions.

Regarding the accuracy rates, the mean percentage values were as follows: typical / early acquired 1.41 %, typical / late acquired 2.83 %, atypical / early acquired 6.52 % and atypical / late acquired 7.50 %. There was a statistically significant main effect of TYP ($F(1,22) = 27.50$, $p < .001$) with more errors in atypical vs. typical items, whereas there was none for AOA ($F(1,22) = .23$, $p > .05$) and no interaction between TYP and AOA ($F(1,22) = 3.65$, $p > .05$).

5.3.2 ERP results

5.3.2.1 Congruity effects – control condition

Grand average ERPs on selected electrodes are shown in Figure 4. ERPs for congruent and incongruent trials both display a large negativity in the time windows from 350 ms to 750 ms which is more pronounced for the incongruent target trials and peaks around 500 ms. Topographical maps of the difference waves (incongruent minus congruent target trials) confirm a broad symmetrical distribution of this N400 effect, Figure 5).

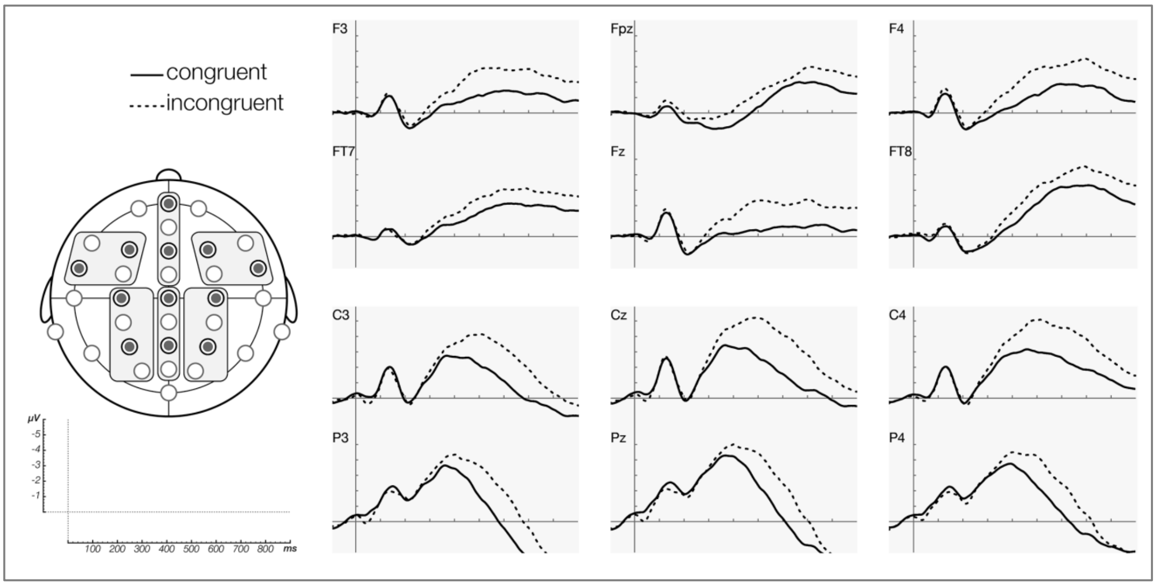

Figure 4 Congruity: Grand average ERPs at selected electrodes time-locked to the onset of the target word displaying congruent and incongruent words.

Within the time window 350 to 750 ms, the ANOVA of CONGR × ROI revealed a statistically significant main effect of CONGR ($F(1,22) = 20.15$, $p < .001$). Post-hoc analyses showed significantly greater mean amplitudes for incongruent targets than for congruent targets ($t(22) = 4.49$, $p < .001$).

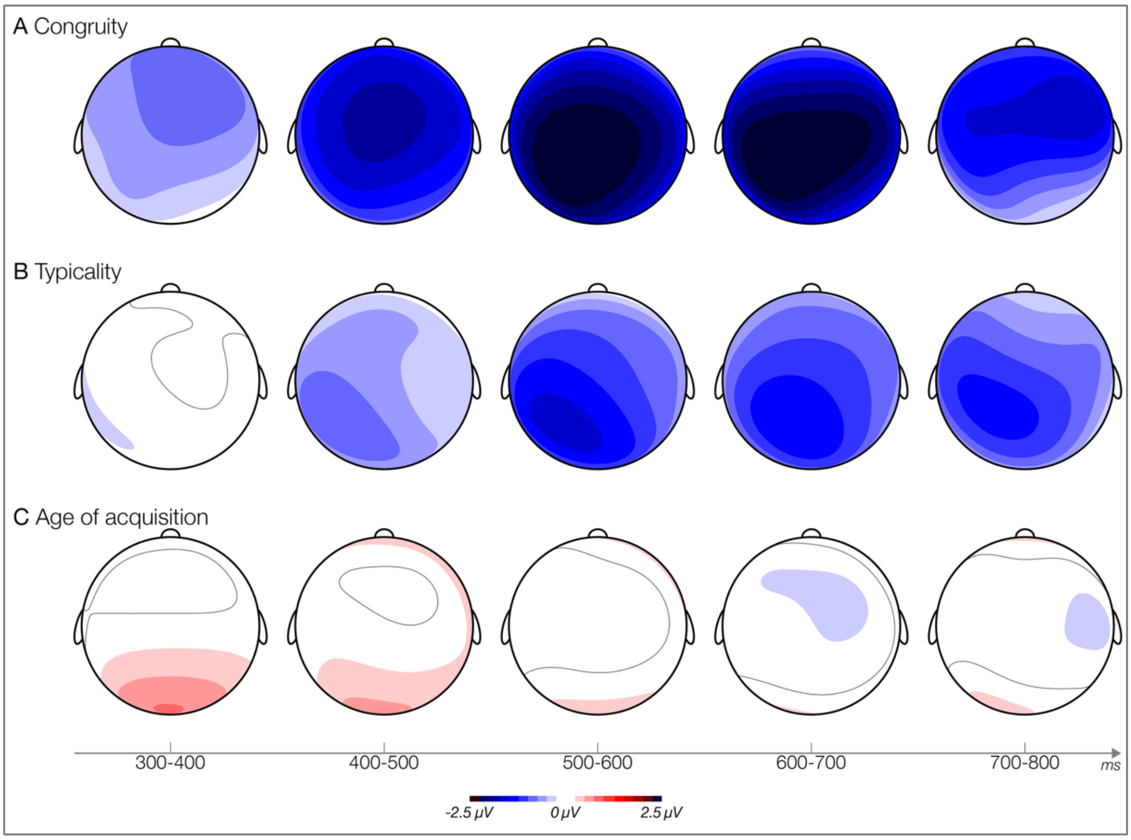

Figure 5 Topographical map of difference waves for congruity (incongruent minus congruent target amplitudes), typicality (atypical minus typical target amplitudes), and age of acquisition (late acquired minus early acquired target amplitudes) in 100 ms time windows.

The 100 ms interval analyses revealed significant CONGR main effects in each of the intervals starting 400 – 500 ms and persisting until 700 – 800 ms (see Table 1). Post-hoc *t*-tests revealed an increased negativity for incongruent targets compared to congruent targets within each of the following time windows: 400 – 500 ms: $t(22) = 4.77$, $p < .001$; 500 – 600 ms: $t(22) = 4.98$, $p < .001$; 600 – 700 ms: $t(22) = 4.1$, $p < .001$; 700 – 800 ms: $t(22) = 2.41$, $p < .05$. The effects were broadly distributed over the scalp (see Table 1). The largest effects could be seen in centro-parietal regions in the typical N400 time interval of 400 – 500 ms. Effects sustained the largest in right anterior regions (time intervals: 600 – 700 ms, 700 – 800 ms, Table 2, Figure 5).

Table 1 *F*-values for main effects of congruity, typicality and age of acquisition and interactions of these factors with regions of interest in 100 ms time windows

ANOVA	df	*F*-values per time window (in ms)				
		300 - 400	400 - 500	500 - 600	600 - 700	700 - 800
CONGR	1, 22	0.10	22.76***	24.83***	17.59***	5.81*
CONGR × ROI	5, 110	37.77***	12.15***	0.92	11.08***	24.66***
TYP	1, 22	2.6	3.75	10.10**	8.13**	6.34*
TYP × ROI	5, 110	1.03	1.78	4.39**	1.99	1.25
AOA	1, 22	0.59	2.73	0.21	0.01	0.00
AOA × ROI	5, 110	0.33	0.20	0.33	0.21	0.20
TYP × AOA	1, 22	2.64	5.14*	0.17	0.48	1.73
TYP × AOA × ROI	5, 110	0.73	0.17	1.09	0.51	0.53

Notes: Greenhouse and Geisser (1959) corrected levels of significance: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, df: degrees of freedom, CONGR: congruity, TYP: typicality, AOA: age of acquisition, ROI: region of interest.

Table 2 *T*-values for the distributional analyses of significant interactions of CONGR × ROI in 100 ms time windows

CONGR effects per ROI	*t*-values per time window (in ms, df = 22)			
	300 - 400	400 - 500	600 - 700	700 - 800
Midline anterior	0.31	3.75**	2.33*	2.11*
Midline posterior	-0.21	4.85***	5.22***	1.82
Left anterior	0.91	3.42**	2.75*	2.32*
Left posterior	0.24	4.43***	5.78***	2.24*
Right anterior	0.58	5.10***	3.33**	3.08**
Right posterior	-0.45	4.60***	4.95***	1.82

Notes: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$, df: degrees of freedom.

5.3.2.2 TYP and AOA effects

Grand average ERPs on TYP and AOA are presented in Figure 6 and Figure 7. The analysis of the ANOVA TYP × AOA × ROI over the broad time window 350 – 750 ms revealed a significant main effect of TYP ($F(1,22) = 7.14$, $p < .05$), whereas neither an interaction involving the factors TYP or AOA nor a main effect of AOA were present. Atypical targets evoked a significant larger amplitude than typical items ($t(22) = 2.67$, $p < .05$).

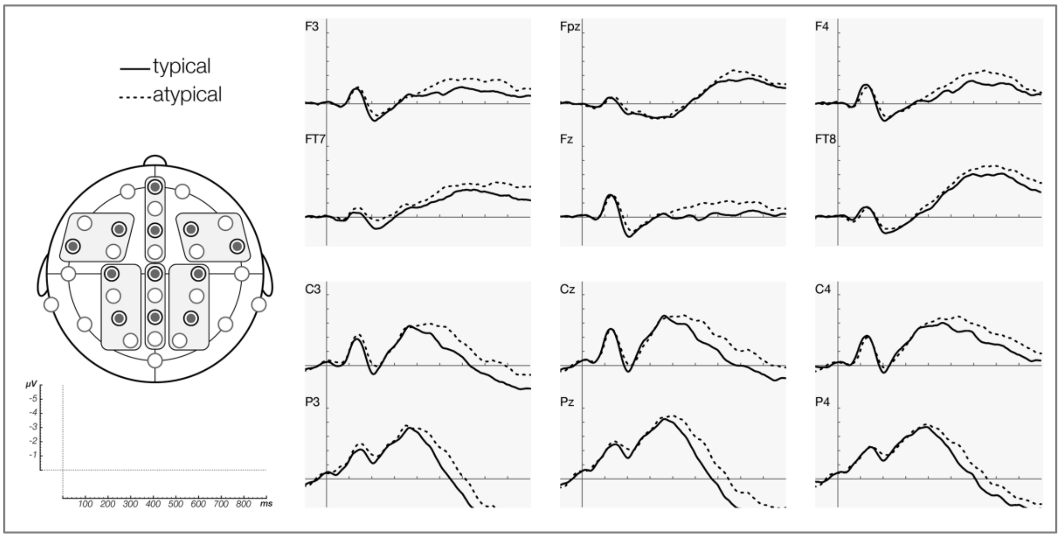

Figure 6 Typicality: Grand average ERPs at selected electrodes time-locked to the onset of the target word displaying typical and atypical words.

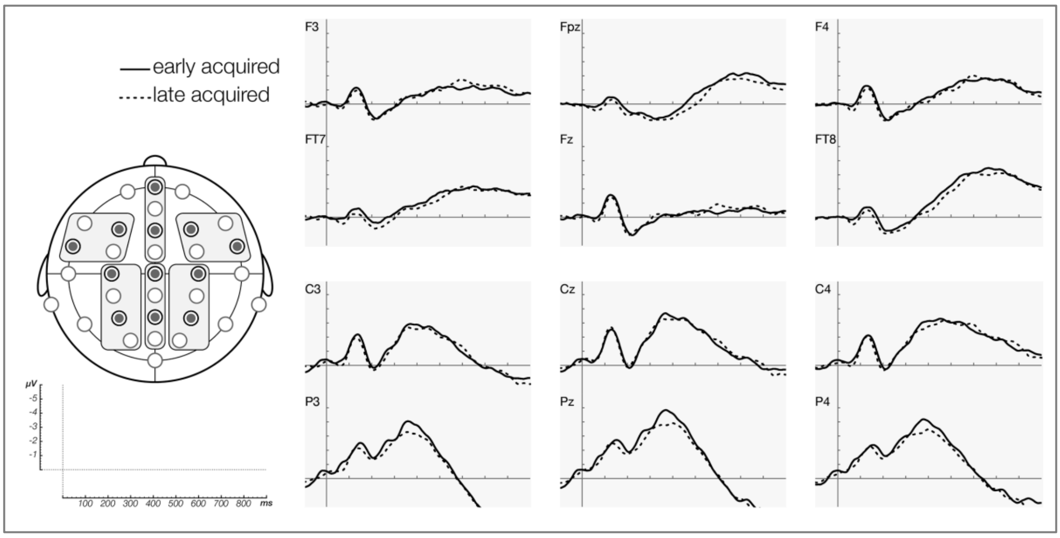

Figure 7 Age of acquisition: Grand average ERPs at selected electrodes time-locked to the onset of the target word displaying early and late acquired words.

The ANOVAs of TYP × AOA × ROI for each of the 100 ms time windows revealed a statistically significant main effect of TYP for the time windows 500 – 600 ms, 600 – 700 ms, and 700 – 800 ms, and a significant interaction of TYP × ROI for the time window 500 – 600 ms (see Table 1). Post-hoc paired *t*-tests of TYP in each of the significant time intervals showed that the mean amplitude of atypical targets was significantly more negative and longer lasting than that of typical targets across the six ROIs: 500 – 600 ms: $t(22) = 3.18$, $p < .01$, 600 – 700 ms: $t(22) = 2.85$, $p < .01$, 700 – 800 ms: $t(22) = 2.52$, $p < .05$. TYP effects were, as CONGR, broadly distributed over the scalp. Within the time interval 500 – 600 ms post-hoc paired *t*-tests revealed TYP effects predominantly in the following ROIs: midline posterior

($t(22) = 3.73$, $p < .01$), left anterior ($t(22) = 2.86$, $p < .01$), left posterior ($t(22) = 4.3$, $p < .001$), and right posterior ($t(22) = 3.18$, $p < .01$) indicating a slight asymmetrical distribution to the left hemisphere (see Figure 5). A main effect of AOA was not present in any of the time windows (see also). Only the time window 400 – 500 ms revealed a significant interaction of TYP × AOA across all ROIs. A post-hoc analysis of this interaction was based on an AOA effect found within the atypical items only. Here, within the atypical items, early acquired words had a greater N400 in comparison to late acquired words ($t(22) = -2.33$, $p < .05$). Within the typical items, there was no significant difference concerning the AOA ($t(22) = 1.14$, $p > .05$).

5.3.3 Summary of the results

In sum, the reaction time analyses revealed statistically significant TYP and AOA main effects, with no significant interaction of both variables. As expected, typical / early acquired words were processed faster than atypical / late acquired words. The TYP effect was also reflected in the accuracy data (more errors in atypical than typical words). Similar results for TYP were seen within the ERP data. Besides a highly significant effect of congruity in the control condition (greater N400 amplitude for incongruent vs. congruent targets), a main effect of TYP was observed: Atypical congruent targets had a statistically significant greater N400 amplitude than typical congruent targets. No main effect of AOA or interaction of this factor with typicality was observed for the broad time window (350 – 750 ms). Note that the time-course analyses yielded a TYP by AOA interaction for one single time window spanning N400 (400 – 500 ms epoch). However, the direction of the ERP effect (larger N400 amplitudes for early than late acquired words) goes into the opposite direction than the reaction time effect (faster RTs for early than late acquired words).

5.4 Discussion

To our knowledge, the present study is the first to systematically evaluate TYP and AOA effects in semantic processing in an auditory category-member verification task using both, behavioural (reaction times and accuracy rates) and electrophysiological (ERP) data. The reaction time data showed significant TYP and AOA main effects. The mean reaction time for confirming the category membership of an auditorily presented item was longest for atypical / late acquired targets and shortest for typical / early acquired targets. A potential influence of word frequency can be ruled out because the stimuli were controlled for this variable. These results entirely replicate the effects of earlier studies separately examining TYP and AOA effects in visual semantic tasks (Brysbaert et al., 2000; Johnston & Barry, 2006; Kiran et al., 2007; Larochelle et al., 2000; Morrison & Gibbons, 2006). Beyond that, the presence of statistically significant main effects for both variables along with the absence of an interaction within the same experiment provide further evidence that the two variables affect semantic processing independently from each other.

The pattern of results supporting the notion of orthogonal effects arising at the semantic processing level is not fully reflected in the accuracy data, since accuracy was only affected by TYP, with atypical items being more error-prone than typical items; AOA did not affect the accuracy of the responses. Given that accuracy rates were generally very high, it cannot be excluded that a ceiling effect may have obscured a potential influence of AOA on the accuracy score.

Turning to the ERP data, we first evaluated the efficacy of the design by replicating congruity effects in the N400 time window.

As expected for a priming study, we found that semantically unrelated (i.e., incongruent) prime-target pairs resulted in a statistically significant larger N400 amplitude than semantically related (i.e., congruent) prime-target pairs. Hence, our auditory experimental design has proven suitable to reliably elicit an electrophysiological response to priming processes at a semantic level, such as the visually evoked N400 congruity-effect previously described for sentences (Kutas & Hillyard, 1980, 1983, 1984) or word-pairs (Bentin et al., 1985; Bermeitinger et al., 2010; Chwilla et al., 1995). As expected by the use of the inter-stimulus-interval of 300 ms and a consequently rather long stimulus onset asynchrony the auditory evoked N400 effects followed a very similar pattern as in Anderson and Holcomb (1995). Our results further show a symmetrical distribution with a slight asymmetry to the left hemisphere, as well as a relatively long duration of the N400 response, which is typical for auditory processing (Friederici, 2004; Hagoort, 2008; Kutas & Federmeier, 2011; Kutas et al., 2006). Building on this, we were primarily interested in looking at TYP and AOA effects within the ERP data of correctly confirmed congruent target trials. TYP significantly modulated the N400 amplitude, with atypical targets producing a greater amplitude than typical targets. These results in the auditory modality are comparable to ERP studies investigating TYP effects in the visual modality (Fujihara et al., 1998; Heinze et al., 1998; Núñez-Peña & Honrubia-Serrano, 2005; Pritchard et al., 1991; Stuss et al., 1988). Thus, our results provide evidence for a modality-independent effect of TYP. Notably, the effects of TYP look similar to the effects of congruity (see Figures 4 and 6), indicating that both may rest on comparable mechanisms. Slight differences with respect to the time course of the electrophysiological response in comparison to the studies in the visual domain (e.g., a seemingly more sustained N400 amplitude and/or a later amplitude peak in the auditory modality) are possibly attributable to the format of presentation (auditory vs. visual) (Hagoort, 2008; Kutas & Van Petten, 1994).

On the basis of previous reaction time studies investigating AOA effects in semantic tasks -and our own behavioural results-, we expected to find an influence of AOA on the N400 response, in that late acquired targets would result in a greater N400 amplitude than early acquired targets. In contrast to the reaction time results (but similar to the accuracy rates), the ERP analyses did not reveal such an AOA main effect at the electrophysiological level.

Unexpectedly, the ERP data revealed solely in the time window 400 to 500 ms a small effect for AOA within the atypical target items. This interaction contrasts with the behavioural as well as the ERP results, since it features a reversed effect of AOA (with a larger N400 amplitude for atypical / early acquired than atypical / late acquired items) and disappears completely in later and/or broader time windows. To our knowledge, a comparable result has not been described in the literature so far. However, since the effect is so small compared to the behavioural and electrophysiological main effects, we hereafter focus on the discussion of the main results and their integration in existing models and studies, and return to the issue of the unexpected interaction later.

Taken together, our ERP data indicate that the initial hypothesis predicting an influence of both variables on auditory semantic processing that can be seen at the electrophysiological level has to be reconsidered. If we consider the N400 response reflecting mainly semantic processing, the ERP data reveal an influence of congruity and TYP on semantic processing, but question the locus of AOA on a semantic level.

To date, ERP literature on AOA itself is very sparse. In fact, the present study is the first to investigate AOA effects by means of the N400. Hence, comparison with previous studies using different modalities (perceptual vs. productive) and diverging experimental tasks is not warranted. Nevertheless, the following electrophysiological studies also failed to provide evidence for a semantic level origin of AOA effects. In an auditory lexical decision oddball paradigm, Tainturier et al. (2005) did not find N400 differences between early and late acquired words, whereas the P300 component as well as the RTs (faster RTs for early acquired words vs. late acquired word) were affected by AOA, indicating a lexical rather than semantic level influence of AOA. However, the missing N400 effect could also be attributed to the experimental task, since N400 effects are per se not systematically detected in lexical decision tasks. Adorni et al. (2013) assessed AOA and word frequency effects in a high density EEG study using an orthographic detection paradigm. The topographical EEG data analyses showed that the processing of early acquired words is associated with left occipito-temporal brain regions which are predominantly involved in lexical rather than semantic processes. Similar to our behavioural data, studies focusing on word production processes in object naming show that AOA modulates the production time (early acquired words are produced faster, Laganaro & Perret, 2011; Perret et al., 2014). Concerning the waveform analyses on ERPs, AOA affected the data at a later stage of word production, endorsing the hypothesis that AOA effects are linked with phonological encoding processes and thereby lending support to phonological locus theories rather than semantic or multiple processing accounts. However, contrary to the previously mentioned studies and our own results, Cuetos et al. (2009) found a significant effect of AOA in silent reading of words, reflected in a larger negativity for late acquired words within the time window of 400-610 ms in central and posterior electrodes, indicating a semantic rather than a lexical/phonological influence of AOA in reading.

Despite these inconsistent ERP findings in the above cited studies, numerous semantic processing studies found stable AOA effects at the behavioural level. So far and based on these facts a semantic locus of AOA cannot entirely be rejected.

A potentially relevant model to explain our data could be the N400-model of Kutas and Federmeier (2011). The authors do not interpret the time interval of the N400 as a semantic integration process, but rather as correlate of a very dynamic, stimulus-driven preactivation process, which changes continuously during the entire recognition process and collects its information out of a broad, multi-modal long-term memory. Kutas and Federmeier assume that semantic concepts are not fully looked up, but depending on the present prime context, stored information relating to the stimulus material is activated. This includes experiences and knowledge of the world, activation of linguistic (e.g., phonological neighbours, semantic features) and non-linguistic information, but also attentional states and moods. Thus, the N400 component reflects very early aspects of semantic processing and forms the basis for later explicit and conscious processing of words, and certainly the access of the entire meaning of the word. With regard to the observed TYP effect in our ERP data, we conclude that TYP, like congruity, is a crucial variable in this early semantic process during which stimulus related information such as semantic features are being generated. Considering our design, the category prime would lead to a preactivation of typical, highly intercorrelated semantic features. Mismatches between preactivated semantic features and the presented target item would lead to larger N400 amplitudes, as is the case for atypical items.

Regarding the absence of AOA main effects in our ERP data, this could mean that in early semantic processing, basically the context prime (i.e., the category name) seems not to specifically activate semantic features that are directly linked to the time point of concept acquisition. The early semantic retrieval of the meaning of a word would therefore integrate diverse multi-modal elements, which are individually acquired at very different time points throughout life. A concrete age of acquisition for the conglomerate of these multi-modal experiences may principally not be derived at the stage of semantic processing, explaining absent AOA main effects in this early processing stage at the electrophysiological level. Nevertheless with regard to the relation of TYP and AOA, it seems likely that the early access to related information on an incoming target word and their alignment of preactivated features by the context prime include both, TYP and AOA characteristics, although this interaction cannot be captured in later processing stages and at the behavioural level.

An alternative explanation could be that AOA is not represented in the semantic features but in the strengths of connections between stored conceptual information (Ellis & Lambon Ralph, 2000). Hence, early acquired concepts can be accessed more easily as shown in faster response times in our data. However, the number of preactivated semantic features would not differ between early and late acquired target words but only between typical and atypical members of a category – only the latter would lead to a modulation of the N400.

Notably, we have no clear explanation for the unexpected, reversed effect of AOA that in particular atypical / early acquired targets evoke a larger amplitude within the time window 400 to 500 ms than atypical / late acquired targets. It could be conceivable that during this early step of feature alignment of the prime and the target the atypical words, which are less expected in any case (main effect TYP in ERP, RT, and accuracy data) call for a deeper analysis of the words. At this processing stage, atypical / early acquired target information might lead to larger mismatches than atypical / late acquired words due to the natural correlation of TYP and AOA. At later processing stages, this specific interaction has no longer any influence.

Overall, our ERP data do not indicate a semantic origin of AOA. Considering the AOA effects on the reaction times; it seems likely that AOA originates in later processing levels of the recognition process. This is in accordance with Holmes and Ellis (2006), who have already discussed a sequential later processing time point of AOA in contrast to TYP. They suppose that AOA effects occur "where similar objects are individuated one from another. If so, AOA effects might be detected in name-to-picture matching or very precise semantic classification but not in the sort of broad classification" (Holmes & Ellis, 2006, p. 907). Hence, we interpret the RT differences of AOA to be based on either later, conceivably more explicit semantic processes or on post-semantic decision processes. Alternatively, AOA might merely be represented in the connection strength of conceptual information – stronger connections of early acquired information would lead to faster RTs with absent ERP differences. Future studies would need to confirm these hypotheses, while consulting complementary research techniques, as ERPs and behavioural data in different tasks disentangling lexical, semantic, and decision-making processes.

In sum, we observed significant TYP as well as AOA effects in the reaction time analysis of an auditory category-member verification task. In contrast, but in line with the accuracy-data, the analysis of ERPs revealed significant and broad effects of TYP, but no main effect of AOA. In atypical items only we found a small reversed AOA effect modulating the N400 amplitude during an early time window of 400 to 500 ms. To date we can only speculate that the diverging results found in our ERP and reaction time data are possibly due to the implemented study design, which was primarily designed to measure stable N400 priming effects. Assuming that the N400 amplitude is a reflector of early semantic access, our data allocate TYP effects at an early semantic processing level, while AOA effects principally seem to have their origin at later semantic levels of language processing, at the level of the decision-making processes or might originate from differences in connection strengths, which are not captured by the N400 priming component. Our results hence provide evidence that TYP and AOA inherently influence different stages of auditory word processing. However, a specific interaction of both variables at a very early stage of semantic access -that does not influence later levels of processing- cannot be ruled out.

5.5 Acknowledgements

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6. Judging the animacy of words - The influence of typicality and age of acquisition in a semantic decision task[8]

Abstract

The age at which members of a semantic category are learned (age of acquisition), the typicality they demonstrate within their corresponding category, and the semantic domain to which they belong (living, non-living) are known to influence the speed and accuracy of lexical/semantic processing. So far, only a few studies have looked at the origin of age of acquisition and its interdependence with typicality and semantic domain within the same experimental design. Twenty adult participants performed an animacy decision task in which nouns were classified according to their semantic domain as being living or non-living. Response times were influenced by the independent main effects of each parameter: typicality, age of acquisition, semantic domain, and frequency. However, there were no interactions. The results are discussed with respect to recent models concerning the origin of age of acquisition effects.

6.1 Introduction

Word processing has been shown to be influenced by various psycholinguistic variables which are naturally highly intercorrelated (e.g., Hernández-Muñoz et al., 2006; Kuperman et al., 2012). For the majority of variables, the origin of the respective effect is considered rather uncontroversial. For example, variables such as imageability, concreteness, familiarity, semantic domain, or semantic typicality are regarded as relating to the semantic processing level (e.g., Brysbaert et al., 2000), whereas frequency effects are assigned to lexical-phonological processing stages (Levelt et al., 1999). Besides these, another important variable is the age of acquisition, for which the origin with respect to the processing level has not yet fully been resolved.

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[8] This chapter was adapted from the final draft post-refereeing: Räling, R., Hanne, S., Schröder, A., Keßler, C., & Wartenburger, I. (2016). Judging the animacy of words - The influence of typicality and age of acquisition in a semantic decision task. *The Quarterly Journal of Experimental Psychology*, 1–21. doi:10.1080/17470218.2016.1223704

Age of acquisition refers to the order and the point in time at which a semantic concept has been learned and the corresponding lexical item has first been produced (Carroll & White, 1973; Ellis, 2011; Johnston & Barry, 2006; Juhasz, 2005). Words acquired earlier in life are much easier to produce than late acquired items in tasks such as category fluency (Hernández-Muñoz et al., 2006), naming to definition (Navarrete et al., 2015), and picture naming (Barry, Morrison, & Ellis, 1997b; Carroll & White, 1973; Chalard & Bonin, 2006; Cuetos et al., 1999; Hodgson & Ellis, 1998; Johnston & Barry, 2006; Johnston, Dent, Humphreys, & Barry, 2010; Morrison & Ellis, 1995) as indicated by faster response times for early compared to late acquired words. Accordingly, the majority of studies on age of acquisition effects have focused on tasks that require spoken word production and involve pictured stimuli. Several studies also investigated the influence of age of acquisition on reaction times in tasks that do not involve speech production and found lower effect sizes as compared to tasks demanding spoken responses[9] (see also Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2009). Tasks that do not involve speech production are, for instance, lexical decision (e.g., De Deyne & Storms, 2007; Morrison & Ellis, 2000; Smith et al., 2006), semantic categorization (e.g., Brysbaert et al., 2000; Ghyselinck et al., 2004; Holmes & Ellis, 2006), or animacy decision using printed words (De Deyne & Storms, 2007; Menenti & Burani, 2007; Morrison & Gibbons, 2006) or pictures (Catling & Johnston, 2006a).

There are different theoretical accounts explaining the age of acquisition effects found in offline[10] response time measurements in semantic processing: Single locus theories ascribe age of acquisition effects to the structure of semantic representations rather than to lexical form processing levels (Brysbaert et al., 2000). For example, in the model of semantic network development by Steyvers and Tenenbaum (2005), semantic representations of early acquired concepts are more closely interconnected and have more central positions in the semantic

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[9] But see Cortese and Khanna (2007) for larger effect sizes in lexical decisions compared to reading aloud. However, note that both tasks do not necessarily involve access to the semantic processing level, although the authors interpreted the larger effect sizes in lexical decisions as reflecting additional processing load due to access to semantic representations, which they do not assume for reading words aloud.

[10] Here, we refer to behavioural data (response times and accuracy rates) as offline measurements, tapping into the end product of language processing, and to electrophysiological data as online data that provide insights into real-time language processing as it unfolds over time.

network. In contrast, multiple level theories assume age of acquisition effects to be located at several levels of language processing (Belke et al., 2005; Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2006a, 2009). Catling and Johnston (2006a, 2009) propose the “accumulation hypothesis” to account for varying age of acquisition effects that occur depending on the processing levels involved: They provide evidence for age of acquisition effects which increase as more connections between processing levels are activated during the task. Moreover, and in the framework of multi-level theories, Belke et al. (2005) and Brysbaert and Ghyselinck (2006) distinguish between frequency-related and frequency-independent effects of age of acquisition. Frequency-related age of acquisition effects are assumed to occur whenever access to learned and stored information is necessary. Hence, (cumulative) word frequency and age of acquisition (here, particularly the order of entry) effects are highly coupled because both rest on the same learning mechanism (Ghyselinck et al., 2004; Lewis, 1999). However, the existence of frequency-independent age of acquisition effects is assumed to explain increased effect sizes in tasks that demand spoken responses as a result of a deep semantic analysis (e.g., picture naming, response to definition), as well as age of acquisition effects that are not related to word frequency effects. Brysbaert and Ghyselinck (2006) assume frequency-independent effects to originate at the level of lemma selection (i.e., the link between semantic system and the output word form level) or at the semantic level, while the origin of frequency-related age of acquisition effects is not restricted to any particular language processing level.

Apart from the above-mentioned accounts, which functionally locate age of acquisition effects at a certain level of language processing, there are other approaches seeking to simulate age of acquisition effects in neural network models. Ellis and Lambon Ralph (2000) assume that age of acquisition effects occur whenever a learning network is trained in a cumulative and interleaved manner. In their model, age of acquisition thus influences connection weights for items presented in an interleaved fashion during learning (Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2010). The authors predict further that age of acquisition has a particular impact on input-output structures that are unpredictable and hence arbitrary (e.g., the arbitrary mapping to or from semantics in comparison to more consistent or regular mappings, such as reading words with a regular graphemephoneme-mapping; see also Zevin & Seidenberg, 2002, 2004). Therefore, it should be more likely to observe age of acquisition effects in tasks that involve semantic processing than in reading.

In line with the additive factors approach for interpreting interaction effects (Sternberg, 1969), investigating the interplay of age of acquisition and other variables that are assumed to originate at the semantic level might provide further insights concerning the semantic origin of age of acquisition effects. Two of those semantic variables are typicality and semantic domain. The typicality of an exemplar of a semantic category reflects the degree to which a concept (e.g., penguin, sparrow) is representative of a given semantic category (e.g., BIRDS, Rosch, 1975; Rosch & Mervis, 1975). Some items in a category can be considered good or typical exemplars of their category because they share many semantic features with a category prototype (e.g., sparrow for BIRDS), whereas others are considered less typical because they share fewer features with typical exemplars of a given category (e.g., penguin for BIRDS). More recent theories assume typicality to be reflected in the semantic features of connectionist models of the semantic system (McRae et al., 1999). As has been emphasised by Woollams (2012), typicality effects are considered to originate from the semantic processing level. This proposal is supported by findings on response time modulations in various semantic tasks: Typicality effects with faster response times for typical than for less typical members of a category have been found in various offline semantic classification or category-verification tasks (Holmes & Ellis, 2006; Kiran et al., 2007; Kiran & Thompson, 2003; Rips et al., 1973; Rosch & Mervis, 1975; Sandberg et al., 2012; Smith et al., 1974), in animacy decision tasks (Morrison & Gibbons, 2006), and in tasks requiring spoken responses such as picture naming (Dell'Acqua et al., 2000; Holmes & Ellis, 2006) or category fluency (Hernández-Muñoz et al., 2006).

Previous studies on the interdependence of age of acquisition and typicality have reported inconsistent results concerning the respective interplay of both variables. Holmes and Ellis (2006) showed that age of acquisition effects disappeared when item typicality was controlled in a category-verification task using printed category labels and subsequent target pictures. Moreover, in the first study on either of the two variables involving German native-speakers, Räling et al. (2015) further disentangled the effects of typicality and age of acquisition within the same experiment gathering offline (accuracy rates, response times) as well as online (electrophysiological) measurements in an auditory category-verification task involving young adults. In this study, we found no significant interactions of age of acquisition and typicality, thus providing evidence for the independent occurrence of both variables in offline response times during category verification. Notably, the electrophysiological data revealed an effect on the N400 component, which is mainly associated with semantic processing, for typicality only. In line with the ERP results, the accuracy data also revealed a main effect of typicality only. Age of acquisition effects were not found. The absence of a main effect of age of acquisition together with the non-significant interaction of age of acquisition and typicality during auditory category-verification challenge the assumption that typicality and age of acquisition effects originate at a common processing level (Sternberg, 1969). However, it supports previous findings on a semantic origin for typicality effects (see also Räling et al., 2016, for a study investigating the interplay of age of acquisition and typicality in healthy elderly and semantically impaired individuals with aphasia in an auditory category-verification task).

Besides typicality and age of acquisition, it has repeatedly been shown that semantic domain (i.e., living and non-living) also constitutes an important variable in semantic processing. The potential distinction of the semantic system between living and non-living concepts has been proposed in studies investigating category-specific deficits in individuals with an aphasia (Caramazza & Shelton, 1998; Moss et al., 1998; Warrington & Shallice, 1984). Findings on impaired performance occurring in one of the semantic domains, while the other was preserved, led to the development of various theories about the underlying structure of the semantic system (for reviews, see: Capitani, Laiacona, Mahon, & Caramazza, 2003; Caramazza & Mahon, 2006). For instance, the Organised Unitary Content Hypothesis (OUCH) by Caramazza and colleagues (Caramazza, Hillis, Rapp, & Romani, 1990) assumes that the distinction between semantic domains is due to the underlying structure of semantic features: Living objects share many semantic features which are highly correlated, whereas non-living items are represented by rather distinctive semantic features. In individuals with an aphasia, it seems that living items are generally harder to access than non-living items (but, see Låg, 2005 for a discussion). However, in unimpaired processing, studies reported a processing advantage for living vs. non-living concepts (Laws, 2000; Laws & Neve, 1999), which might be due to the evolutionary importance of living objects (Caramazza & Shelton, 1998). Without focussing on the semantic domain as a factor, some of the above-mentioned animacy-decision-tasks also revealed faster response times for living compared to non-living items (Catling & Johnston, 2006a; Menenti & Burani, 2007; Morrison & Gibbons, 2006).

Moreover, previous studies reported rather inconsistent results with respect to a possible interdependence of age of acquisition, typicality, and the semantic domain (which would be indicated by significant interactions, see Sternberg, 1969). For typicality, effects have always been reported to be equally present in living and non-living domains (Kiran et al., 2007; Kiran & Thompson, 2003; Morrison & Gibbons, 2006). Regarding age of acquisition, Morrison and Gibbons (2006) reported a significant interaction of age of acquisition and semantic domain, with age of acquisition effects to be present only in living objects. In addition, there were larger effects for the living domain in the study by De Deyne and Storms (2007; notably, the authors did not report statistical results for this observation). In contrast, Catling and Johnston (2006a) found no significant interaction of age of acquisition and semantic domain (or object type as they labelled it) for reaction times in an animacy decision task involving object pictures. However, they reported a significant interaction for the accuracy data: For living objects, effects of age of acquisition were evident but there were no age of acquisition effects for items of the non-living domain.

In sum, age of acquisition effects have repeatedly been described for tasks that involve lexical (i.e., word form) as well as semantic processing. Notably, tasks that require semantic processing and subsequent spoken output have been shown to reveal the largest effect sizes compared to tasks such as semantic categorization or lexical decision (Belke et al., 2005; Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2006a, 2009). There is still a debate regarding the underlying origin of age of acquisition effects, although it is likely that frequency-independent effects of age of acquisition occurring in tasks demanding speech production originate either at the link between semantics and output phonology or at the semantic level itself (Brysbaert & Ghyselinck, 2006). The influence of typicality on the semantic processing level has repeatedly been reported for category verification tasks (e.g., Casey, 1992; Larochelle et al., 2000; McCloskey & Glucksberg, 1979) and for animacy decisions (Morrison & Gibbons, 2006). Our recent electrophysiological studies indicated that different underlying origins are responsible for typicality and age of acquisition effects in auditory category verification (Räling et al., 2015; Räling et al., 2016). Since previous studies have shown conflicting results with respect to the interdependence of semantic domain, age of acquisition and typicality, there is need for a systematic investigation (Catling & Johnston, 2006a; De Deyne & Storms, 2007; Morrison & Gibbons, 2006).

Therefore, the aim of the present study is to determine the origin of age of acquisition effects by evaluating its relation to and its dependency on the semantic variables of semantic domain and typicality. For that purpose, we conducted a semantic living/non-living (animacy) decision task that did not demand spoken output and recorded accuracy rates and reaction times. In doing so, we expand our previous findings on age of acquisition and typicality (Räling et al., 2015; Räling et al., 2016) by adding the factor of semantic domain and by using a different task (animacy decision vs. category-member-verification) as well as a different input modality (written vs. spoken words).

Based on our previous findings, we expect to replicate the offline results of Räling et al. (2015) with a different but comparable item set in a different group of participants. Hypothesising distinct origins of age of acquisition and typicality/semantic domain, we expect that reaction times should be influenced by typicality (faster reaction times for typical vs. atypical words), semantic domain (faster reaction times for living vs. non-living items), and age of acquisition (faster reaction times for early vs. late acquired words). Effects on participants' accuracy are expected to be driven by typicality and semantic domain only. Based on the previous findings, significant interactions of age of acquisition and typicality are expected neither in reaction times nor in accuracy rates. Such an absence of interactions would provide evidence against a common origin of the variables (Sternberg, 1969).

6.2 Material and Methods

6.2.1 Participants

Twenty German-speaking right-handed participants (10 female) with no history of psychiatric or neurological disorders and a mean age of 25.0 years (SD = 3.00, range = 20-31) took part in the experiment. They were recruited from Potsdam University and the surrounding community. All participants gave their written informed consent before participating in the study and received either course credit or reimbursement for their participation.

6.2.2 Stimuli

Words were chosen from a German database including rating norms for typicality, age of acquisition, and familiarity (Schröder et al., 2012) and they were selected with respect to the factors under investigation (typicality: typical, atypical; age of acquisition: early, late; semantic domain: living, non-living). Four sets of items were developed (typical / early acquired, typical / late acquired, atypical / early acquired, atypical / late acquired). Initially, each set contained an equal number of 20 exemplars from the living (8 ANIMALS, 5 BIRDS, 3 FRUITS, and 4 VEGETABLES) and non-living (8 CLOTHES, 4 FURNITURE, 3 MUSICAL INSTRUMENTS, and 5 VEHICLES) domains. Items in these four sets were further matched for their word length in letters and syllables, and normalized (per million) word frequency (obtained using the DLEXDB database, Heister et al., 2011). After data collection, however, it turned out that, for statistical analyses, four items had to be excluded from the item set for two reasons: a) three items had to be removed because they were ambiguous (homonymous) and could be classified as belonging to the living as well as non-living domain[11], and, b) one item had to be removed because it was presented twice due to a programming error (the second reaction to this item was discarded from the data). Although the four conditions of the final data set of 156 items, with 39 items per condition, were still balanced with respect to word length, three of the item sets became significantly different in terms of their mean word frequencies (atypical / early acquired vs. atypical / late acquired: $t(76) = 2.18$,

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[11] The items "Jaguar" (English Jaguar: a vehicle, or jaguar: an animal), "Sprossen" (English rungs: parts of a ladder, or sprouts: vegetables), and "Sonnenhut" (English sun hat: a piece of clothing, or coneflower: a plant) could have been assigned to the living as well as the non-living domain.

$p < .05$; typical / early acquired vs. atypical / late acquired: $t(76) = 3.36$, $p < .05$; see Table 3 for final word characteristics of the four item sets). For this purpose, frequency was included in the statistical analysis as an additional predictor in order to control for a potential confounding effect of this variable.

Table 3 Varied and matched variables of the four item sets (total nb. of items, n = 156) used in the animacy decision task.

	Condition			
	typical		**atypical**	
	early acquired	**late acquired**	**early acquired**	**late acquired**
	e.g., carrot, bus	*e.g., elk, cello*	*e.g., celery, crane*	*e.g., bison, tuba*
Rated age of acquisition *(7-point scale; Schröder et al., 2012)*				
M	2.92	4.53	3.24	4.87
SD	0.73	0.74	0.62	0.78
Range	1.70 - 4.80	3.30 - 6.00	1.80 - 4.26	3.45–6.50
Rated typicality *(7-point scale; Schröder et al., 2012)*				
M	2.05	2.31	3.82	4.02
SD	0.67	0.52	1.01	1.02
Range	1.00 - 3.75	1.10 - 3.80	2.45 - 5.82	2.50 - 6.13
Word frequency *(Heister et al., 2011)*				
M	1.60	1.06	1.21	0.78
SD	1.31	1.49	0.98	0.77
Range	0.07 - 6.97	0.01 - 5.79	0.00 - 3.20	0.00 - 3.25
Word length *(no. of letters)*				
M	7.79	8.00	8.10	7.56
SD	2.90	2.76	2.99	2.62
Range	3 - 15	4 - 17	3 - 14	4 - 13
Word length *(no. of syllables)*				
M	2.59	2.59	2.62	2.59
SD	0.93	0.84	1.00	0.90
Range	1 - 5	1 - 5	1 - 5	1 - 4

6.2.3 Procedure

The animacy decision task required participants to indicate via button press whether a visually presented word belongs to the living (natural) or non-living (artificial) domain. First, a central fixation cross was displayed for 1000 ms on a laptop screen. Subsequently, the target item was centrally presented as a written word (font type: Arial, type size: 48 pts) for a maximum of 5000 ms, and the participants were to indicate as correctly and quickly as possible whether the presented item belonged to the living or non-living domain using the left and right shift key. The button press terminated the experimental trial and the next trial was presented. The allocation of the response keys (left vs. right, living vs. non-living) was counterbalanced across participants.

The experiment was run using the software Presentation® (Presentation 14.1., http://www.neurobs.com/). Participants were presented with written instructions on the computer screen followed by verbal clarifications about the task. Before the experiment started, 16 different practice stimuli involving two members of each of the eight experimental categories were shown. The procedure was similar for the practice trials and the experimental trials. Items were presented in a pseudo-randomised order with no more than three subsequent items from the same semantic domain (living or non-living). In addition to accuracy, we collected response time data measured from the presentation of the target until participants' button press. The total duration of the experiment was about 15 minutes.

6.2.4 Data analysis

Accuracy scores were analysed as binomial data. For the response time analyses, only correct responses were included and the raw data were transformed using a negative reciprocal conversion (-1/RT) to correct for skewness in the distribution. This was the optimal transformation for the raw data according to the boxcox function of the MASS package (Venables & Ripley, 2002) available in the R programming environment (R Core Team, 2014). Statistical analyses were carried out using linear mixed models (LMMs) (Bates & Sarkar, 2007) implemented in the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) and included random components adjusting for individual differences between the participants overall as well as for the fixed effects and adjusting for item-specific effects. The use of LMMs is particularly favourable given the rather small sample size in order to ensure that any observed effects are solidly grounded (for a discussion of the advantages of LMMs relating to statistical power see for example Baayen, Davidson, & Bates, 2008; Barr, Levy, Scheepers, & Tily, 2013).

For data on accuracy, a generalised linear mixed model with a binomial link function was fit using the glmer function, for response time data, we applied a linear mixed model with a Gaussian link function (lmer). The models included the fixed effects of typicality and age of acquisition (both as continuous predictors to maintain the maximum amount of information of the rating data) and their interaction, as well as semantic domain (living vs. non-living), and word frequency. Word frequency was included as a predictor to account for the fact that the final sets of typical and atypical, early and late acquired items were not equally matched with respect to their lemma frequencies (see above). We centred all continuous predictors (typicality, age of acquisition, word frequency) to their grand means in order to reduce the correlation between them. Each model (for accuracy and for response times) was specified with a maximal random effects structure (cf., Barr et al., 2013) with simultaneous entry of all fixed effects (i.e., the main effects of word frequency, domain, age of acquisition and typicality and the interaction of age of acquisition and typicality) using the maximum likelihood estimation procedure. Residuals in the linear mixed models were checked for their distributional properties. For the coded contrasts of predictors, we report coefficient estimates (b), their standard errors, t- or z-scores (depending on the dependent measure), p-values, and corresponding confidence intervals.

6.3 Results

6.3.1 Accuracy

The accuracy data in the animacy decision task is provided in Table 4. Participants generally performed at ceiling in all of the four conditions (between 98 % and 99 % correct). The generalised linear mixed model revealed no significant effects of any of the predictors on response accuracy (frequency: $b = -0.294$, $SE = 0.4$, $z = -0.74$, $p > .05$; semantic domain: $b = -0.876$, $SE = 0.52$, $z = -1.69$, $p > .05$; typicality: $b = -0.463$, $SE = 0.41$, $z = -1.13$, $p > .05$; age of acquisition: $b = -0.697$, $SE = 0.47$, $z = -1.5$, $p > .05$; typicality × age of acquisition interaction: $b = 0.434$, $SE = 0.35$, $z = 1.26$, $p > .05$).

Table 4 Mean response times of correct responses and accuracy (proportion in parentheses) in the task by condition.

Condition	***N***	**Accuracy rates**			**Response times (in ms)**		
		M	***SD***	***Range***	***M***	***SD***	***Range***
typical / early acquired	39	38.7 (.99)	0.56	37 - 39	803.7	106.03	679 - 1000
typical / late acquired	39	38.1 (.98)	1.07	36 - 39	830.7	107.67	659 - 1038
atypical / early acquired	39	38.4 (.98)	0.57	37 - 39	848.9	112.93	679 - 1085
atypical / late acquired	39	38.3 (.98)	1.10	35 - 39	941.6	163.88	710 - 1234
Total	156	153 (.98)	0.91	145 - 156	856.2	134.3	682 - 1089

6.3.2 Response times

Table 4 also depicts the mean response times for the four different conditions. Within early and late acquired words, response times were higher for atypical compared to typical items and, in addition, within typical and atypical items, response times were higher for late acquired compared to early acquired items. Moreover, participants took longer to respond to items of the non-living compared to the living domain (non-living: *M* = 890.61, *SD* = 133.67, range = 702 - 1123; living: *M* = 821.61, *SD* = 110.19, range = 653 - 1006).

The linear mixed model for the response time data revealed main effects of typicality (*b* = 0.000034, *SE* = 0.00001, *t* = 3.44, *p* < .05, 95% CI [0.000015, 0.000054]), age of acquisition (*b* = 0.00003, *SE* = 0.00001, *t* = 2.55, *p* < .05, 95% CI [0.000007, 0.000052]), semantic domain (*b* = –0.00003, *SE* = 0.00001, *t* = –2.07, *p* < .05, 95% CI [0.000003, 0.000106]), and frequency (*b* = –0.00003, *SE* = 0.00001, *t* = –2.73, *p* < .05, 95% CI [–0.000049, –0.000008]). There was no significant typicality × age of acquisition interaction (*b* = 0.00001, *SE* = 0.000008, *t* = 1.64, *p* > .05, 95% CI [–0.000003, 0.000029]). A graphical summary of the results regarding the effects of typicality and age of acquisition is given in Figure 8.

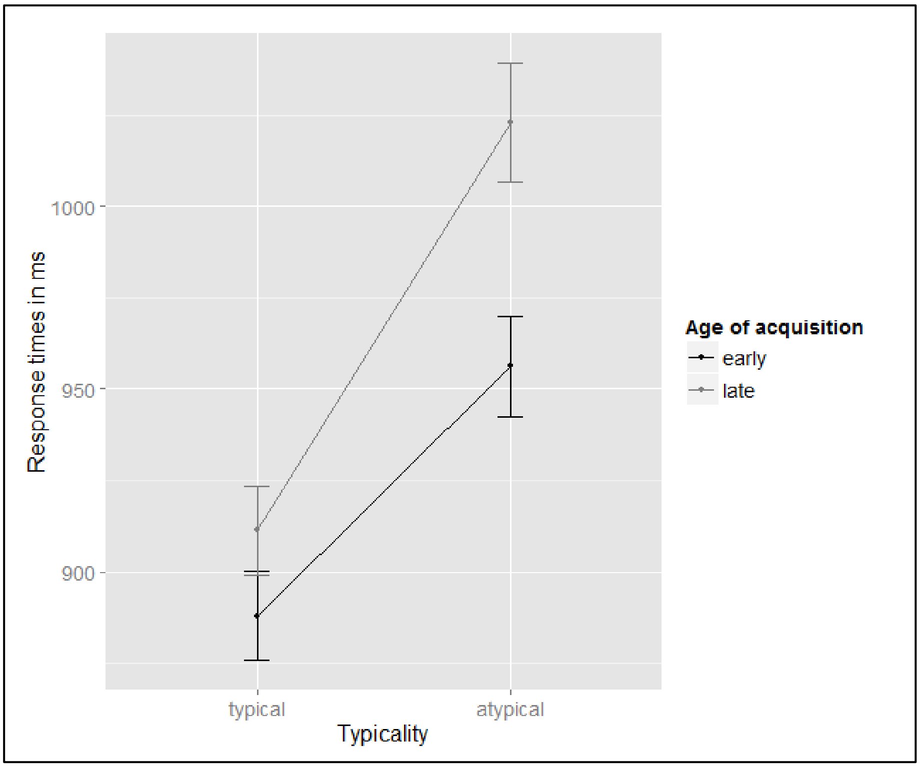

Figure 8 Mean response times in milliseconds for the control group, depicted as a function of typicality and age of acquisition, with standard errors of means as error bars.

6.4 Discussion

The purpose of the present study was to determine the origin of age of acquisition effects by investigating their dependency on semantic variables. Therefore, we conducted an animacy decision task and recorded response times and accuracy rates. We assumed that age of acquisition effects arise independently from effects of typicality and semantic domain, which are associated with semantic processing. In sum, the response time results revealed significant main effects of typicality, age of acquisition, semantic domain, and word frequency. There were no interactions between typicality and age of acquisition. Participants responded more quickly to typical vs. atypical items and to words that are acquired earlier vs. later in life. In addition, response times were faster for words in the living compared to the non-living domain, and high frequency words were processed more quickly than low frequency words. None of the factors had an effect on response accuracy which was generally at ceiling for all conditions. Thus, the results will be discussed with respect to the response time data.

Considering the factor of semantic domain, we provide further evidence of a general processing benefit for living compared to non-living items. This corroborates previous findings of faster reaction times for living items than for non-living items in animacy decision tasks (Catling & Johnston, 2006a; Menenti & Burani, 2007; Morrison & Gibbons, 2006); although these studies did not report statistical results on semantic domain differences. It has been suggested that the processing advantage for living items could arise due to differences in the entrenchment of the semantic domains in the semantic system, with a greater evolutionarily importance of living than non-living objects (Caramazza & Shelton, 1998; Gelman, 1990) as discussed in the introduction. Thus, accounts such as the Organised Unitary Content Hypothesis (OUCH, Caramazza et al., 1990) proposing highly correlated and numerous shared semantic features for living objects in comparison to rather distinctive, less correlated semantic features for non-living items might explain the faster response times for items belonging to the living domain.

With respect to the effect of typicality, our data nicely replicate the findings of Morrison and Gibbons (2006) showing typicality effects in an animacy decision task, with faster response times for typical vs. atypical items. Our results are in line with studies investigating typicality effects in other semantic tasks, such as category-member-verification or object classification (Hampton, 1997; Kiran et al., 2007; Kiran & Thompson, 2003; Larochelle et al., 2000; Räling et al., 2015), manifesting the importance of this variable for semantic processing and supporting its semantic origin.

Yet, the focus of the present study is on age of acquisition effects for which the origin is still under debate. Our results confirm previous findings that not only semantic domain and typicality but also age of acquisition significantly affects response times in an animacy decision task across both living and non-living semantic domains (Catling & Johnston, 2006a; De Deyne & Storms, 2007; Menenti & Burani, 2007). Consequently, our results contrast the findings of Morrison and Gibbons (2006), who reported reliable age of acquisition effects exclusively for items in the living domain. However, our findings are in line with studies reporting age of acquisition effects in semantic tasks such as category-member-verification or object classification (Brysbaert et al., 2000; Ghyselinck et al., 2004; Holmes & Ellis, 2006; Johnston & Barry, 2005).

Based on the additive factors approach by Sternberg (1969), the consideration of null interactions of typicality and age of acquisition and individual main effects of semantic domain, typicality, age of acquisition, and word frequency provide evidence for an independent influence of each of the variables on animacy decisions[12]. The task used in the present study required participants to access the graphemic input lexicon as well as the semantic system (with regard to the Logogen model: e.g., De Bleser et al., 1997; Patterson, 1988). Thus, the offline effects (reaction time differences with regard to typicality, age of acquisition, semantic domain, and word frequency) might have arisen at different processing levels. The occurrence of word frequency effects in a task that involves access to written word forms is not surprising and could have been expected, since the items were not fully balanced with respect to this variable (Levelt, 1989). However, it is

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[12] It has to be noted that the non-significant interactions might also arise due to the rather small sample of the present study. However, the application of linear mixed models allows overcoming this issue (see further, Baayen et al. (2008); Barr et al. (2013)) and the results of the present study corroborate findings of a series of studies we recently conducted Räling et al. (2015); Räling et al. (2016), in which we also observed overall null interactions between age of acquisition and typicality in thoroughly larger samples of participants, albeit in a different task.

unlikely that frequency-related age of acquisition effects affected processing in our study, because word frequency and age of acquisition effects occurred independently from each other (see further Sternberg, 1969). Thus, the results presented here instead support the assumption of frequency-independent age of acquisition effects (Brysbaert & Ghyselinck, 2006). Brysbaert and Ghyselinck (2006) ascribe frequency-independent effects either to the link between semantics and phonology (lemma level) or to the semantic level itself, at least in tasks involving speech production subsequent to semantic analysis. In Räling et al. (2015; see also Räling et al., 2016), we assumed distinct underlying origins for typicality and age of acquisition effects based on the ERP results (effects on the N400 component for typicality only) and because of independent effects of typicality and age of acquisition on reaction time data. In the present study, the reaction times exactly replicate these earlier findings: Only the independent effects of age of acquisition and the other semantic variables (typicality and/or semantic domain) might have originated from distinct processing levels.

In consideration of the previous ERP studies (Räling et al., 2015; Räling et al., 2016) and the present offline results, we argue against a common source for effects of the truly semantic variables (typicality and semantic domain) and the age of acquisition variable. Instead, we assume that the observed frequency-independent age of acquisition effects originate at the link between the input lexicon and the semantic system, while typicality and semantic domain effects have their origin at the semantic level (and word frequency effects at the word form level). Moreover, enhanced age of acquisition effects occurring in tasks requiring speech production might be additive, that is, stemming from the links to and from the semantic system, as previously suggested by Catling and Johnston (2006a, 2009). Our findings are also in line with Ellis and Lambon Ralph (2000), who propose that age of acquisition effects are represented in the connection strength between representations which become more important in relationships that are arbitrary.

To conclude, we report the results of an animacy decision task with items systematically controlled for semantic domain, typicality, and age of acquisition. The response time data revealed an independent influence of each of the investigated variables, namely typicality, age of acquisition, semantic domain, and word frequency on animacy decisions. Together, the findings provide evidence for the existence of frequency-independent age of acquisition effects originating from the link between the lexical word form level and the semantic system. Future studies should focus on the complementary and simultaneous application of online and offline measurements and should also investigate impaired (pre- and post-) semantic processing in order to provide further evidence for the proposed origin of age of acquisition effects.

6.5 Acknowledgment

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7. The origins of age of acquisition and typicality effects: Semantic processing in aphasia and the ageing brain[13]

Abstract

Age of acquisition (AOA) has frequently been shown to influence response times and accuracy rates in word processing and constitutes a meaningful variable in aphasic language processing, while its origin in the language processing system is still under debate. To find out where AOA originates and whether and how it is related to another important psycholinguistic variable, namely semantic typicality (TYP), we studied healthy, elderly controls and semantically impaired individuals using semantic priming. For this purpose, we collected reaction times and accuracy rates as well as event-related potential data in an auditory category-member-verification task. The present results confirm a semantic origin of TYP, but question the same for AOA while favouring its origin at the phonology-semantics interface. The data are further interpreted in consideration of recent theories of ageing.

7.1 Introduction

Various linguistic variables influence word processing in healthy individuals, as well as in individuals with aphasia (IWA). In IWA, those variables often indicate the specific underlying deficit during language assessment (critical-variable approach; Shallice, 1988). Increased effects of variables such as concreteness or typicality in aphasic speech perception or production often point to a semantic deficit, while word frequency effects indicate lexical-phonological impairments (Nickels & Howard, 1995). Age of acquisition (AOA) has been described as one of the most important variables in aphasic speech production (Brysbaert & Ellis, 2015). However, its actual role at stages of speech perception in IWA has not been investigated so far.

Age of acquisition (AOA) characterises the point in time when a word has first been learned and produced in language acquisition (for reviews, see Johnston & Barry,

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[13] This chapter was adapted from the final draft post-refereeing: Räling, R., Schröder, A., & Wartenburger, I. (2016). The origins of age of acquisition and typicality effects: Semantic processing in aphasia and the ageing brain. *Neuropsychologia*, 86, 80–92. doi:10.1016/j.neuropsychologia.2016.04.019

2006; Juhasz, 2005). The influence of AOA in word processing was first differentiated from word frequency by Carroll and White (1973) in a picture naming task. Early acquired words are processed faster and more accurately than late acquired words, that is generally referred to as the AOA effect. To date, numerous behavioural studies in healthy young participants investigated the influence of AOA on a wide range of psycholinguistic tasks. Aside from written picture naming (Bonin et al., 2006), increased AOA effect sizes have been found in tasks requiring spoken output processes, such as word reading (Bonin et al., 2004; Gerhand & Barry, 1998; Monaghan & Ellis, 2010; Morrison & Ellis, 2000) and picture naming (Belke et al., 2005; Catling & Johnston, 2009; Cuetos et al., 1999; Holmes & Ellis, 2006). Further, AOA effects have also been described in tasks related to the perception of words and pictures, albeit with smaller effect sizes than in the studies above: in lexical decision tasks (Ghyselinck et al., 2004; Menenti & Burani, 2007; Smith et al., 2006), semantic categorisation tasks (Brysbaert et al., 2000; Ghyselinck et al., 2004), and particularly in animacy decision tasks (Catling & Johnston, 2006a; De Deyne & Storms, 2007; Räling, Schröder, Hanne, Keßler, & Wartenburger, under revision). However, others have been unsuccessful in finding AOA effects in semantic processing (e.g., Holmes & Ellis, 2006; Morrison et al., 1992).

To date, a consensus on the origin of AOA effects in cognitive models of language processing has not yet been achieved. The range of AOA effects in language processing tasks that involve input and output levels casts doubts on accounts that pinpoint effects of AOA at speech production levels only (e.g., at the phonological output level, Brown & Watson, 1987; Gerhand & Barry, 1998; Laganaro & Perret, 2011; Perret et al., 2014). For this purpose, an origin of AOA effects at the semantic processing level that accounts for AOA effects occurring in tasks that involve input as well as output modalities has been discussed (Brysbaert et al., 2000; Ghyselinck et al., 2004; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985). To account for varying of AOA effects sizes, some authors also discuss an origin of AOA effects at multiple levels of language processing: Belke et al. (2005; see also Brysbaert & Ghyselinck, 2006) suppose a distinction between frequency-related and frequency-independent AOA effects. Frequency-related AOA effects have been shown to be highly yoked with (cumulative) frequency effects (Lewis, 1999) and might occur wherever learning plays a role. Thus, effects of frequency-related effects are supposed to appear independently from modality and processing stage. They are assumed to be disseminated in the connection strengths between representations within the entire cognitive system and occur whenever access to learned information is mandatory (as has been proposed by Ellis & Lambon Ralph, 2000, in a connectionist model). Frequency-independent effects enable explanations of increased AOA effect sizes which are not related to word frequency and have been reported in tasks that require spoken output subsequent to a semantic analysis (i.e., in picture naming). Accordingly, Brysbaert and Ghyselinck (2006) propose the origin of frequency-independent AOA effects to be located either at the conceptual/semantic level or, more likely, at the semantics-phonology interface at output stages (lemma level) (see also Belke et al., 2005). These accounts refer to speech production (i.e., output level). Another account that postulates AOA effects at multiple levels is the accumulative account of Catling and Johnston (2006a, 2009). The authors assume additive AOA effects, the more levels of language representation are involved in task-relevant processing. Accordingly, tasks requiring additional spoken output result in increased AOA effect sizes as compared to lexical decision or semantic categorisation tasks. Catling and Johnston (2009) set the origins of AOA effects on early perceptual/structural, phonological and/or semantic-phonological-mapping representation levels. Here, we aim at evaluating frequency-independent AOA effects at the auditory input level by using a category-member verification task.

When determining the origin of AOA effects, it seems useful to consider not only behavioural data such as reaction times and accuracy rates in young healthy adults, but to expand the data by means of electrophysiological measures and different populations. So far, event-related potential (ERP) studies exclusively evaluating the AOA variable are very rare, and present rather inconsistent findings. For silent word reading, Cuetos et al. (2009) report an influence of AOA on the N400 component – a negative ERP wave peaking at about 400 ms post-stimulus onset, which is associated with semantic processing and varies with the effort of the preceding context alignment (Federmeier & Laszlo, 2009; Kutas & Federmeier, 2011; Kutas & Hillyard, 1984). In contrast, other ERP studies instead found no evidence for a semantic origin (at input stages: lexical decision: Tainturier et al., 2005; category-member-verification: Räling et al., 2015; or at output stages: object naming: Laganaro & Perret, 2011; Perret et al., 2014).

Investigating word processing in IWA is supposed to provide additional significant insights into the language processing system and may help to verify or modify existing cognitive models. With regard to AOA, its influence on impaired language processing has been examined to predict naming performance and vocabulary loss in various studies, including individuals suffering from Alzheimer's disease, semantic dementia, acquired dyslexia and aphasia (see Brysbaert & Ellis, 2015; Ellis, 2011 for reviews), indicating its significant impact on speech production following semantic analyses. Studies investigating aphasic language processing were not aimed at pinpointing the origin of AOA effects but at determining AOA as a significant predictor of picture naming accuracy only and mostly neglected a possible influence of AOA on speech perception. From today's perspective, drawing conclusions about the origin of AOA on the basis of previous studies on aphasia is hardly possible since a) the focus was primarily on picture naming and b) IWA were not selected with respect to their specific underlying language deficit, but based on the presence of general word-finding difficulties, which might occur on various levels in word production. This could explain why, in these studies, AOA was a predictor of semantic as well as phonological errors in aphasic picture naming (semantic errors: Cuetos et al., 2002; Nickels & Howard, 1995; phonological errors: Cuetos et al., 2002; Kittredge et al., 2008).

AOA intercorrelates very highly with semantic variables such as imageability or concreteness, and to a lesser extent with lexical variables such as word frequency (e.g., Morrison et al., 1997; Ramey, Chrysikou, & Reilly, 2013; Rubin, 1980)14. Thus, systematically analysing further relationships of AOA with semantic variables such as semantic typicality (TYP) while controlling for word frequency might provide further insight into the origin of AOA effects (Brysbaert et al., 2000). TYP has been described as a category member's representativeness of a superordinate, semantic category. The underlying theory of prototypes (Osherson & Smith, 1981; Rosch, 1973a, 1975; Rosch & Mervis, 1975) assumes that typical members (e.g., sparrow

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[14] But, see Schröder et al. (2012) for comparable correlation coefficients of AOA and word frequency (r = -.57), AOA and concept familiarity (r = -.58), and AOA and TYP (r = .50).

for BIRDS) share many semantic features with a mental, idealised prototype of a category. More recent accounts consider TYP to be represented in the semantic system by the typicality of features in connectionist models (McRae et al., 1999). Thus, typical members possess features which are highly intercorrelated with the features of other typical members (e.g., having feathers and wings as typical intercorrelated features for the category BIRDS), while atypical members are represented by rather distinct and less intercorrelated features (McClelland & Rogers, 2003; Rogers et al., 2004). Numerous behavioural studies on TYP (see Räling et al., 2015, for a summary) demonstrated a processing advantage for typical vs. atypical words during semantic processing, stressing its semantic origin (see also Woollams, 2012 for a discussion on the semantic origin of TYP). Typical words are processed faster and with greater accuracy than atypical words in semantic tasks without speech production, such as category-member-verification (e.g., Holmes & Ellis, 2006; Kiran et al., 2007) and animacy decisions (Morrison & Gibbons, 2006; Räling et al., under revision). TYP effects have also been found in tasks requiring verbal output, such as picture naming (Dell'Acqua et al., 2000), word reading (Garrod & Sanford, 1977), or category-member-generation (Hernández-Muñoz et al., 2006). ERP studies on the N400 component support a semantic origin of TYP. Studies report a more negative N400 for atypical compared to typical words in visual and auditory category-member-verification tasks (e.g., Fujihara et al., 1998; Heinze et al., 1998; Pritchard et al., 1991; Räling et al., 2015; Stuss et al., 1988).

Analogous to AOA, TYP also significantly influences language processing in aphasia, in that typical items are better preserved than atypical ones, as reflected in reaction times and accuracy rates. TYP effects in aphasia have mainly been studied at input stages with semantic category-member-verification tasks (Grober et al., 1980; Kiran et al., 2007; Kiran & Thompson, 2003; Riley & Thompson, 2010; Sandberg et al., 2012), but also in tasks requiring speech production, such as picture naming (Rossiter & Best, 2013) or category-exemplar generation (Grossman, 1981; Hough, 1993). The majority of studies did not select the participating IWA with respect to their specific underlying language deficit, but rather based on their underlying aphasic syndrome or lesion site and hence provide inconsistent results. These results taken together, it seems that IWA with a primary comprehension deficit (which might also result from a semantic impairment), as is the case in fluent, posterior, or Wernicke's aphasia, show attenuated TYP effects in comparison to individuals with other aphasic syndromes and healthy controls (Grober et al., 1980; Grossman, 1981; Hough, 1993; Hough & Pierce, 1989; Kiran & Thompson, 2003). In a study on category-member-verification of inanimate categories, Kiran et al. (2007) selected IWA with respect to their specific underlying language deficit as diagnosed by the Psycholinguistic Assessment of Language Processing Abilities in Aphasia (PALPA, Kay et al., 1992). IWA with a primary semantic deficit produced significantly more errors than the non-semantically impaired IWA, and each of the different groups (younger and older healthy adults, semantically impaired and unimpaired aphasic individuals) themselves showed significant TYP effects and performed more accurately and faster on typical compared to atypical items. Taken together, only the study of Kiran et al. (2007) provides convincing results to support a semantic origin of TYP. These findings are in line with studies on semantic dementia pointing to the impact of TYP on naming accuracy and error patterns during picture naming in individuals suffering from a progressive semantic impairment (Woollams, 2012; Woollams et al., 2008).

To date, well-controlled studies on TYP and AOA within the same experimental task are very rare. Holmes and Ellis (2006) reported a series of experiments on AOA, including object/non-object decisions and (delayed) object naming, as well as category-member-verification. Unexpectedly, the AOA effects, which had been significant across their first experiments, disappeared within the category-member-verification task as soon as the items were controlled for TYP. Hence, the authors argue against a common origin of both variables. In line with this interpretation but with other results than those reported in Holmes and Ellis (2006), we recently investigated the influence of TYP and AOA while controlling for word frequency in two different studies on semantic processing without speech production in healthy participants (Räling et al., 2015; Räling et al., under revision). First, conducting an offline animacy decision experiment on printed words in participants from a broad age range, we obtained independent effects for both TYP and AOA on reaction times (Räling et al., under revision), while the accuracy rates were at ceiling and hence not conclusive. Second, in an auditory category-member-verification experiment in young, healthy participants (Räling et al., 2015), we revealed a similar pattern at the reaction time level as in the animacy decision experiment with independent main effects of TYP and AOA, while the interaction of both was non-significant. However, accuracy and electrophysiological data showed TYP effects only, with increased error rates and a more negative N400 amplitude for atypical compared to typical target items. We assumed the null effects for AOA at the ERP level and the non-existent interactions of TYP and AOA in each of the comparisons in both studies to be due to distinct processing levels, and assumed hence different origins of TYP and AOA: While we obtained evidence for a semantic origin of TYP effects, we rejected the same for AOA effects. In Räling et al. (under review), we concluded that frequency-independent AOA effects occur not only in tasks that involve speech production (Belke et al., 2005; Brysbaert & Ghyselinck, 2006) but also in tasks that only involve levels of speech perception. It thus seems likely, that frequency-independent effects originate at the transitions between the word form levels and the semantic system at input and output stages, while the role of the semantic system itself cannot finally be evaluated.

Therefore, the aim of the current study is to scrutinise the semantic origin of frequency-independent AOA effects by investigating the impact of the interplay of AOA with the semantic variable TYP in a semantic processing task that only involves input stages in aphasic participants with a specific central semantic deficit (IWA). Because IWA are generally older than the university students who have mainly been investigated in the above-mentioned healthy populations, we add a group of elderly, healthy, age-matched individuals as a control group (EC). To further disentangle the origins of both variables, we combine behavioural (reaction times and accuracy rates) and ERP measures in an auditory category-member-verification task. The same design was recently used in young healthy participants (Räling et al., 2015). This complementary use of different research methods provides further insight into the time course and the outcome of semantic processing and allows further conclusions as to a) the diverging pattern of aphasic word processing and the variables that have an influence, and b) the influence of ageing on semantic processing.

Based on the above summarised literature and on our recent studies (Räling et al., 2015; Räling et al., under revision), we assume distinct origins of AOA and TYP while originating TYP at the semantic level. Hence, we hypothesise different magnitudes on the effects of TYP and AOA and significant interactions of TYP and/or AOA by participant group (EC vs. IWA) on behavioural and electrophysiological data. Because semantic processing seems not to be affected by age (Burke & Shafto, 2008), we expect to find comparable results at the behavioural level for the elderly control group to those we found for the younger participants (Räling et al., 2015; Räling et al., under revision)15, namely independent main effects of TYP and AOA and an absent interaction of both in the reaction time data with faster responses for typical and early acquired items, respectively, while the accuracy data are supposed to be influenced by TYP only (Räling et al., 2015). With respect to the IWA, we expect that their semantic impairment should impact the semantic variable TYP (Kiran et al., 2007). If the origin of AOA effects is considered at the transition between the phonological input lexicon and the semantic system, AOA should not (or only to a lesser degree than is TYP) be affected by the semantic impairment in IWA compared to the EC. At the ERP level, we expect to find N400 effects for TYP and also congruity (ERP control condition) in the elderly as in Räling et al. (2015), probably with reduced priming effects (see Cameli & Phillips, 2000; Kutas & Iragui, 1998 for ageing effects on the N400). Since young participants in Räling et al. (2015) did not demonstrate AOA effects at the electrophysiological level, we did not expect to find such for older adults, either. Suggesting a hypothesis on the ERPs in IWA is quite speculative, since there are no comparable studies on the respective variables and only a few studies have been published on the application of ERPs to aphasic language processing at all (for reviews, see Friederici, 2001; Swaab, 1998). In general, we expect to obtain reduced and delayed N400 amplitudes for IWA with a semantic deficit in contrast to the elderly control group.

7.2 Materials and methods

7.2.1 Participants

Thirty-three healthy elderly controls (EC) and nine IWA participated in the study. Each participant gave informed consent and received reimbursement for

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[15] Statistical comparisons of the young, healthy participants (data taken from Räling et al., 2015) with the elderly controls in the current study will additionally be reported in the results section. For detailed information on the younger controls, see Räling et al. (2015).

participating. The study was approved by the local ethics committee of the University of Potsdam.

In the group of EC, all participants were native speakers of German and right-handed, as evaluated by a German version of the Edinburgh Handedness Inventory (Oldfield, 1971). All participants had normal or corrected-to-normal vision and hearing and none of them reported a history of neurological or psychiatric disorders. Unimpaired cognitive processing was indicated by scores within the normal range in CERAD-Plus, the German Version of the Consortium to Establish a Registry for Alzheimer's Disease (Ehrensperger, Berres, Taylor, & Monsch, 2010) including the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975).

For data analysis, three elderly participants had to be excluded because of technical problems during the experiment, and two participants were excluded due to EEG-artefacts (see below). Accordingly, we report the results of the data for twenty-eight older participants (13 female, 15 male) with a mean age of 66.71 years (SD: 6.69 years; range: 49 to 79 years).

The IWA ($n = 9$, 2 female, 7 male) were selected from a pool of individuals with speech and language impairments of the Neurocognition of Language Laboratory at the University of Potsdam (M: 63.22 years; SD: 9.83 years; range: 47 to 73 years). IWA and elderly adults did not statistically differ with respect to their mean age ($t(35) = -1.211$, $p > .343$). Each of the IWA was pre-tested and classified as being aphasic using the Aachen Aphasia Test (AAT, Huber, Poeck, Weniger, & Willmes, 1983) by a qualified speech and language therapist. The individual profile of the underlying impairment was determined with the LEMO 2.0 battery (Stadie, Cholewa, & De Bleser, 2013) – a German aphasia assessment based on the Logogen Model (De Bleser et al., 1997; Morton, 1979; Patterson & Shewell, 1987). The IWA were selected with respect to the following criteria: native speakers of German, premorbid right-handed, normal or corrected-to-normal vision and hearing, no reported psychiatric disorders, left-hemispheric cerebrovascular stroke (left media infarction, at least 9 months prior to the experiment), and a diagnosed central deficit at the semantic processing level. A semantic deficit was classified if the participants showed impaired performances as determined in LEMO 2.0 (Stadie et al., 2013) in both auditory and written synonym judgement tasks with semantic distractors (average performance cut-off 90 % accuracy)16. In addition, we only included IWA with an intact auditory analysis level and phonological input lexicon. Each of the IWA generally performed with high accuracy in word-picture matching tasks. This was expected since word-picture matching can be easily solved and does not necessarily indicate specific semantic deficits (Cole-Virtue & Nickels, 2004; Kiran et al., 2007). All participants were able to give informed consent. Background information and selected assessments are summarised in Table A 2. As expected, the IWA showed a huge heterogeneity with respect to their syndrome classification, indicating its inappropriateness in assessment of aphasic syndromes in studying semantic processing (see also: Badecker & Caramazza, 1985; Caramazza, 1984; Schwartz, 1984).

7.2.2 Stimuli

The same auditory category-member-verification task and stimuli were used as those in Räling et al. (2015). The stimulus material contained 240 prime-target pairs. Nine semantic categories served as one of the auditorily presented category primes (animate: FRUITS, VEGETABLES, BIRDS, ANIMALS; inanimate: CLOTHING, FURNITURE, VEHICLES, TOOLS, MUSICAL INTRUMENTS). Each of the member targets belonged to one of the nine semantic categories and was chosen from a German database with norms for semantic typicality, age of acquisition and familiarity (Schröder et al., 2012). Semantic category and target words were semantically related (congruent condition) in 160 out of 240 word pairs. Congruent and incongruent target words differed significantly with respect to their typicality (typical vs. atypical words) and their age of acquisition (early vs. late acquired words). Hence, each of the target words clearly belonged to one of the four following conditions: typical / early acquired; typical / late acquired, atypical / early acquired or atypical / late acquired. In addition, the target words were balanced for their animacy. There were no significant differences across the four conditions in word frequency (obtained from the German database dlexDB,

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[16] Note that patient A02 was the only IWA that was tested with LEMO 2.0 visual synonym judgement without semantic distractors. Therefore, the test-specific cut-off for impaired performance was 95 % in this case.

www.dlexdb.de; Heister et al., 2011), the mean values of word length (number of phonemes/syllables), duration of the stimuli, and duration until the uniqueness point. For stimulus presentation, four pseudo-randomized lists of the 240 word pairs were prepared (see Räling et al., 2015, for detailed information on the stimulus material).

7.2.3 Procedure

Reaction times, accuracy rates, and EEG were recorded in a sound-attenuating chamber while performing an auditory category-member-verification task. The participants were asked to listen to the prime and target words and to verify the semantic relationship between the two words. They were instructed to respond as fast and as accurately as possible by pressing their left index or middle finger on a green button for semantically related prime-target pairs and a red button for semantically unrelated pairs (Cedrus RB-830 Response Pad, http://cedrus.com/). For half of the participants, button assignments were changed. Stimulus presentation was controlled by Presentation® software (Version 14.1, Neurobehavioral Systems, http://www.neurobs.com/) and took place over loudspeakers at a normal speakering volume, which could be individually adapted in the case of presbycusis. Stimuli were spoken by a trained female in a natural voice with normal speed. An experimental trial started with a white fixation cross in the middle of a black screen, while a semantic category prime was played auditorily (mean duration: 607.6 ms; SD: 126.78 ms; duration range: 369-767 ms). After an inter-stimulus interval (ISI) of 300 ms, the target word was presented auditorily (mean duration: 722.2 ms; SD: 167.4 ms, duration range: from 393 ms to 1269 ms). To guarantee understanding of the task, the experimental session started with six practice trials, including other, but comparable, stimuli than in the experiment. Each participant listened to one of the four pseudo-randomized lists, where each word pair was offered only once. Target presentation was followed by an inter-trial interval (ITI), which was jittered between 4 and 12 s (mean ITI: 6 s), which should allow for additional near-infrared spectroscopy (NIRS) recording (these data will not be presented). To relax, short pauses were integrated every 10 minutes. Including the preparation of the EEG cap, the whole experimental session lasted about 60 minutes.

7.2.4 EEG recording

EEG was recorded at a sampling rate of 1000 Hz through 32 active Ag/AgCl electrodes (actiCAP, Brain Products, Germany) fixed in an elastic EEG cap (EASYCAP) at the following scalp positions: Fp2, Fpz, AFz, F3/4, F7/8, Fz, FC3/4, FCz, FT7/8, C3/4, Cz, T7/8, T10, CP3/4, CPz, P3/4, Pz, P7/8, PO3/4, POz, and Oz with Fp1 as the ground electrode (terminology based on the international 10-10 system of the American Clinical Neurophysiology Society, Epstein et al., 2006), an online reference against the left mastoid and an offline re-reference to averaged left and right mastoids. Impedance of the electrodes was kept below 5 kΩ. To detect blinks and vertical eye movements, an electro-occulogram (EOG) was recorded by means of electrodes placed above (FP2) and below the right eye.

7.2.5 Behavioural data analysis

For the analysis of reaction times (RTs), data were log-transformed to meet the assumption of parametric tests, and incorrect responses have been excluded. To hold the processes of analysis as consistently and as comparably as possible, we applied the same statistical analyses as in Räling et al. (2015), but added an additional between-subject factor (GROUP). Comparisons were run by calculating 2 × 2 repeated measures analyses of variance (ANOVA) with the within-subject factors TYP (typical vs. atypical) and AOA (early vs. late acquired) and a between-subject factor GROUP (either EC and IWA (GROUP1), or YC (younger controls from Räling et al., 2015) and EC (GROUP2)) on the congruent data (accuracy and RTs) only, since the incongruent data served as fillers. Only significant interactions of TYP and AOA with the factor GROUP were considered in post-hoc comparisons. Significant main effects in the group comparisons were not reported.

7.2.6 ERP data analysis

For the pre-processing of the EEG data, Brain Vision Analyzer Software (Version 2.01; Brain Products, Gilching, Germany) was used. To eliminate muscle artefacts and slow drifts, a digital band-pass filter was set on the raw data to 0.01 to 100 Hz (slope: 12 dB) and a notch filter to 50 Hz. The continuous EEG signal was segmented into epochs of 1000 ms, relative to the onset of the target words (time window: 100 ms prior and 900 ms after target onset). To correct for vertical eye movements, the algorithm of Gratton et al. (1983) was applied offline. Artefact rejection was done semi-automatically based on the following criteria: maximal allowed voltage step of 35 µV/ms, maximal allowed difference of values in intervals of 150 µV, lowest allowed activity in intervals of 0.5 µV. Epochs with incorrect behavioural responses were also excluded in this part of the analysis. Participants with more than 15 % rejected trials were excluded from further analysis, as was the case for two elderly participants. ERPs were averaged for each participant and for each condition, with a baseline correction of 100 ms to pre-stimulus-onset. For presentation purposes only, grand average ERPs were filtered offline with an 8 Hz low-pass filter (12 dB).

The mean number of averaged trials per older participant for the congruent trials was 38.2 for the typical / early acquired targets (SD = 1.81; 95 %), 38.1 for the typical / late acquired targets (SD = 1.56; 95 %), 36.3 for the atypical / early acquired targets (SD = 2.23; 91%), and 36.9 for the atypical / late acquired targets (SD = 1.88; 92 %). For the incongruent trials, the mean number of averaged trials per participant was 75.5 (SD = 3.57; 94 %). For the IWA, the number of averaged trials was 31.9 for the typical / early acquired targets (SD = 7.46; 80 %), 32.2 for the typical / late acquired targets (SD = 7.12; 81 %), 31.9 for the atypical / early acquired targets (SD = 7.46; 80 %), and 32.2 for the atypical / late acquired targets (SD = 7.12; 81 %). For the incongruent trials, the mean number of averaged trials per aphasic participant was 57.1 (SD = 19.08; 71 %). The reduction of the number of included segments for the aphasic group was due to the higher error rates, since segments containing incorrect responses were excluded in the ERP data analyses.

As in Räling et al. (2015), the same time windows and regions of interest (ROIs) have been selected for statistical analyses of the N400 effect to hold the analysing process throughout the groups as stably and comparably as possible. Therefore, statistical analyses have been performed in 100 ms time windows from 300 ms to 800 ms, as well as in the broader time interval of 350 ms to 750 ms on six ROIs (left anterior: F7, F3, FT7, FC3; left posterior: C3, CP3, P3, PO3; midline anterior: Fpz, AFz, Fz, FCz; midline posterior: Cz, CPz, Pz, POz, right anterior: F4, F8, FC4, FT8; and right posterior: C4, CP4, P4, PO4) by calculating the mean amplitudes of the respective four electrodes.

For statistical analyses, the following ANOVAs were carried out: First, we calculated congruity effects by using a 2 × 6 × 2 ANOVA with the within-subject factors CONGR (congruity: congruent vs. incongruent/filler targets) and ROI (left anterior, left posterior, midline anterior, midline posterior, right anterior, right posterior) and a between-subject factor GROUP (either GROUP1 or GROUP2, see above). Second, to analyse TYP and AOA effects, 2 × 2 × 6 × 2 ANOVAs were applied, including the within-subject factors TYP (typicality: typical vs. atypical), AOA (age of acquisition: early acquired vs. late acquired), ROI and the between-subject factor GROUP. The statistical ERP analysis followed a hierarchical pattern (see Bornkessel, Schlesewsky, & Friederici, 2003; Burmester, Spalek, & Wartenburger, 2014; Rossi et al., 2011 for comparable analyses). Subsequently, therefore, only statistically significant main effects and interactions ($p \leq .05$) with the factors GROUP, CONGR, TYP, and AOA as well as interactions of the factors of interest with ROI were included in post-hoc comparisons. Significant multiple interactions were broken down by applying ANOVAs on the next level. As soon as was appropriate, the Greenhouse-Geisser correction was applied and, in these cases, the corrected F- and p-values were reported with the uncorrected degrees of freedom.

7.3 Results

7.3.1 Accuracy rates

Accuracy rates are summarised in Figure 9 (striped bars) and Table 5. Group comparisons with regard to TYP and AOA revealed a significant interaction between TYP and GROUP1 ($F(1, 35) = 5.73$, $p < .05$). Post-hoc tests within the groups showed a significant main effect of TYP within the EC ($F(1, 27) = 41.68$, $p < .001$) and within the IWA ($F(1, 8) = 28.20$, $p < .001$), with typical words producing fewer errors than atypical ones within each group (EC: $t(27) = 6.46$, $p < .001$; IWA: $t(8) = 5.31$, $p < .01$). Most importantly, post-hoc t-tests revealed that the IWA produced significantly more errors than the EC within both typical items ($t(35) = 2.654$, $p < .05$) and atypical items ($t(35) = 5.154$, $p < .001$). Further significant interactions by GROUP1 were not observed (AOA × GROUP1: $F(1, 35) = 1.06$, $p = .31$; TYP × AOA × GROUP1: $F(1, 35) = .05$, $p = .83$).

Comparisons between the younger controls (YC) from our previous study (Räling et al., 2015) and the EC from the current study on the accuracy data revealed no significant differences between both groups with regard to AOA and TYP with the between-subject factor GROUP2 (all *p*'s > .05). The accuracy data did also not reveal a main effect of GROUP2 indicating general age differences ($F(1, 49) = .256$, $p = .613$).

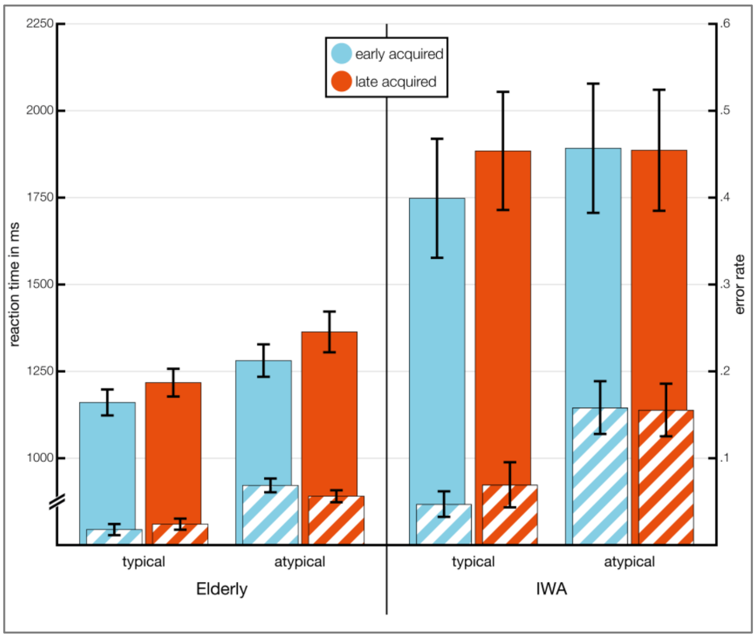

Figure 9 Mean reaction times (filled bars) and proportion of mean error rates (striped bars) with standard error bars per group and condition

7.3.2 Reaction times

Reaction times are summarised in Figure 9 (filled bars) and Table 5**.** There was a significant interaction for TYP × AOA × GROUP1 ($F(1, 35) = 6.88$, $p < .05$). Post-hoc analyses revealed no significant within-group interactions between TYP and AOA in any of the groups. In all conditions, the EC responded significantly faster than the IWA (all p's < .001).

Statistical comparisons revealed a significant interaction for TYP × GROUP1 ($F(1, 35) = 4.41$, $p < .05$), with the elderly responding faster than the IWA with typical ($t(35) = -5.284$, $p < .001$) and atypical ($t(35) = -4.298$, $p < .001$) words, respectively. Within-group analysis revealed a significant main effect for TYP in the elderly ($F(1, 27) = 59.76$, $p < .001$) and in the IWA ($F(1, 8) = 5.60$, $p < .05$). The interaction AOA × GROUP1 was not significant ($F(1, 35) = 0.44$, $p = .51$).

Table 5 Mean accuracy (proportion in parentheses) and mean logarithmised reaction times (RT) of correct responses by condition

Group	accuracy				log RT			
	typical		atypical		typical		atypical	
	early	late	early	late	early	late	early	late
Elderly								
Mean	39.29 (.98)	39.04 (.98)	37.25 (.93)	37.75 (.94)	7.02	7.06	7.09	7.15
SD	1.36	1.35	1.67	1.46	0.15	0.16	0.17	0.19
Range	33-40	35-40	32-40	35-40	6.75-7.43	6.84-7.51	6.89-7.53	6.90-7.69
IWA								
A01	37 (.93)	31 (.78)	30 (.75)	33 (.83)	7.80	7.85	7.84	7.82
A02	40 (1.0)	40 (1.0)	37 (.93)	33 (.83)	7.50	7.51	7.51	7.52
A03	37 (.93)	37 (.93)	28 (.70)	32 (.80)	7.69	7.77	7.88	7.81
A04	38 (.95)	39 (.98)	36 (.90)	37 (.93)	7.07	7.18	7.09	7.23
A05	39 (.98)	36 (.90)	36 (.90)	33 (.83)	7.22	7.29	7.40	7.24
A06	40 (1.0)	40 (1.0)	38 (.95)	37 (.93)	7.33	7.42	7.39	7.38
A07	35 (.88)	34 (.85)	31 (.78)	31 (.78)	7.02	7.14	7.06	7.11
A08	37 (.93)	38 (.95)	31 (.78)	28 (.70)	7.60	7.67	7.57	7.69
A09	40 (1.0)	40 (1.0)	36 (.90)	40 (1.0)	7.21	7.25	7.36	7.32
Mean	38.11 (.95)	37.22 (.93)	33.67 (.84)	33.78 (.84)	7.38	7.45	7.45	7.46
SD	1.76	3.11	3.64	3.63	0.28	0.26	0.29	0.26

Group comparisons on the RTs in YC and EC revealed a main effect of the between-subject factor GROUP2 ($F(1, 49) = 11.28$, $p < .01$), with EC producing significantly longer RT's than YC. There was also a significant TYP × GROUP2 interaction ($F(1, 49) = 9.81$, $p < .01$).Within-group comparisons revealed significant main effects of TYP, with typical words to be faster processed than atypical words in both groups (YC: $F(1, 22) = 15.15$, $p < .001$; EC: $F(1, 27) = 59.76$, $p < .001$). Between-group comparisons on AOA ($F(1, 49) = 0.04$, $p > .05$) and AOA × TYP ($F(1, 49) = 0.15$, $p > .05$) did not reveal significant effects.

7.3.3 ERP results

7.3.3.1 Visual inspection

Grand average ERPs of the elderly and IWA are presented in Figures 2, 3 and 4. Visual inspection of the elderly group revealed for CONGR a broad and prolonged negativity peaking around 500 ms that can be observed across all target types, with the greatest amplitude differences between congruent and incongruent targets at the right-frontal electrodes (with incongruent targets more negative than congruent ones). For typicality, the waves of typical and atypical words seem to be coincident, while for AOA early acquired words generally tend to have a more negative amplitude than late acquired words. Although the IWA generally show a greater noise due to the smaller number of participants, a similar negativity as described in the elderly group is obvious in centro-parietal regions for congruity. Waveforms representing TYP and AOA effects also seem to be coincident in the IWA.

7.3.3.2 Congruity effects - control condition

ERP group analyses are summarised in Table 6. The three-way interaction CONGR × ROI × GROUP1 revealed significant effects in the relevant time windows of the N400 (500 – 600 ms, 600 – 700 ms, and 700 – 800 ms). This effect was still significant when analysing the time interval of 350 – 750 ms ($F(5, 175) = 3.07$, $p < .05$). Within-group analyses revealed in the IWA neither significant main effects of CONGR nor significant interactions of CONGR with ROI within the 100 ms time windows. The significant CONGR × ROI interaction in the broader time window 350 – 750 ms ($F(5, 40) = 19.52$, $p < .001$) was not due to the effect of congruity, but related to significant differences in the ROIs. However, within-group comparisons of the elderly revealed significant CONGR effects in right anterior electrodes in the time windows 500 – 600 ms ($t(27) = 3.24$, $p < .01$) and 600 – 700 ms ($t(27) = 2.81$, $p < .01$), with incongruent targets resulting in more negative amplitudes than congruent targets. Post-hoc tests in the time window 300 to 400 ms revealed more positive amplitudes for incongruent targets than for congruent targets in midline posterior ($t(27) = -3.57$, $p < .001$) and right posterior ($t(27) = -2.57$, $p < .05$) electrodes. These differences might rather be a manipulation of extensions of the P200 ERP component, which is not of interest in this study. Analysing the broader time window 350 – 750 ms, the interaction of CONGR with ROI remains highly significant ($F(5, 135) = 30.69$, $p < .001$), with right frontal sites resulting in a more negative amplitude for incongruent vs. congruent targets ($t(27) = 2.68$, $p < .05$).

The interaction CONGR × GROUP1 showed a significant difference between the two groups in the early time window of 300 – 400 ms. Within-group analysis revealed in the elderly no main effects of CONGR in any of the time windows. The IWA showed a significant main effect of CONGR in the time window 300 to 400 ms ($F(5, 40) = 16.55$, $p < .001$), in which incongruent targets led to significantly more negative amplitudes in incongruent compared to congruent targets ($t(8) = -23.31$, $p < .05$) (see Figure 10).

Table 6 F-values for interactions of congruity, typicality and age of acquisition by group (GROUP1: EC and IWA; GROUP2: YC and EC) and region of interest (ROI) in 100-ms time windows

ANOVA	df	*F*-values per time window (ms)				
		300-400	400-500	500-600	600-700	700-800
GROUP1	1, 35	1.76	0.55	0.01	0.35	1.93
CONGR × GROUP1	1, 35	8.65**	0.37	0.02	0.22	0.27
CONGR × ROI × GROUP1	5, 175	0.38	1.02	4.03*	5.78**	4.93**
TYP × GROUP1	1, 35	0.35	0.05	0.15	0.45	0.06
TYP × ROI × GROUP1	5, 175	0.64	0.32	0.70	0.89	0.73
AOA × GROUP1	1, 35	0.07	0.66	0.05	0.01	1.32
AOA × ROI × GROUP1	5, 175	2.37	1.54	0.92	1.34	1.24
TYP × AOA × GROUP1	1, 35	1.62	0.82	0.09	0.97	0.03
TYP × AOA × ROI × GROUP1	5, 175	0.11	0.10	1.04	1.25	0.61
GROUP2	1, 49	0.42	3.87	5.94*	3.81	1.43
CONGR × GROUP2	1, 49	9.31**	13.86***	9.92**	6.64*	1.82
CONGR × ROI × GROUP2	5, 235	1.44	5.45**	10.34***	19.43***	24.20***
TYP × GROUP2	1, 49	0.11	1.28	2.38	2.85	1.74
TYP × ROI × GROUP2	5, 235	0.16	1.94	2.69	2.62	2.09
AOA × GROUP2	1, 49	1.22	2.63	5.03*	1.48	0.49
AOA × ROI × GROUP2	5, 235	0.27	0.52	0.61	1.40	0.78
TYP × AOA × GROUP2	1, 49	0.01	0.01	0.18	1.02	2.73
TYP × AOA × ROI × GROUP2	5, 235	0.53	0.17	0.45	0.12	0.23

Notes: Greenhouse and Geisser (1959) corrected levels of significance: *$p \leq .05$, **$p \leq .01$, ***$p \leq .001$; df: degrees of freedom

The interaction CONGR × GROUP2 showed significant differences between the YC and EC in the time windows from 300 – 700 ms (see Table 6). Within-group analyses revealed in the elderly no main effects of CONGR in any of the time windows and in the younger controls significant CONGR effects in the time windows from 300 – 700 ms (see Räling et al., 2015, for detailed statistics), with incongruent target words evoking a more negative amplitude than congruent target words. The three-way interaction CONGR × ROI × GROUP2 revealed significant results in the time windows 400 – 800 ms. Within-group analyses revealed in the elderly a significant effect of CONGR in the time window 500 – 700 ms in right-frontal electrodes only (see above) and in the YC group a broadly distributed

CONGR effect with the largest effects at centro-parietal regions in the time windows 400 to 700 ms (see Räling et al., 2015).

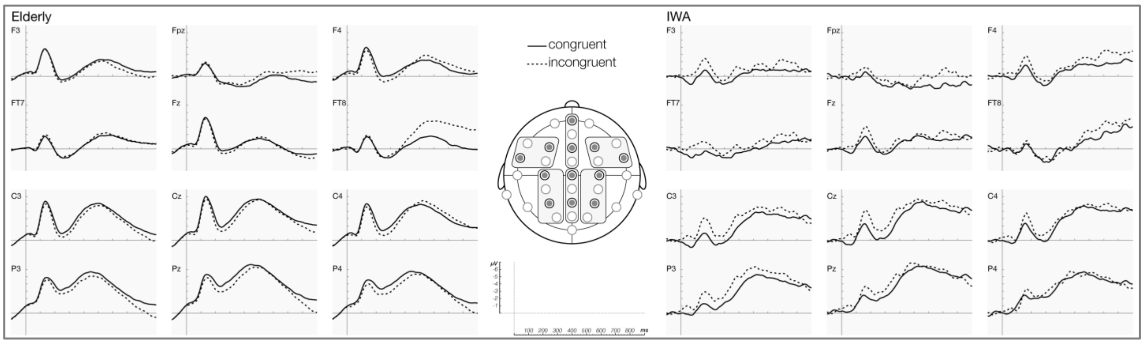

Figure 10 Congruity: Grand average ERPs time-locked to the onset of the category member in elderly adults and individuals with aphasia

7.3.3.3 TYP and AOA effects

Grand average ERPs on TYP and AOA with respect to the two groups (EC and IWA) are depicted in Figure 11 and 12. Analyses of the interaction of TYP and AOA with the between-subject factor GROUP1 did not reach significance throughout the analyses in 100 ms time windows, as well as in the broader time window (see Table 6).

Statistical analyses on TYP and AOA with regard to the between-subject factor GROUP2 (YC and EC) revealed only one significant AOA × GROUP2 interaction in the time window (500 – 600 ms, see Table 6). Within-group analyses showed that in the elderly the amplitude was inversely affected by the factor AOA, with early acquired words resulting in a significantly more negative amplitude compared to late acquired words ($t(27) = -3.04$, $p < .01$). In the younger control group, there was no effect of AOA in the respective time window (see Räling et al., 2015, for detailed information).

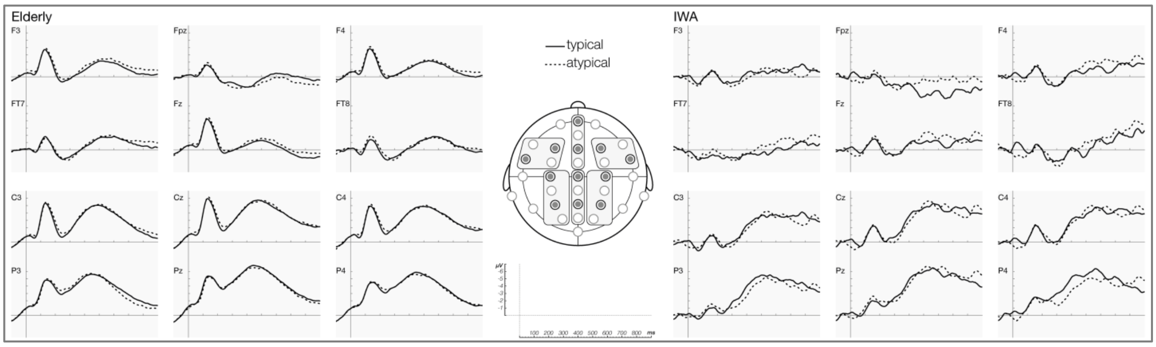

Figure 11 Typicality: Grand average ERPs time-locked to the onset of the category member in elderly adults and individuals with aphasia

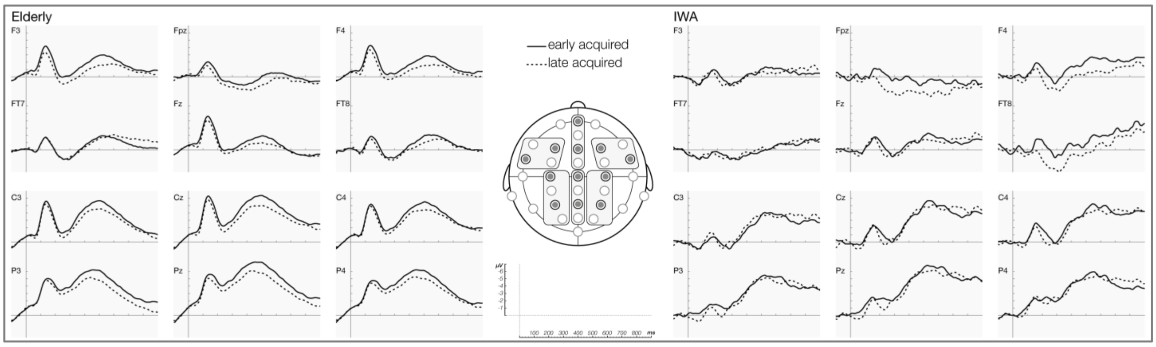

Figure 12 Age of acquisition: Grand average ERPs time-locked to the onset of the category member in elderly adults and individuals with aphasia

7.3.4 Summary of the results

To sum up, the offline behavioural data revealed that IWA performed significantly more slowly and with significantly more errors than the elderly control group. The accuracy and the reaction time data further showed significant by-group interactions for TYP only. In comparison to the elderly, the IWA showed an enhanced TYP effect: They produced significantly more errors in atypical vs. typical items, but both groups were slower for atypical compared to typical items.

At the electrophysiological level, group comparisons revealed that the elderly control group showed a significant congruity effect, with incongruent words resulting in a more negative N400-like amplitude than congruent words, only in right frontal electrodes (500 to 800 ms), while the IWA only showed a small congruity effect in the time interval from 300 - 400 ms. Regarding TYP and AOA, there were no significant interactions with the between-subject factor GROUP1.

Additional analyses on the elderly controls in comparison to younger controls (data taken from an earlier study, Räling et al., 2015) revealed no differences between YC and EC on the accuracy rates but a general slowing of the EC on the reaction times. The analysis of the ERP data revealed a shift of the N400 congruity effect from a broad distribution in the YC to only right-anterior electrodes in the EC-group. In addition, there was an inverse AOA effect in the EC in a single time window, which was not present in the younger group.

7.4 Discussion

This study aimed at systematically investigating the influence of TYP and AOA on auditory semantic processing in two specific populations, namely in a small group of IWA suffering from a specific semantic deficit and in aged-matched elderly controls, in order to determine their origins. For that purpose, we collected offline behavioural (reaction times and accuracy rates) and online ERP data, while both groups performed an auditory category-member-verification task. Category members differed with respect to their CONGR with the preceding prime category (semantically related/congruent vs. semantically unrelated/incongruent), TYP (typical vs. atypical), and AOA (early vs. late acquired). Before discussing the present results, it should be emphasised that investigating IWA also requires taking the age factor into consideration, because aphasia typically occurs in a population above 50 years of age. In the present study, both participating groups (IWA and EC) were matched with respect to their age (EC: M: 66.71; SD: 6.69; range: 49 to 79; IWA: M: 63.22 years; SD: 9.83; range: 47 to 73). We will first discuss the impact of age on semantic word processing, before discussing the influence of AOA and TYP on semantic processing in both groups of participants.

7.4.1 Semantic processing in ageing

The semantic system in healthy older people has been described as robust, stable, and more elaborate than the semantic system in younger ones, which is due to richer semantic representations and a generally greater linguistic experience developing during adulthood. However, besides preserved semantic abilities, decreasing working memory and perceptual-phonological processing skills have been repeatedly reported in ageing (for review, see Burke & Shafto, 2008). Particularly the latter are mainly due to age-related hearing loss (presbycusis) and a decline in auditory temporal processing (Humes, 1996; Schneider & Pichora-Fuller, 2001). The maintenance of semantic abilities has been reflected in offline accuracy data, since, in comprehension-related tasks older participants generally perform the equivalent or even better in comparison to younger participants (Wlotko, Lee, & Federmeier, 2010), despite an overall slowing (Drag & Bieliauskas, 2010; Verhaeghen, 1999; Verhaeghen & Cerella, 2008). Thus, in the present study, we expected the individuals in the healthy, elderly control group to perform similarly to what has been described in previous ageing studies. The behavioural data alone confirm this hypothesis, since the elderly control group performed as good as the younger group, but showed a general slowing at the reaction time level.

7.4.1.1 General age effects in ERPs

With regard to the ERP data, however, we found differences compared to the offline behavioural data. This is in line with previous ERP studies on ageing which showed that, although behavioural semantic access performances are quite similar to that of younger groups, with regard to online data, older people usually show a distinctive pattern (Federmeier, 2007; Friedman, 2012). With respect to the N400 component in ERP data, a decrease in the amplitude and an increase in the peak latency have been reported with rising age (Federmeier & Kutas, 2005; Gunter, Jackson, & Mulder, 1995; Kutas & Iragui, 1998; Wlotko & Federmeier, 2012). Notably, N400 priming effects in ageing have been found in some studies (e.g., Federmeier, Van Petten, Schwartz, & Kutas, 2003; Grieder et al., 2012), but not in others (e.g., Cameli & Phillips, 2000; Federmeier et al., 2010; Federmeier, McLennan, Ochoa, & Kutas, 2002; Hamberger & Friedman, 1992; Kutas & Iragui, 1998). In the present study, we found a different activation pattern in the elderly control group as in the younger group in Räling et al. (2015). The non-existing N400 effects on congruity in centro-parietal regions in the elderly controls (the shift to right anterior electrodes will be discussed in the next paragraph) support previous findings on absent N400 priming effects in ageing (e.g., Cameli & Phillips, 2000; Federmeier et al., 2002; Kutas & Iragui, 1998), which may result from extenuated inhibition processes occurring with rising age (so-called inhibition deficit theory, Hasher, Lustig, & Zacks, 2007; Hasher & Zacks, 1988). Inhibition prevents irrelevant information from entering the current processing level and suppresses previously activated information or competitors that are not relevant (see further: Pires, Leitão, Guerrini, & Simões, 2014). Deficits in the inhibition of irrelevant information lead to the activation of larger amounts of information as needed with respect to the task (Burke & Shafto, 2008; Drag & Bieliauskas, 2010). Therefore, similar activation patterns for congruent/incongruent or typical/atypical target words might occur and could be indexed by coincident ERP waveforms, while the behavioural outcome seems to show a mere general slowing of the processing in EC but not a qualitative difference (as seen in non-deviating accuracy rates of EC and young participants).

7.4.1.2 Shifted age effects in CONGR

While we found a fairly standard CONGR effect in centro-parietal electrodes in the young, healthy participants (Räling et al., 2015), the present data revealed in the elderly group CONGR effects at the right frontal electrodes only (more negative amplitude in incongruent vs. congruent words). A shift in the N400 congruity effect from centro-parietal to right frontal electrodes has not previously been reported in the ageing literature (e.g., Friedman, 2012; Wlotko et al., 2010), nor with respect to the standard topography of the N400 component (Kutas & Federmeier, 2011; Kutas & Hillyard, 1983). Possible reasons for this rather unusual shift in the elderly might include neural-structural changes emerging with rising age (Cabeza, 2002), which nevertheless seem not to influence the behavioural outcome except for a general slowing. Hence, the slowing might possibly be related to these neuro-structural changes (see also, Burke & Shafto, 2008).

7.4.1.3 Inverse AOA effect

Turning to AOA, we did not hypothesise an influence of AOA on the ERP data due to absent electrophysiological AOA main effects in young, healthy participants (Räling et al., 2015). Even more unexpected, the elderly controls show in comparison to the younger controls an inverse ERP response to AOA in a small time window (500 – 600 ms), in that early acquired words result in a more negative N400 amplitude than late acquired words. However, this effect is very small in comparison to the shift of the congruity effect described above. That is why we cannot draw any inferences on an influence of AOA on online processing based on the current ERP data.

7.4.2 ERP data in IWA

Contrary to expectations, the ERP data revealed that the IWA did not significantly deviate in their ERP responses from the elderly control group with respect to the variables TYP and AOA (as indicated by non-significant interactions between group and TYP and/or AOA) and tended to produce a similar N400-like component. However, these null effects might be due to the limited number of participating IWA and a noisy ERP signal. The following discussion is thus rather restrained. So far, only a few studies have been published on the measurement of ERP correlates in IWA while focusing on lexical-semantic processing (for reviews, see Friederici, 2001; Swaab, 1998). Single-case ERP studies reported an absence of the N400 component in auditory sentence paradigms (Friederici, Hahne, & Cramon, 1998; Revonsuo & Laine, 1996). In contrast, studies with syndrome-based groups of IWA (Broca's and Wernicke's aphasia) describe the magnitude of the N400 component in relation to the severity of the comprehension deficit, in that IWA with a severely impaired comprehension score showed a reduced and delayed N400 amplitude in comparison to IWA with a mild comprehension impairment or individuals with a right hemisphere lesion (Hagoort et al., 1996; Swaab et al., 1997)17. In line with the findings of Haagort et al. (1996), the coincident ERP waves in the elderly and IWA might underline that the majority of participating IWA did not suffer from a severe semantic deficit. Moreover, the IWA did not show a CONGR effect in right-frontal electrodes as in the elderly or in centro-parietal electrodes as in the younger controls. We interpret the absence of CONGR effects in the IWA as related to the semantic deficit. The absent TYP effect in IWA is not surprising and in line with the absent effects in the EC participants – but can additionally be caused by the limited number of participating IWA. In summary, the ERP group comparisons of elderly controls and IWA do not provide meaningful results in order to distinguish between TYP and AOA effects as was possible in the young, healthy group in Räling et al. (2015). The most informative results on AOA and TYP reveal the behavioural accuracy data, which are discussed in the following.

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[17] It has to be noted that those studies also run their ERP analyses only with a small number of IWA (7 to 13 IWA, depending on the syndrome-based group in Hagoort et al., 1996; 12 IWA in Swaab et al., 1997).

The verification of auditory presented category members requires access to the following stages of auditory word perception: the auditory analysis level, the phonological input lexicon (comparable to the lexeme-level), the transition between the input lexicon and the semantic system (comparable to the lemma-level) and the semantic level, where the verification is generated (with regard to the Logogen Model, Morton, 1979; Patterson & Shewell, 1987; see also the model of speech production by Levelt, 1989; Levelt et al., 1999). The individual diagnosis of the participating IWA indicated a specific impairment at the semantic level with intact pre-semantic processing levels.

7.4.3 Behavioural data in IWA

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7.4.3.1 Typicality effects in IWA

Group comparisons revealed differences between both groups only for TYP, while the elderly and the IWA showed similar performances for AOA in both accuracy and reaction time data. For TYP, both groups performed with a higher accuracy and more quickly to typical words compared to atypical words, but the IWA showed significantly more errors than the elderly controls in atypical items. Therefore, compared to the elderly, in particular the deviating accuracy data confirm that the variable TYP significantly influences semantic categorisation in IWA and thus once more confirm a semantic origin of TYP. These results are in line with Kiran et al. (2007), reporting a significant influence of TYP in nine semantically impaired individuals. However, the current results are in contrast to other studies that did not control the specific underlying deficit of the IWA (Grober et al., 1980; Grossman, 1981; Hough, 1993; Hough & Pierce, 1989; Kiran & Thompson, 2003; Riley & Thompson, 2010). In the literature, impaired performance in semantic tasks in IWA are discussed to result either from deficits on the refractory access to the semantic system, which are usually modality-specific, or on the stored amodal representations themselves (e.g., Warrington & Cipolotti, 1996). The IWA participating in the present study showed impaired performances on auditory and visual synonym judgements with semantic distractors, though to different degrees. Hence, they can be classified as suffering from a central semantic impairment. To be more specific, storage deficits might also result from the damage to either the semantic concept itself or -more likely- the specific semantic features within the semantic system. Our behavioural data provide evidence for the assumption that the enhanced difficulties on atypical items in IWA (especially higher error rates) are due to the higher vulnerability of weakly intercorrelated, atypical semantic features (Woollams, 2012). This is in accordance with recent theoretical accounts on simulating TYP effects in connectionist semantic models (e.g., McRae et al., 1999; Rogers et al., 2004). Our findings are further in line with studies on individuals with semantic dementia, showing TYP to be a significant predictor of vocabulary loss (e.g., Woollams, 2012). Hence, our accuracy data support a semantic origin of the variable TYP.

7.4.3.2 AOA effects in IWA

With respect to AOA, to our knowledge, this is the first study investigating AOA effects in IWA during semantic processing involving only stages of speech perception. Previous studies determined AOA to be a significant predictor of accuracy rates during picture naming (e.g., Brysbaert & Ellis, 2015; Cuetos et al., 2002; Nickels & Howard, 1995). Since previous studies did not carefully select their participating IWA according to their specific underlying deficit, it is not clear whether the difficulties obtained in naming result from central semantic deficits or from post-semantic impairments on the access to lexical-phonological entries (lemma or lexeme level). In the present study, we avoided such ambiguities by only including IWA with a specific semantic deficit. Interestingly, despite a general slowing, the behaviour of the IWA did not significantly differ from the elderly control group with regard to AOA. Despite the limited number of tested IWA, the fact that the semantic deficit did not lead to deviant or increased AOA effects in the accuracy rates of the IWA can be seen as further evidence against a purely semantic origin of frequency-independent AOA effects, but supports an origin at the phonology-semantics interface.

Moreover, obtained AOA effects at the reaction time level in healthy young semantic processing (Räling et al., 2015; Räling et al., under revision) underline an origin of frequency-independent AOA effects not only at the output lemma-level (as has been proposed by Belke et al., 2005; Brysbaert & Ghyselinck, 2006), but also at analogous stages at the input side, namely, at the transition from the phonological input lexicon to the semantic system. We are thus in favour of multiple origins of frequency-independent effects, which we assume at every transition to (our data; Räling et al., 2015; Räling et al., under revision) and from (Belke et al., 2005; Brysbaert & Ghyselinck, 2006) the semantic system. An origin at multiple levels would also explain increasing effect sizes that cumulatively occur in tasks that demand additional speech production (as proposed by Catling & Johnston, 2006a, 2009).

7.5 Conclusion

In line with our previous studies (Räling et al., 2015; Räling et al., under revision), the obtained behavioural data with overall non-significant interactions of the variables TYP and AOA, support the independence of both variables in tasks that involve semantic processing without requiring access to speech output stages and point to their different origins. With respect to the variable TYP, the accuracy data confirm earlier studies on a semantic origin (Räling et al., 2015; Räling et al., under revision; Woollams, 2012). It is very likely that TYP reflects the intercorrelation of semantic features: The more typical an item is, the higher it is intercorrelated with semantic features of other typical items leading to less vulnerability than it is the case in atypical items.

According to AOA, frequency-independent effects have so far been proposed for tasks that involve speech production processes and they are assumed to originate either at the semantic level or at the transition between semantics and phonology (lemma-level) (Belke et al., 2005; Brysbaert & Ghyselinck, 2006). Our behavioural data -in particular the accuracy data- and the group comparisons speak against a semantic origin of frequency-independent AOA effects during speech perception. We finally argue that frequency-independent AOA effects originate at multiple stages, namely at each transition to and from the semantic system, whose effects cumulate as soon as input and output stages are involved during word processing (see further, Catling & Johnston, 2006a, 2009).

Consequently, it seems useful to integrate the variable AOA into the diagnosis and treatment of impairments specifically affecting the transition between phonology and semantics (and, hence, refractory semantic access impairments), whereas TYP should be considered a relevant variable in central semantic deficits. The current study also emphasises the importance of age-matched controls in neurocognitive research, particularly in studies investigating aphasic language processing.

7.6 Acknowledgements

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8. References

Adorni, R., Manfredi, M., & Proverbio, A. M. (2013). Since when or how often? Dissociating the roles of age of acquisition (AoA) and lexical frequency in early visual word processing. *Brain and Language*, *124*(1), 132–141. doi:10.1016/j.bandl.2012.11.005

Allen, P. A., Goldstein, B., Madden, D. J., & Mitchell, D. B. (1997). Adult age differences in long-term semantic priming. *Experimental aging research*, *23*(2), 107–135. doi:10.1080/03610739708254028

Anderson, J. E., & Holcomb, P. J. (1995). Auditory and visual semantic priming using different stimulus onset asynchronies: An event-related brain potential study. *Psychophysiology*, *32*(2), 177–190. doi:10.1111/j.1469-8986.1995.tb03310.x

Andrews, S., & Heathcote, A. (2001). Distinguishing common and task-specific processes in word identification: A matter of some moment? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(2), 514–544. doi:10.1037//0278-7393.27.2.514

Armstrong, S. L., Gleitman, L. R., & Gleitman, H. (1983). What some concepts might not be. *Cognition*, *13*(3), 263–308. doi:10.1016/0010-0277(83)90012-4

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412. doi:10.1016/j.jml.2007.12.005

Badecker, W., & Caramazza, A. (1985). On considerations of method and theory governing the use of clinical categories in neurolinguistics and cognitive neuropsychology: The case against agrammatism. *Cognition*, *20*(2), 97–125. doi:10.1016/0010-0277(85)90049-6

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*(3), 255–278. doi:10.1016/j.jml.2012.11.001

Barry, C., & Gerhand, S. (2003). Both concreteness and age-of-acquisition affect reading accuracy but only concreteness affects comprehension in a deep dyslexic patient. *Brain and Language*, *84*(1), 84–104. doi:10.1016/S0093-934X(02)00522-9

Barry, C., Morrison, C. M., & Ellis, A. W. (1997a). Naming the Snodgrass and Vanderwart Pictures: Effects of age of acquisition, frequency, and name agreement. *The Quarterly Journal of Experimental Psychology*, *50*(3), 560–585. doi:10.1080/783663595

Barry, C., Morrison, C. M., & Ellis, A. W. (1997b). Naming the Snodgrass and Vanderwart Pictures: Effects of Age of Acquisition, Frequency, and Name Agreement. *The Quarterly Journal of Experimental Psychology A*, *50*(3), 560–585. doi:10.1080/027249897392026

Barsalou, L. W. (1983). Ad hoc categories. *Memory & Cognition*, *11*(3), 211–227. doi:10.3758/BF03196968

Barsalou, L. W. (1985). Ideals, central tendency, and frequency of instantiation as determinants of graded structure in categories. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *11*(4), 629–654. doi:10.1037/0278-7393.11.1-4.629

Bates, D. & Sarkar, D. (2007). lme4: Linear mixed-effects models using S4 classes.: R package version 0.9975-13. Retrieved from https://cran.r-project.org/

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1). doi:10.18637/jss.v067.i01

Belke, E., Brysbaert, M., Meyer, A. S., & Ghyselinck, M. (2005). Age of acquisition effects in picture naming: Evidence for a lexical-semantic competition hypothesis. *Cognition*, *96*(2), 45–54. doi:10.1016/j.cognition.2004.11.006

Bentin, S., Kutas, M., & Hillyard, S. A. (1995). Semantic processing and memory for attended and unattended words in dichotic listening: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(1), 54–67. doi:10.1037/0096-1523.21.1.54

Bentin, S., McCarthy, G., & Wood, C. C. (1985). Event-related potentials, lexical decision and semantic priming. *Electroencephalography and Clinical Neurophysiology*, *60*(4), 343–355. doi:10.1016/0013-4694(85)90008-2

Berger, H. (1929). Über das Elektrenkephalogramm des Menschen (On the human electroencephalogram). *Archiv für Psychiatrie und Nervenkrankheiten*, *87*(1), 527–570. doi:10.1007/BF01797193

Bermeitinger, C., Frings, C., & Wentura, D. (2010). N400 effects for category exemplars primed by category labels. *Scientific Report, PsyDok*, 1–10. Retrieved from http://psydok.sulb.uni-saarland.de/volltexte/2010/2604/.

Bird, H., Howard, D., & Franklin, S. (2000). Why is a verb like an inanimate object? Grammatical category and semantic category deficits. *Brain and Language*, *72*(3), 246–309. doi:10.1006/brln.2000.2292

Bonin, P., Barry, C., Méot, A., & Chalard, M. (2004). The influence of age of acquisition in word reading and other tasks: A never ending story? *Journal of Memory and Language*, *50*(4), 456–476. doi:10.1016/j.jml.2004.02.001

Bonin, P., Malardier, N., Méot, A., & Fayol, M. (2006). The scope of advance planning in written picture naming. *Language and Cognitive Processes*, *21*(1-3), 205–237. doi:10.1080/01690960400002141

Bonin, P., & Méot, A. (2002). Writing to dictation in real time in adults: What are the determinants of written latencies? In S. P. Shohov (Ed.), *Advances in psychology research* (Vol. 16, pp. 139–165). Hauppauge, New York: Nova Science Publishers.

Bornkessel, I., Schlesewsky, M., & Friederici, A. D. (2003). Contextual information modulates initial processes of syntactic integration: the role of inter- versus intrasentential predictions. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(5), 871–882. doi:10.1037/0278-7393.29.5.871

Brown, G. D., & Watson, F. L. (1987). First in, first out: Word learning age and spoken word frequency as predictors of word familiarity and word naming latency. *Memory & Cognition*, *15*(3), 208–216. doi:10.3758/BF03197718

Brysbaert, M., & Ellis, A. W. (2015). Aphasia and age-of-acquisition: are early-learned words more resilient? *Aphasiology.* doi:10.1080/02687038.2015.1106439

Brysbaert, M., & Ghyselinck, M. (2006). The effect of age of acquisition: Partly frequency related, partly frequency independent. *Visual Cognition*, *13*(7-8), 992–1011. doi:10.1080/13506280544000165

Brysbaert, M., Stevens, M., De Deyne, S., Voorspoels, W., & Storms, G. (2014). Norms of age of acquisition and concreteness for 30,000 Dutch words. *Acta psychologica*, *150*, 80–84. doi:10.1016/j.actpsy.2014.04.010

Brysbaert, M., van Wijnendaele, I., & De Deyne, S. (2000). Age-of-acquisition effects in semantic processing tasks. *Acta Psychologica*, *104*(2), 215–226. doi:10.1016/S0001-6918(00)00021-4

Burke, D. M., & Shafto, M. A. (2008). Language and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (3rd ed., pp. 373–443). New York: Psychology Press.

Burmester, J., Spalek, K., & Wartenburger, I. (2014). Context updating during sentence comprehension: The effect of aboutness topic. *Brain and Language*, *137C*, 62–76. doi:10.1016/j.bandl.2014.08.001

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging*, *17*(1), 85–100. doi:10.1037//0882-7974.17.1.85

Cameli, L., & Phillips, N. A. (2000). Age-related differences in semantic priming: Evidence from event-related brain potentials. *Brain and Cognition*, *43*(1-3), 69–73. doi:10.1006/brcg.1999.1133

Capitani, E., Laiacona, M., Mahon, B., & Caramazza, A. (2003). What are the facts of semantic category-specific deficits? A critical review of the clinical evidence. *Cognitive Neuropsychology*, *20*(3), 213–261. doi:10.1080/02643290244000266

Caramazza, A. (1984). The logic of neuropsychological research and the problem of patient classification in aphasia. *Brain and Language*, *21*(1), 9–20. doi:10.1016/0093-934X(84)90032-4

Caramazza, A., Hillis, A. E., Rapp, B. C., & Romani, C. (1990). The multiple semantics hypothesis: Multiple confusions? *Cognitive Neuropsychology*, *7*(3), 161–189. doi:10.1080/02643299008253441

Caramazza, A., & Mahon, B. Z. (2006). The organisation of conceptual knowledge in the brain: The future's past and some future directions. *Cognitive Neuropsychology*, *23*(1), 13–38. doi:10.1080/02643290542000021

Caramazza, A., & Shelton, J. R. (1998). Domain-Specific Knowledge Systems in the Brain: The Animate-Inanimate Distinction. *Journal of Cognitive Neuroscience*, *10*(1), 1–34. doi:10.1162/089892998563752

Carroll, J. B., & White, M. N. (1973). Word frequency and age of acquisition as determiners of picture-naming latency. *The Quarterly Journal of Experimental Psychology*, *25*(FEB), 85–95. doi:10.1080/14640747308400325

Carter, M. D., Hough, M. S., Stuart, A., & Rastatter, M. P. (2011). The effects of inter-stimulus interval and prime modality in a semantic priming task. *Aphasiology*, *25*(6-7), 761–773. doi:10.1080/02687038.2010.539697

Casey, P. (1992). A Reexamination of the Roles of Typicality and Category Dominance in Verifying Category Membership. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(4), 823–834. doi:10.1037//0278-7393.18.4.823

Catling, J. C., Dent, K., Johnston, R. A., & Balding, R. (2010). Age of acquisition, word frequency, and picture-word interference. *The Quarterly Journal of Experimental Psychology*, *63*(7), 1304–1317. doi:10.1080/17470210903380830

Catling, J. C., & Johnston, R. A. (2006a). The effects of age of acquisition on an object classification task. *Visual Cognition*, *13*(7-8), 968–980. doi:10.1080/13506280544000138

Catling, J. C., & Johnston, R. A. (2006b). Age of acquisition effects on an object-name verification task. *British Journal of Psychology*, *97*(1), 1–18. doi:10.1348/000712605X53515

Catling, J. C., & Johnston, R. A. (2009). The varying effects of age of acquisition. *The Quarterly Journal of Experimental Psychology*, *62*(1), 50–62. doi:10.1080/17470210701814352

Chalard, M., & Bonin, P. (2006). Age-of-acquisition effects in picture naming: Are they structural and/or semantic in nature? *Visual Cognition*, *13*(7-8), 864–883. doi:10.1080/13506280544000084

Chwilla, D. J., Brown, C. M., & Hagoort, P. (1995). The N400 as a Function of the Level of Processing. *Psychophysiology*, *32*(3), 274–285. doi:10.1111/j.1469-8986.1995.tb02956.x

Chwilla, D. J., & Kolk, H. H. J. (2005). Accessing world knowledge: evidence from N400 and reaction time priming. *Brain research. Cognitive brain research*, *25*(3), 589–606. doi:10.1016/j.cogbrainres.2005.08.011

Chwilla, D. J., Kolk, H. H. J., & Mulder, G. (2000). Mediated Priming in the Lexical Decision Task: Evidence from Event-Related Potentials and Reaction Time. *Journal of Memory and Language*, *42*(3), 314–341. doi:10.1006/jmla.1999.2680

Cole-Virtue, J., & Nickels, L. (2004). Why cabbage and not carrot?: An investigation of factors affecting performance on spoken word to picture matching. *Aphasiology*, *18*(2), 153–179. doi:10.1080/02687030344000517

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, *82*(6), 407–428. doi:10.1037/0033-295X.82.6.407

Coltheart, M. (2007). The MRC psycholinguistic database. *The Quarterly Journal of Experimental Psychology Section A*, *33*(4), 497–505. doi:10.1080/14640748108400805

Cortese, M. J., & Khanna, M. M. (2007). Age of acquisition predicts naming and lexical-decision performance above and beyond 22 other predictor variables: An analysis of 2,342 words. *The Quarterly Journal of Experimental Psychology*, *60*(8), 1072–1082. doi:10.1080/17470210701315467

Cuetos, F., Aguado, G., Izura, C., & Ellis, A. W. (2002). Aphasic naming in Spanish: predictors and errors. *Brain and Language*, *82*(3), 344–365. doi:10.1016/S0093-934X(02)00038-X

Cuetos, F., Barbon, A., Urrutia, M., & Dominguez, A. (2009). Determining the time course of lexical frequency and age of acquisition using ERP. *Clinical Neurophysiology*, *120*(2), 285–294. doi:10.1016/j.clinph.2008.11.003

Cuetos, F., Ellis, A. W., & Alvarez, B. (1999). Naming times for the Snodgrass and Vanderwart pictures in Spanish. *Behavior Research Methods*, *31*(4), 650–658. doi:10.3758/bf03200741

Cuetos, F., Herrera, E., & Ellis, A. W. (2010). Impaired word recognition in Alzheimer's disease: the role of age of acquisition. *Neuropsychologia*, *48*(11), 3329–3334. doi:10.1016/j.neuropsychologia.2010.07.017

Cuetos, F., Rodriguez-Ferreiro, J., Sage, K., & Ellis, A. W. (2012). A fresh look at the predictors of naming accuracy and errors in Alzheimer’s disease. *JOURNAL OF NEUROPSYCHOLOGY*, *6*(2), 242–256. doi:10.1111/j.1748-6653.2011.02025.x

De Bleser, R., Cholewa, J., & Tabatabaie, N. S. S. (1997). LeMo, an Expert System for Single Case Assessment of Word Processing Impairments in Aphasic Patients. *Neuropsychological Rehabilitation*, *7*(4), 339–366. doi:10.1080/713755540

De Deyne, S., & Storms, G. (2007). Age-of-acquisition differences in young and older adults affect latencies in lexical decision and semantic categorization. *Acta Psychologica*, *124*(3), 274–295. doi:10.1016/j.actpsy.2006.03.007

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, *93*(3), 283–321. doi:10.1037//0033-295X.93.3.283

Dell, G. S., & O'Seaghdha, P. G. (1992). Stages of lexical access in language production. *Cognition*, *42*(1-3), 287–314. doi:10.1016/0010-0277(92)90046-K

Dell'Acqua, R., Lotto, L., & Job, R. (2000). Naming times and standardized norms for the italian PD/DPSS set of 266 pictures: Direct comparisons with American, English, French, and Spanish published databases. *Behavior Research Methods, Instruments, & Computers*, *32*(4), 588–615. doi:10.3758/BF03200832

Drag, L. L., & Bieliauskas, L. A. (2010). Contemporary review 2009: cognitive aging. *Journal of geriatric psychiatry and neurology*, *23*(2), 75–93. doi:10.1177/0891988709358590

Duncan, C. C., Barry, R. J., Connolly, J. F., Fischer, C., Michie, P. T., Näätänen, R.,. . . Van Petten, C. (2009). Event-related potentials in clinical research: Guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400. *Clinical Neurophysiology*, *120*(11), 1883–1908. doi:10.1016/j.clinph.2009.07.045

Ehrensperger, M. M., Berres, M., Taylor, K. I., & Monsch, A. U. (2010). Early detection of Alzheimer's disease with a total score of the German CERAD. *Journal of the International Neuropsychological Society*, *16*(5), 910–920.

Ellis, A. W. (2011). The acquisition, retention and loss of vocabulary in aphasia, dementia and other neuropsychological conditions. In M. Faust (Ed.), *Handbook of the neuropsychology of language* (pp. 637–660). Oxford: Blackwells.

Ellis, A. W., & Lambon Ralph, M. A. (2000). Age of acquisition effects in adult lexical processing reflect loss of plasticity in maturing systems: Insights from connectionist networks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(5), 1103–1123. doi:10.1037/0278-7393.26.5.1103

Ellis, A. W., Lum, C., & Lambon Ralph, M. A. (1996). On the use of regression techniques for the analysis of single case aphasic data. *Journal of Neurolinguistics*, *9*(3), 165–174. doi:10.1016/0911-6044(96)00008-5

Epstein, C. M., Bej, M. D., Foldvary-Schaefer, N., Lagerlund, T. D., Helmers, S. L., & Husain, A. M. (2006). American Clinical Neurophysiology Society - Introduction to the 2006 revisions: Guideline 5: Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *23*, 107–110. Retrieved from https://www.acns.org/pdf/guidelines/Guideline-5.pdf

Federmeier, K. D. (2007). Thinking ahead: the role and roots of prediction in language comprehension. *Psychophysiology*, *44*(4), 491–505. doi:10.1111/j.1469-8986.2007.00531.x

Federmeier, K. D., & Kutas, M. (1999). A Rose by Any Other Name: Long-Term Memory Structure and Sentence Processing. *Journal of Memory and Language*, *41*(4), 469–495. doi:10.1006/jmla.1999.2660

Federmeier, K. D., & Kutas, M. (2005). Aging in context: Age-related changes in context use during language comprehension. *Psychophysiology*, *42*(2), 133–141. doi:10.1111/j.1469-8986.2005.00274.x

Federmeier, K. D., Kutas, M., & Schul, R. (2010). Age-related and individual differences in the use of prediction during language comprehension. *Brain and Language*, *115*(3), 149–161. doi:10.1016/j.bandl.2010.07.006

Federmeier, K. D., & Laszlo, S. (2009). Time for Meaning: Electrophysiology provides Insights in to the Dynamics of Representation and Processing in semantic Memory. *The Psychology of Learning and Motivation*, *51*, 1–44. doi:10.1016/S0079-7421(09)51001-8

Federmeier, K. D., McLennan, D. B., Ochoa, E. de, & Kutas, M. (2002). The impact of semantic memory organization and sentence context information on spoken language processing by younger and older adults: An ERP study. *Psychophysiology*, *39*(2), 133–146.

Federmeier, K. D., Van Petten, C., Schwartz, T. J., & Kutas, M. (2003). Sounds, words, sentences: age-related changes across levels of language processing. *Psychology and Aging*, *18*(4), 858–872. doi:10.1037/0882-7974.18.4.858

Feyereisen, P., van der Borght, & Seron, X. (1988). The operativity effect in naming: A re-analysis. *Neuropsychologia*, *26*(3), 401–415. doi:10.1016/0028-3932(88)90094-2

Fodor, J. A. (1983). *The modularity of mind: An essay on faculty psychology*. *A Bradford book*. Cambridge, Mass.: MIT PRESS.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State - Practical Method for Grading Cognitive State of Patients for Clinician. *Journal of Psychiatric Research*, *12*(3), 189–198. doi:10.1016/0022-3956(75)90026-6

Friederici, A. D., Hahne, A., & Cramon, D. Y. von. (1998). First-pass versus second-pass parsing processes in a Wernicke's and a Broca's aphasic: electrophysiological evidence for a double dissociation. *Brain and Language*, *62*(3), 311–341. doi:10.1006/brln.1997.1906

Friederici, A. D. (2001). Event-related potentials and aphasia. In R. S. Berndt, F. Boller, & J. Grafman (Eds.), *Handbook of neuropsychology (2nd ed.): Vol. 3. Language and aphasia* (pp. 353–373). Amsterdam, New York: Elsevier.

Friederici, A. D. (2004). Event-related brain potential studies in language. *Current neurology and neuroscience reports*, *4*(6), 466–470. doi:10.1007/s11910-004-0070-0

Friedman, D. (2012). The Components of Aging. In S. J. Luck & E. S. Kappenman (Eds.), *Oxford library of psychology. Oxford handbook of event-related potential components.* Oxford: Oxford University Press. doi:10.1093/oxfordhb/9780195374148.013.0243

Friendly, M., Franklin, P. E., Hoffman, D., & Rubin, D. C. (1982). The Toronto Word Pool: Norms for imagery, concreteness, orthographic variables, and grammatical usage for 1,080 words. *Behavior Research Methods & Instrumentation*, *14*(4), 375–399. doi:10.3758/BF03203275

Fujihara, N., Nageishi, Y., Koyama, S., & Nakajima, Y. (1998). Electrophysiological evidence for the typicality effect of human cognitive categorization. *International Journal of Psychophysiology*, *29*(1), 65–75. doi:10.1016/S0167-8760(97)00099-8

Gainotti, G., Silveri, M. C., Villa, G., & Miceli, G. (1986). Anomia with and without lexical comprehension disorders. *Brain and Language*, *29*(1), 18–33. doi:10.1016/0093-934X(86)90031-3

Garlock, V. M., Walley, A. C., & Metsala, J. L. (2001). Age-of-Acquisition, Word Frequency, and Neighborhood Density Effects on Spoken Word Recognition by

Children and Adults. *Journal of Memory and Language*, *45*(3), 468–492. doi:10.1006/jmla.2000.2784

Garrett, M. F. (1980). Levels of Processing in Sentence Production. In B. Butterworth (Ed.), *Language production* (pp. 177–220). London: Academic Press.

Garrod, S. (2006). Psycholinguistic Research Methods. In BrownKeith (Ed.), *Encyclopedia of Language and Linguistics* (2nd ed., pp. 251–257). San Diego, Saint Louis: Elsevier Science & Technology Books; Elsevier Distributor. doi:10.1016/B0-08-044854-2/04155-9

Garrod, S., & Sanford, A. (1977). Interpreting anaphoric relations: The integration of semantic information while reading. *Journal of Verbal Learning and Verbal Behavior*, *16*(1), 77–90. doi:10.1016/S0022-5371(77)80009-1

Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and the animate-inanimate distinction as examples. *Cognitive Science*, *14*(1), 79–106. doi:10.1016/0364-0213(90)90027-T

Gerhand, S., & Barry, C. (1998). Word frequency effects in oral reading are not merely age-of-acquisition effects in disguise. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*(2), 267–283. doi:10.1037/0278-7393.24.2.267

Gerhand, S., & Barry, C. (2000). When does a deep dyslexic make a semantic error? The roles of age-of-acquisition, concreteness, and frequency. *Brain and Language*, *74*(1), 26–47. doi:10.1006/brln.2000.2320

Ghyselinck, M., Custers, R., & Brysbaert, M. (2004). The effect of age of acquisition in visual word processing: further evidence for the semantic hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(2), 550–554. doi:10.1037/0278-7393.30.2.550

Ghyselinck, M., Lewis, M. B., & Brysbaert, M. (2004). Age of acquisition and the cumulative-frequency hypothesis: a review of the literature and a new multi-task investigation. *Acta Psychologica*, *115*(1), 43–67. doi:10.1016/j.actpsy.2003.11.002

Gilhooly, K. J., & Logie, R. H. (1980). Age-of-acquisition, imagery, concreteness, familiarity, and ambiguity measures for 1,944 words. *Behavior Research Methods & Instrumentation*, *12*(4), 395–427. doi:10.3758/BF03201693

Gilhooly, K. J., & Watson, F. L. (1981). Word age-of-acquisition effects: a review. *Current Psychological Reviews*, *1*(3), 269–286. doi:10.1007/BF02684489

Glass, A. L., & Holyoak, K. J. (1974). Alternative conceptions of semantic theory. *Cognition*, *3*(4), 313–339. doi:10.1016/0010-0277(74)90002-X

Gonzalez-Marquez, M., Mittelberg, I., Coulson, S., & Spivey, M. J. (2007). *Methods in Cognitive Linguistics* (Vol. 18). Amsterdam: John Benjamins Publishing Company.

Gratton, G., Coles, M., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, *55*(4), 468–484. doi:10.1016/0013-4694(83)90135-9

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika*, *24*(2), 95–112. doi:10.1007/BF02289823

Grieder, M., Crinelli, R. M., Koenig, T., Wahlund, L.-O., Dierks, T., & Wirth, M. (2012). Electrophysiological and behavioral correlates of stable automatic semantic retrieval in aging. *Neuropsychologia*, *50*(1), 160–171. doi:10.1016/j.neuropsychologia.2011.11.014

Grober, E., Perecman, E., Kellar, L., & Brown, J. (1980). Lexical knowledge in anterior and posterior aphasics. *Brain and Language*, *10*(2), 318–330. Retrieved from http://www.sciencedirect.com/science/article/B6WC0-4D6YV2B-18/2/bd02c31e989fb6dcc8897ec41d656390

Grosjean, F., & Frauenfelder, U. H. (1997). *A guide to spoken word recognition paradigms*. Hove, East Sussex, U.K.: Psychology Press.

Grossman, M. (1981). A bird is a bird is a bird: Making reference within and without superordinate categories. *Brain and Language*, *12*(2), 313–331. doi:10.1016/0093-934X(81)90022-5

Gunter, T. C., Jackson, J. L., & Mulder, G. (1995). Language, memory, and aging: An electrophysiological exploration of the N400 during reading of memory-demanding sentences. *Psychophysiology*, *32*(3), 215–229. doi:10.1111/j.1469-8986.1995.tb02951.x

Hagoort, P., Brown, C. M., & Swaab, T. Y. (1996). Lexical-semantic event-related potential effects in patients with left hemisphere lesions and aphasia, and patients with right hemisphere lesions without aphasia. *Brain*, *119*, 627–649. doi:10.1093/brain/119.2.627

Hagoort, P. (2008). The fractionation of spoken language understanding by measuring electrical and magnetic brain signals. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *363*(1493), 1055–1069. doi:10.1098/rstb.2007.2159

Hamberger, M., & Friedman, D. (1992). Event-related Potential Correlates of Repetition Priming and Stimulus Classification in Young, Middle-aged, and Older Adults. *Journal of Gerontology*, *47*(6), P395-P405. doi:10.1093/geronj/47.6.P395

Hampton, J. A. (1995). Testing the Prototype Theory of Concepts. *Journal of Memory and Language*, *34*(5), 686–708. doi:10.1006/jmla.1995.1031

Hampton, J. A. (1997). Associative and similarity-based processes in categorization decisions. *Memory & Cognition*, *25*(5), 625–640. doi:10.3758/BF03211304

Hampton, J. A., & Gardiner, M. M. (1983). Measures of internal Category Structure - A correlational Analysis of normative Data. *British Journal of Psychology*, *74*(NOV), 491–516. doi:10.1111/j.2044-8295.1983.tb01882.x

Hasher, L., Lustig, C., & Zacks, R. (2007). Inhibitory Mechanisms and the Control of Attention. In A. R. A. Conway (Ed.), *Variation in working memory* (pp. 227–249). Oxford, New York: Oxford University Press. doi:10.1093/acprof:oso/9780195168648.003.0009

Hasher, L., & Zacks, R. T. (1988). Working Memory, Comprehension, and Aging: A Review and a New View. In G. H. Bower (Ed.), *Psychology of Learning and Motivation: v. 22. The psychology of learning and motivation. Advances in research and theory* (Vol. 22, pp. 193–225). San Diego: Academic Press. doi:10.1016/S0079-7421(08)60041-9

Heinze, H.-J., Muente, T.-F., & Kutas, M. (1998). Context effects in a category verification task as assessed by event-related brain potential (ERP) measures. *Biological Psychology*, *47*(2), 121–135. doi:10.1016/S0301-0511(97)00024-0

Heister, J., Würzner, K.-M., Bubenzer, J., Pohl, E., Hanneforth, T., Geyken, A., & Kliegl, R. (2011). dlexDB – eine lexikalische Datenbank für die psychologische und linguistische Forschung. *Psychologische Rundschau*, *62*(1), 10–20. doi:10.1026/0033-3042/a000029

Hernández-Muñoz, N., Izura, C., & Ellis, A. W. (2006). Cognitive aspects of lexical availability. *European Journal of Cognitive Psychology*, *18*(5), 730–755. doi:10.1080/09541440500339119

Hirsh, K. W., & Ellis, A. W. (1994). Age of acquisition and lexical processing in Aphasia: A case study. *Cognitive Neuropsychology*, *11*(4), 435–458. doi:10.1080/02643299408251981

Hirsh, K. W., & Funnell, E. (1995). Those old, familiar things: Age of acquisition, familiarity and lexical access in progressive aphasia. *Journal of Neurolinguistics*, *9*(1), 23–32. doi:10.1016/0911-6044(95)00003-8

Hodgson, C., & Ellis, A. W. (1998). Last in, first to go: Age of acquisition and naming in the elderly. *Brain and Language*, *64*, 146–163. doi:10.1006/brln.1998.1960

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: implications for the role of the N400 in language processing. *Psychophysiology*, *30*(1), 47–61. doi:10.1111/j.1469-8986.1993.tb03204.x

Holcomb, P. J., & Neville, H. J. (1990). Auditory and Visual Semantic Priming in Lexical Decision: A Comparison Using Event-related Brain Potentials. *Language and Cognitive Processes*, *5*(4), 281–312. doi:10.1080/01690969008407065

Holmes, S. J., & Ellis, A. W. (2006). Age of acquisition and typicality effects in three object processing tasks. *Visual Cognition*, *13*(7-8), 884–910. doi:10.1080/13506280544000093

Hough, M. S. (1993). Categorization in aphasia: Access and organization of goal-derived and common categories. *Aphasiology*, *7*(4), 335–357. doi:10.1080/02687039308249515

Hough, M. S., & Pierce, R. S. (1989). Contextual Influences on Category Concept Generation in Aphasia. In T. E. Prescott (Ed.), *Clinical aphasiology* (pp. 507–520). Boston: College-Hill. Retrieved from http://aphasiology.pitt.edu/archive/00000095/

Howard, D., Nickels, L., Coltheart, M., & Cole-Virtue, J. (2006). Cumulative semantic inhibition in picture naming: experimental and computational studies. *Cognition*, *100*(3), 464–482. doi:10.1016/j.cognition.2005.02.006

Huber, W., Poeck, K., Weniger, D., & Willmes, K. (1983). *Der Aachener Aphasie Test (AAT)*. Göttingen: Verl. für Psychologie, Hogrefe.

Humes, L. E. (1996). Speech Understanding in the Elderly. *Journal of the American Academy of Audiology*, *7*(3), 161–167. Retrieved from http://www.audiology.org/sites/default/files/journal/JAAA_07_03_04.pdf

Jescheniak, J. D., & Levelt, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(4), 824–843. doi:10.1037/0278-7393.20.4.824

Johnston, R. A., & Barry, C. (2005). Age of acquisition effects in the semantic processing of pictures. *Memory & Cognition*, *33*(5), 905–912.

Johnston, R. A., & Barry, C. (2006). Age of acquisition and lexical processing. *Visual Cognition*, *13*(7-8), 789–845. doi:10.1080/13506280544000066

Johnston, R. A., Dent, K., Humphreys, G., & Barry, C. (2010). British-English norms and naming times for a set of 539 pictures: The role of age of acquisition. *Behavior Research Methods*, *42*(2), 461–469. doi:10.3758/brm.42.2.461

Juhasz, B. J. (2005). Age-of-acquisition effects in word and picture identification. *Psychological Bulletin*, *131*(5), 684–712. doi:10.1037/0033-2909.131.5.684

Kay, J., Coltheart, M., & Lesser, R. (1992). *Psycholinguistic assessments of language processing in aphasia (PALPA)*. Hove: L. Erlbaum Associates.

Kelly, M. H., Bock, J. K., & Keil, F. C. (1986). Prototypicality in a linguistic context: Effects on sentence structure. *Journal of Memory and Language*, *25*(1), 59–74. doi:10.1016/0749-596X(86)90021-5

Kiefer, M., Weisbrod, M., Kern, I., Maier, S., & Spitzer, M. (1998). Right hemisphere activation during indirect semantic priming: Evidence from event-related potentials. *Brain and Language*, *64*(3), 377–408. doi:10.1006/brln.1998.1979

Kiran, S., Ntourou, K., & Eubank, M. (2007). The effect of typicality on online category verification of inanimate category exemplars in aphasia. *Aphasiology*, *21*(9), 844–866. doi:10.1080/02687030600743564

Kiran, S., & Thompson, C. K. (2003). Effect of typicality on online category verification of animate category exemplars in aphasia. *Brain and Language*, *85*(3), 441–450. doi:10.1016/S0093-934X(03)00064-6

Kittredge, A. K., Dell, G. S., Verkuilen, J., & Schwartz, M. F. (2008). Where is the effect of frequency in word production? Insights from aphasic picture-naming errors. *Cognitive Neuropsychology*, *25*(4), 463–492. doi:10.1080/02643290701674851

Komatsu, L. K. (1992). Recent views of conceptual structure. *Psychological Bulletin*, *112*(3), 500–526. doi:10.1037//0033-2909.112.3.500

Kuperman, V., Stadthagen-Gonzalez, H., & Brysbaert, M. (2012). Age-of-acquisition ratings for 30,000 English words. *Behavior Research Methods*, *44*(4), 978–990. doi:10.3758/s13428-012-0210-4

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences*, *4*(12), 463–470. doi:10.1016/S1364-6613(00)01560-6

Kutas, M., & Federmeier, K. D. (2011). Thirty Years and Counting: Finding Meaning in the N400 Component of the; Event-Related Brain Potential (ERP). *Annual Review of Psychology*, *62*, 621–647. doi:10.1146/annurev.psych.093008.131123

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science*, *207*(4427), 203–205. doi:10.1126/science.7350657

Kutas, M., & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory & Cognition*, *11*(5), 539–550. doi:10.3758/BF03196991

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, *307*(5947), 161–163. doi:10.1038/307161a0

Kutas, M., & Iragui, V. (1998). The N400 in a semantic categorization task across 6 decades. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *108*(5), 456–471. doi:10.1016/S0168-5597(98)00023-9

Kutas, M., & Van Petten, C. (1994). Psycholinguistics electrified: event-related brain potential investigations. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 83–143). San Diego: Academic Press.

Kutas, M., Van Petten, C., & Kluender, R. (2006). Psycholinguistics Electrified II (1994–2005). In M. Traxler & M. A. Gernsbacher (Eds.), *Handbook of*

Psycholinguistics (pp. 659–724). Elsevier. doi:10.1016/B978-012369374-7/50018-3

Låg, T. (2005). Category-Specific Effects in Object Identification: What is “Normal”? *Cortex*, *41*(6), 833–841. doi:10.1016/S0010-9452(08)70302-2

Laganaro, M., & Perret, C. (2011). Comparing Electrophysiological Correlates of Word Production in Immediate and Delayed Naming Through the Analysis of Word Age of Acquisition Effects. *Brain Topography*, *24*(1), 19–29. doi:10.1007/s10548-010-0162-x

Lambon Ralph, M. A., & Ehsan, S. (2006). Age of acquisition effects depend on the mapping between representations and the frequency of occurrence: Empirical and computational evidence. *Visual Cognition*, *13*(7-8), 928–948. doi:10.1080/13506280544000110

Larochelle, S., & Pineau, H. (1994). Determinants of Response-Times in the Semantic Verification Task. *Journal of Memory and Language*, *33*(6), 796–823. doi:10.1006/jmla.1994.1038

Larochelle, S., Richard, S., & Soulieres, I. (2000). What some effects might not be: The time to verify membership in ''well-defined'' categories. *The Quarterly Journal of Experimental Psychology Section A*, *53*(4), 929–961. doi:10.1080/02724980050156245

Laszlo, S., & Federmeier, K. D. (2009). A Beautiful Day in the Neighborhood: An Event-Related Potential Study of Lexical Relationships and Prediction in Context. *Journal of Memory and Language*, *61*(3), 326–338. doi:10.1016/j.jml.2009.06.004

Laszlo, S., & Federmeier, K. D. (2010). The N400 as a snapshot of interactive processing: Evidence from regression analyses of orthographic neighbor and lexical associate effects. *Psychophysiology.* doi:10.1111/j.1469-8986.2010.01058.x

Lau, E. F., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics: (de)constructing the N400. *Nature reviews. Neuroscience*, *9*(12), 920–933. doi:10.1038/nrn2532

Law, S.-P., & Yeung, O. (2010). Effects of age of acquisition and semantic transparency on reading characters in Chinese dyslexia. *Applied Psycholinguistics*, *31*(04), 711–733. doi:10.1017/S0142716410000214

Laws, K. R. (2000). Category-specific naming errors in normal subjects: the influence of evolution and experience. *Brain and Language*, *75*(1), 123–133. doi:10.1006/brln.2000.2348

Laws, K. R., & Neve, C. (1999). A 'normal' category-specific advantage for naming living things. *Neuropsychologia*, *37*(11), 1263–1269. doi:10.1016/S0028-3932(99)00018-4

Lei, Y., Li, F., Long, C., Li, P., Chen, Q., Ni, Y., & Li, H. (2010). How does typicality of category members affect the deductive reasoning? An ERP study. *Experimental Brain Research*, *204*(1), 47–56. doi:10.1007/s00221-010-2292-5

Levelt, W. J. M. (1989). Lexical Entries and Accessing Lemmas (Chapter 6). In W. J. M. Levelt (Ed.), *ACL-MIT Press series in natural-language processing. Speaking. From intention to articulation* (pp. 181–234). Cambridge, Mass.: MIT PRESS.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*(01), 1–38. Retrieved from http://journals.cambridge.org/article_S0140525X99001776

Lewis, M. B. (1999). Age of acquisition in face categorisation: is there an instance-based account? *Cognition*, *71*(1), B23-B39. doi:10.1016/S0010-0277(99)00020-7

Luck, S. T. (Ed.). (2005). *An Introduction to the Event-Related Potential Technique*: MIT-Press.

McClelland, J. L. (1981). Retrieving general and specific information from stored knowledge af specifics. *Proceedings of the third annual conference of the Cognitive Science Society*, 170–172.

McClelland, J. L., & Rogers, T. T. (2003). The parallel distributed processing approach to semantic cognition. *Nature reviews. Neuroscience*, *4*(4), 310–322. doi:10.1038/nrn1076

McCloskey, M., & Glucksberg, S. (1979). Decision processes in verifying category membership statements: Implications for models of semantic memory. *Cognitive Psychology*, *11*(1), 1–37. doi:10.1016/0010-0285(79)90002-1

McNamara, T. P. (2005). *Semantic priming*. New York, NY [u.a.]: Psychology Press.

McRae, K., Cree, G. S., Westmacott, R., & De Sa, V. R. (1999). Further evidence for feature correlations in semantic memory. *Canadian Journal of Experimental*

Psychology/Revue canadienne de psychologie expérimentale, *53*(4), 360–373. doi:10.1037/h0087323

Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review*, *85*(3), 207–238. doi:10.1037//0033-295X.85.3.207

Mehta, J., Jerger, S., Jerger, J., & Martin, J. (2009). Electrophysiological correlates of word comprehension: event-related potential (ERP) and independent component analysis (ICA). *International journal of audiology*, *48*(1), 1–11. doi:10.1080/14992020802527258

Menenti, L., & Burani, C. (2007). What causes the effect of age of acquisition in lexical processing? *The Quarterly Journal of Experimental Psychology*, *60*(5), 652–660. doi:10.1080/17470210601100126

Mermillod, M., Bonin, P., Méot, A., Ferrand, L., & Paindavoine, M. (2012). Computational evidence that frequency trajectory theory does not oppose but emerges from age-of-acquisition theory. *Cognitive Science*, *36*(8), 1499–1531. doi:10.1111/j.1551-6709.2012.01266.x

Mervis, C. B., Catlin, J., & Rosch, E. H. (1976). Relationships among goodness-of-example, category norms, and word frequency. *Bulletin of the Psychonomic Society*, *7*(3), 283–284. doi:10.3758/BF03337190

Mervis, C. B., & Rosch, E. H. (1981). Categorization of Natural Objects. *Annual Review of Psychology*, *32*(1), 89–115. doi:10.1146/annurev.ps.32.020181.000513

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, *90*(2), 227–234. doi:10.1037/h0031564

Monaghan, J., & Ellis, A. W. (2002). What exactly interacts with spelling--sound consistency in word naming? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(1), 183–206. doi:10.1037/0278-7393.28.1.183

Monaghan, P., & Ellis, A. W. (2010). Modeling reading development: Cumulative, incremental learning in a computational model of word naming. *Journal of Memory and Language*, *63*(4), 506–525. doi:10.1016/j.jml.2010.08.003

Moore, V., Smith-Spark, J., & Valentine, T. (2004). The effects of age of acquisition on object perception. *European Journal of Cognitive Psychology*, *16*(3), 417–439. doi:10.1080/09541440340000097

Moreno-Martínez, F. J., Montoro, P. R., & Rodríguez-Rojo, I. C. (2014). Spanish norms for age of acquisition, concept familiarity, lexical frequency, manipulability, typicality, and other variables for 820 words from 14 living/nonliving concepts. *Behavior Research Methods*, *46*(4), 1088–1097. doi:10.3758/s13428-013-0435-x

Morrison, C. M., Chappell, T. D., & Ellis, A. W. (1997). Age of Acquisition Norms for a Large Set of Object Names and Their Relation to Adult Estimates and Other Variables. *The Quarterly Journal of Experimental Psychology Section A*, *50*(3), 528–559. doi:10.1080/027249897392017

Morrison, C. M., & Ellis, A. W. (1995). Roles of word frequency and age of acquisition in word naming and lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(1), 116–133. doi:10.1037/0278-7393.21.1.116

Morrison, C. M., & Ellis, A. W. (2000). Real age of acquisition effects in word naming and lexical decision. *British Journal of Psychology*, *91*(2), 167–180. doi:10.1348/000712600161763

Morrison, C. M., Ellis, A. W., & Quinlan, P. T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. *Memory & Cognition*, *20*(6), 705–714. doi:10.3758/BF03202720

Morrison, C. M., & Gibbons, Z. C. (2006). Lexical determinants of semantic processing speed. *Visual Cognition*, *13*(7-8), 949–967. doi:10.1080/13506280544000129

Morton, J. (1985). Naming. In S. K. Newman & R. Epstein (Eds.), *Current Perspectives in Dysphasia.* Edinburgh: Churchill Livingstone.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review*, *76*(2), 165–178. doi:10.1037/h0027366

Morton, J. (1970). A functional model for memory. In D. A. Norman (Ed.), *Models of Human Memory* (pp. 203–248). New York: Academic Press.

Morton, J. (1979). Word recognition. In J. Morton & J. C. Marshall (Eds.), *Psycholinguistic. Series II.* London: Elek Scientific Books.

Moss, H. E., Tyler, L. K., Durrant-Peatfield, M., & Bunn, E. M. (1998). 'Two Eyes of a See-through': Impaired and Intact Semantic Knowledge in a Case of Selective Deficit for Living Things. *Neurocase*, *4*(4-5), 291–310. doi:10.1080/13554799808410629

Navarrete, E., Pastore, M., Valentini, R., & Peressotti, F. (2015). First learned words are not forgotten: Age-of-acquisition effects in the tip-of-the-tongue experience. *Memory & cognition*, *43*(7), 1085–1103. doi:10.3758/s13421-015-0525-3

Neely, J. H. (1991). Semantic Priming Effects in Visual Word Recognition: A selective Review of current Findings and Theories. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading - visual word recognition* (pp. 264–336). Hillsdale, NJ [u.a.]: Erlbaum.

Nickels, L. (1997). *Spoken Word Production and Its Breakdown In Aphasia*: Taylor & Francis. Retrieved from https://books.google.de/books?id=zj-4AwAAQBAJ

Nickels, L., & Howard, D. (1995). Aphasic naming: What matters? *Neuropsychologia*, *33*(10), 1281–1303. doi:10.1016/0028-3932(95)00102-9

Nobre, A. C., & McCarthy, G. (1994). Language-related ERPs - Scalp Distributions and Modulation by Word Type and Semantic Priming. *Journal of Cognitive Neuroscience*, *6*(3), 233–255. doi:10.1162/jocn.1994.6.3.233

Nosofsky, R. M. (1988a). Exemplar-based accounts of relations between classification, recognition, and typicality. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*(4), 700–708. doi:10.1037/0278-7393.14.4.700

Nosofsky, R. M. (1988b). Similarity, frequency, and category representations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*(1), 54–65. doi:10.1037/0278-7393.14.1.54

Núñez-Peña, M. I., & Honrubia-Serrano, M. L. (2005). N400 and category exemplar associative strength. *International Journal of Psychophysiology*, *56*(1), 45–54. doi:10.1016/j.ijpsycho.2004.09.006

O'Rourke, T. B., & Holcomb, P. J. (2002). Electrophysiological evidence for the efficiency of spoken word processing. *Biological Psychology*, *60*(2-3), 121–150. doi:10.1016/S0301-0511(02)00045-5

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. doi:10.1016/0028-3932(71)90067-4

Onishi, K. H., Murphy, G. L., & Bock, J. K. (2008). Prototypicality in sentence production. *Cognitive Psychology*, *56*(2), 103–141. doi:10.1016/j.cogpsych.2007.04.001

Osherson, D. N., & Smith, E. E. (1981). On the adequacy of prototype theory as a theory of concepts. *Cognition*, *9*(1), 35–58. doi:10.1016/0010-0277(81)90013-5

Osherson, D. N., Smith, E. E., Wilkie, O., Lopez, A., & Shafir, E. B. (2008). Category-based induction. In J. E. Adler & L. J. Rips (Eds.), *Reasoning. Studies of human inference and its foundations* (pp. 321–342). Cambridge, New York: Cambridge University Press.

Patterson, K. E. (1988). Aquired disorders of spelling. In G. Denes, C. Semenza, & P. Bisiacchi (Eds.), *Perspectives on cognitive neuropsychology* (pp. 213–228). Hove, UK, Hillsdale, USA: L. Erlbaum Associates.

Patterson, K., & Shewell, C. (1987). Speak and spell: Dissociations and word-class effects. In M. Coltheart, G. Sartori, & R. Job (Eds.), *The cognitive neuropsychology of language* (pp. 273–294). Hillsdale, NJ, England: Lawrence Erlbaum Associates, Inc.

Pecher, D., & Raaijmakers, J. (2004). Priming for new associations in animacy decision: evidence for context dependency. *The Quarterly journal of experimental psychology. A, Human experimental psychology*, *57*(7), 1211–1231. doi:10.1080/02724980343000738

Perret, C., Bonin, P., & Laganaro, M. (2014). Exploring the multiple-level hypothesis of AoA effects in spoken and written object naming using a topographic ERP analysis. *Brain and Language*, *135*, 20–31. doi:10.1016/j.bandl.2014.04.006

Pind, J., Jonsdottir, H., Gissurardottir, H., & Jonsson, F. (2000). Icelandic Norms for the Snodgrass and Vanderwart (1980) Pictures: Name and Image Agreement, Familiarity, and Age of Acquisition. *Scandinavian Journal of Psychology*, *41*(1), 41–48. doi:10.1111/1467-9450.00169

Pires, L., Leitão, J., Guerrini, C., & Simões, M. R. (2014). Event-related brain potentials in the study of inhibition: cognitive control, source localization and age-related modulations. *Neuropsychology review*, *24*(4), 461–490. doi:10.1007/s11065-014-9275-4

Plaut, D. C. (1996). Relearning after damage in connectionist networks: toward a theory of rehabilitation. *Brain and Language*, *52*(1), 25–82. doi:10.1006/brln.1996.0004

Posner, M. I., & Keele, S. W. (1968). On the Genises of abstract Ideas. *Journal of Experimental Psychology*, *77*(3, Pt.1), 353–363. doi:10.1037/h0025953

Praamstra, P., Meyer, A. S., & Levelt, W. J. (1994). Neurophysiological Manifestations of Phonological Processing: Latency Variation of a Negative ERP Component Timelocked to Phonological Mismatch. *Journal of Cognitive Neuroscience*, *6*(3), 204–219. doi:10.1162/jocn.1994.6.3.204

Pritchard, W. S., Shappell, S. A., & Brandt, M. E. (1991). Psychophysiology of N200/N400: A review and classification scheme. In *Advances in Psychophysiology. A Research Annual* (pp. 43–106). London: Jessica Kingsley.

R Core Team. (2014). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org

Räling, R., Hanne, S., Schröder, A., Keßler, C., & Wartenburger, I. (2016). Judging the animacy of words - The influence of typicality and age of acquisition in a semantic decision task. *The Quarterly Journal of Experimental Psychology*, 1–21. doi:10.1080/17470218.2016.1223704

Räling, R., Holzgrefe-Lang, J., Schröder, A., & Wartenburger, I. (2015). On the influence of typicality and age of acquisition on semantic processing: Diverging evidence from behavioural and ERP responses. *Neuropsychologia*, *75*, 186–200. doi:10.1016/j.neuropsychologia.2015.05.031

Räling, R., Schröder, A., Hanne, S., Keßler, C., & Wartenburger, I. (under revision). Judging the animacy of words - The influence of typicality and age of acquisition in a semantic decision task.

Räling, R., Schröder, A., & Wartenburger, I. (2016). The origins of age of acquisition and typicality effects: Semantic processing in aphasia and the ageing brain. *Neuropsychologia*, *86*, 80–92. doi:10.1016/j.neuropsychologia.2016.04.019

Ramey, C. H., Chrysikou, E. G., & Reilly, J. (2013). Snapshots of Children's Changing Biases During Language Development: Differential Weighting of Perceptual and Linguistic Factors Predicts Noun Age of Acquisition. *Journal of Cognition and Development*, *14*(4), 573–592. doi:10.1080/15248372.2012.689386

Rein, J. R., Goldwater, M. B., & Markman, A. B. (2010). What is typical about the typicality effect in category-based induction? *Memory & Cognition*, *38*(3), 377–388. doi:10.3758/MC.38.3.377

Revonsuo, A., & Laine, M. (1996). Semantic processing without conscious understanding in a global aphasic: Evidence from auditory event-related brain potentials. *Cortex*, *32*(1), 29–48.

Riley, E. A., & Thompson, C. K. (2010). Semantic typicality effects in acquired dyslexia: Evidence for semantic impairment in deep dyslexia. *Aphasiology*, *24*(6-8), 802–813. doi:10.1080/02687030903422486

Rips, L. J. (1975). Inductive judgments about natural categories. *Journal of Verbal Learning and Verbal Behavior*, *14*(6), 665–681. doi:10.1016/S0022-5371(75)80055-7

Rips, L. J., Shoben, E. J., & Smith, E. E. (1973). Semantic Distance and Verification of Semantic Relations. *Journal of Verbal Learning and Verbal Behavior*, *12*(1), 1–20. doi:10.1016/S0022-5371(73)80056-8

Rochford, G., & Williams, M. (1962). I The relationship between nominal dysphasia and the acquisition of vocabulary in childhood. *Journal of Neurology, Neurosurgery & Psychiatry*, *25*(3), 222–227. doi:10.1136/jnnp.25.3.222

Rogers, T. T., Lambon Ralph, M. A., Garrard, P., Bozeat, S., McClelland, J. L., Hodges, J. R., & Patterson, K. (2004). Structure and deterioration of semantic memory: a neuropsychological and computational investigation. *Psychological Review*, *111*(1), 205–235. doi:10.1037/0033-295X.111.1.205

Rosch, E. H. (1973a). Natural Categories. *Cognitive Psychology*, *4*(3), 328–350. doi:10.1016/0010-0285(73)90017-0

Rosch, E. H. (1973b). On the internal structure of perceptual and semantic categories. In T. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 111–144). New York: Academic Press.

Rosch, E. H. (1975). Cognitive Representations of Semantic Categories. *Journal of Experimental Psychology: General*, *104*(3), 192–233. doi:10.1037//0096-3445.104.3.192

Rosch, E. H. (1978). Principles of categorization. In E. H. Rosch & B. Lloyd (Eds.), *Cognition and Categorization* (pp. 27–48). Lawrence Elbaum Associates.

Rosch, E. H., & Mervis, C. B. (1975). Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology*, *7*(4), 573–605. doi:10.1016/0010-0285(75)90024-9

Rossi, S., Jurgenson, I. B., Hanulikova, A., Telkemeyer, S., Wartenburger, I., & Obrig, H. (2011). Implicit Processing of Phonotactic Cues: Evidence from Electrophysiological and Vascular Responses. *Journal of Cognitive Neuroscience*, *23*(7), 1752–1764.

Rossiter, C., & Best, W. (2013). "Penguins don't fly": An investigation into the effect of typicality on picture naming in people with aphasia. *Aphasiology*, *27*(7), 784–798. doi:10.1080/02687038.2012.751579

Rubin, D. C. (1980). 51 properties of 125 words: A unit analysis of verbal behavior. *Journal of Verbal Learning and Verbal Behavior*, *19*(6), 736–755. doi:10.1016/S0022-5371(80)90415-6

Rugg, M. D. (1984). Event-related potentials and the phonological processing of words and non-words. *Neuropsychologia*, *22*(4), 435–443. doi:10.1016/0028-3932(84)90038-1

Sandberg, C., Sebastian, R., & Kiran, S. (2012). Typicality mediates performance during category verification in both ad-hoc and well-defined categories. *Journal of communication disorders*, *45*, 69–83. doi:10.1016/j.jcomdis.2011.12.004

Schneider, B. A., & Pichora-Fuller, M. K. (2001). Age-Related Changes in Temporal Processing: Implications for Speech Perception. *Seminars in Hearing*, *22*(03), 227–240. doi:10.1055/s-2001-15628

Schröder, A., Gemballa, T., Ruppin, S., & Wartenburger, I. (2012). German Norms for Typicality, Age of Acquisition, and Concept Familiarity. *Behavior Research Methods*, *44*(2), 380–394. doi:10.3758/s13428-011-0164-y

Schröder, A., Kauschke, C., & De Bleser, R. (2003). Messungen des Erwerbsalters für konkrete Nomina. *Neurolinguistik*, *17*(2), 83–114.

Schwartz, M. F. (1984). What the classical aphasia categories can't do for us, and why. *Brain and Language*, *21*(1), 3–8. doi:10.1016/0093-934X(84)90031-2

Shallice, T. (1988). *From Neuropsychology to Mental Structure*. Cambridge: Cambridge University Press.

Smith, E. E., & Medin, D. L. (1981). *Categories and concepts*. *Cognitive science series: Vol. 4*. Cambridge, Mass.: Harvard University Press.

Smith, E. E., Shoben, E. J., & Rips, L. J. (1974). Structure and process in semantic memory: A featural model for semantic decisions. *Psychological Review*, *81*(3), 214–241. doi:10.1037/h0036351

Smith, P. T., Turner, J. E., Brown, P. A., & Henry, L. A. (2006). The distinct contributions of age of acquisition and word frequency in auditory word perception. *The Quarterly Journal of Experimental Psychology*, *59*(12), 2121–2134. doi:10.1080/17470210500438387

Sommers, M. S. (1996). The structural organization of the mental lexicon and its contribution to age-related declines in spoken-word recognition. *Psychology and Aging*, *11*(2), 333–341. doi:10.1037/0882-7974.11.2.333

Stadie, N., Cholewa, J., & De Bleser, R. (2013). *LEMO 2.0 - Lexikon modellorientiert: Diagnostik für Aphasie, Dyslexie und Dysgraphie*. Hofheim: NAT-Verlag.

Sternberg, S. (1969). Memory-scanning - Mental processes revealed by reaction-time experiments. *American Scientist*, *57*(4), 421–457.

Steyvers, M., & Tenenbaum, J. B. (2005). The large-scale structure of semantic networks: Statistical analyses and a model of semantic growth. *Cognitive Science*, *29*(1), 41–78. doi:10.1207/s15516709cog2901_3

Storms, G., Boeck, P. de, & Ruts, W. (2000). Prototype and Exemplar-Based Information in Natural Language Categories. *Journal of Memory and Language*, *42*(1), 51–73. doi:10.1006/jmla.1999.2669

Strain, E., Patterson, K., & Seidenberg, M. S. (1995). Semantic effects in single-word naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(5), 1140–1154. doi:10.1037/0278-7393.21.5.1140

Stuss, D. T., Picton, T. W., & Cerri, A. M. (1988). Electrophysiological Manifestations of Typicality Judgment. *Brain and Language*, *33*(2), 260–272. doi:10.1016/0093-934X(88)90068-5

Swaab, T. Y. (1998). Event-related potentials in cognitive neuropsychology: Methodological considerations and an example from studies of aphasia. *Behavior Research Methods, Instruments, & Computers*, *30*(1), 157–170.

Swaab, T. Y., Brown, C. M., & Hagoort, P. (1997). ERP evidence for delayed lexical selection in Broca's aphasia. *Journal of Psychophysiology*, *11*(4), 379–380.

Tainturier, M.-J., Tamminen, J., & Thierry, G. (2005). Age of acquisition modulates the amplitude of the P300 component in spoken word recognition. *Neuroscience Letters*, *379*(1), 17–22. doi:10.1016/j.neulet.2004.12.038

Turner, J. E., Valentine, T., & Ellis, A. W. (1998). Contrasting effects of age of acquisition and word frequency on auditory and visual lexical decision. *Memory & Cognition*, *26*(6), 1282–1291. doi:10.3758/BF03201200

Van Berkum, J. J. A., Hagoort, P., & Brown, C. M. (1999). Semantic Integration in Sentences and Discourse: Evidence from the N400. *Journal of Cognitive Neuroscience*, *11*(6), 657–671. doi:10.1162/089892999563724

van Loon-Vervoorn, W. A. (1985). *Voorstelbaarheidswaarden van nederlandse woorden: 4600 substantieven, 1000 verba en 500 adjectieven*. Lisse: Swets en Zeitlinger.

van Loon-Vervoorn, W. A. (1989). *Eigenschappen van basiswoorden*. Amsterdam: Swets & Zeitlinger Pub. Service.

Van Petten, C. (1993). A comparison of lexical and sentence-level context effects in event-related potentials. *Language and Cognitive Processes*, *8*(4), 485–531. doi:10.1080/01690969308407586

Van Petten, C., Coulson, S., Rubin, S., Plante, E., & Parks, M. (1999). Time course of word identification and semantic integration in spoken language. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*(2), 394–417. doi:10.1037/0278-7393.25.2.394

Venables, W. N., & Ripley, B. D. (2002). *Modern applied statistics with S* (4th ed.). *Statistics and computing*. New York: SPRINGER.

Verhaeghen, P. (1999). The Effects of Age-Related Slowing and Working Memory on Asymptotic Recognition Performance. *Aging, Neuropsychology, and Cognition (Neuropsychology, Development and Cognition: Section B)*, *6*(3), 201–213. doi:10.1076/anec.6.3.201.781

Verhaeghen, P., & Cerella, J. (2008). Everything We Know About Aging and Response Times: A Meta-Analytic Integration. In *Handbook of Cognitive Aging: Interdisciplinary Perspectives* (pp. 134–150). Thousand Oaks, California, United States: SAGE Publications, Inc. doi:10.4135/9781412976589.n8

Vitevitch, M. S., & Luce, P. A. (1999). Probabilistic Phonotactics and Neighborhood Activation in Spoken Word Recognition. *Journal of Memory and Language*, *40*(3), 374–408. doi:10.1006/jmla.1998.2618

Vitkovitch, M., & Tyrrell, L. (1995). Sources of Disagreement in Object Naming. *The Quarterly Journal of Experimental Psychology Section A*, *48*(4), 822–848. doi:10.1080/14640749508401419

Warrington, E. K. (1975). The selective impairment of semantic memory. *The Quarterly Journal of Experimental Psychology*, *27*(4), 635–657. doi:10.1080/14640747508400525

Warrington, E. K., & Cipolotti, L. (1996). Word comprehension. *Brain*, *119*(2), 611–625. doi:10.1093/brain/119.2.611

Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, *107*(3), 829–853. doi:10.1093/brain/107.3.829

Wlotko, E. W., & Federmeier, K. D. (2012). Age-related changes in the impact of contextual strength on multiple aspects of sentence comprehension. *Psychophysiology*, *49*(6), 770–785. doi:10.1111/j.1469-8986.2012.01366.x

Wlotko, E. W., Lee, C.-L., & Federmeier, K. D. (2010). Language of the aging brain: Event-related potential studies of comprehension in older adults. *Language and linguistics compass*, *4*(8), 623–638. doi:10.1111/j.1749-818X.2010.00224.x

Woollams, A. M. (2012). Apples are not the only fruit: the effects of concept typicality on semantic representation in the anterior temporal lobe. *Frontiers in Human Neuroscience*, *6.* doi:10.3389/fnhum.2012.00085

Woollams, A. M., Cooper-Pye, E., Hodges, J. R., & Patterson, K. (2008). Anomia: A doubly typical signature of semantic dementia. *Neuropsychologia*, *46*(10), 2503–2514. doi:10.1016/j.neuropsychologia.2008.04.005

Zevin, J. D., & Seidenberg, M. S. (2002). Age of acquisition effects in word reading and other tasks. *Journal of Memory and Language*, *47*(1), 1–29. doi:10.1006/jmla.2001.2834

Zevin, J. D., & Seidenberg, M. S. (2004). Age-of-acquisition effects in reading aloud: Tests of cumulative frequency and frequency trajectory. *Memory & Cognition*, *32*(1), 31–38. doi:10.3758/BF03195818

9. Appendix

Table A 1 Target stimuli and their characteristics of study I and III

Item	English translation	AOA	TYP	SYL	PHON	Log FREQ	DUR	UP
CONGRUENT CONDITION (*n* = 160)								
typical / early acquired (n = 40)								
Blaubeere	blueberry	2.80	2.10	3	7	-0.690	810	470
Braunbär	brown bear	3.15	2.20	2	7	-0.883	691	510
Brombeere	blackberry	2.70	2.25	3	8	-0.062	739	422
Geier	vulture	3.80	2.58	2	3	0.305	451	32
Giraffe	giraffe	2.35	1.60	3	6	-0.023	568	177
Hamster	hamster	2.75	1.90	2	6	0.036	718	387
Känguru	kangaroo	3.60	2.50	3	7	-1.610	608	243
Mandarine	tangerine	3.70	1.50	4	9	0.009	720	587
Marienkäfer	ladybird	2.05	2.70	5	10	-0.508	952	606
Meerschweinchen	guinea pig	2.75	2.55	3	10	0.089	892	343
Nashorn	rhinoceros	3.55	2.20	2	7	0.231	720	419
Rentier	reindeer	3.90	2.70	2	6	0.276	689	224
Rotkehlchen	robin	3.15	1.55	3	9	-0.332	978	438
Rotkohl	red cabbage	2.85	1.80	2	6	-0.218	742	477
Stachelbeere	gooseberry	2.80	2.15	4	10	-0.242	870	530
Süßkirsche	sweet cherry	3.00	1.70	3	8	-0.596	807	438
Wassermelone	water melon	3.90	2.15	5	10	-0.941	876	500
Weißkohl	white cabbage	3.35	2.15	2	6	-0.058	693	460
Wellensittich	budgerigar	3.10	1.85	4	10	-0.092	952	507
Wildschwein	wild boar	2.90	1.80	2	8	0.111	875	345
Akkordeon	accordion	3.55	2.30	4	8	-0.195	821	417
Anorak	anorak	3.00	1.80	3	6	-0.508	565	302
Bücherschrank	bookcase	3.35	1.80	3	9	None	896	559
Bus	bus	1.70	1.00	1	3	0.843	399	135
Couch	couch	3.00	1.33	1	4	0.419	482	308
Gitarre	guitar	2.50	1.30	3	6	0.415	717	451
Hängeschrank	wall cupboard	3.75	2.50	3	9	-1.088	601	398
Hocker	stool	3.05	2.20	2	4	0.305	491	291
Küchentisch	kitchen table	2.35	1.40	3	8	0.349	789	473
Motorrad	motorcycle	3.25	2.20	3	7	0.696	822	534
Nachttisch	bedside table	2.85	2.35	2	7	0.321	829	541
Regenjacke	raincoat	3.30	2.30	4	9	-2.088	742	345
Schaufel	shovel	3.05	2.70	2	5	0.589	694	522
Schraubenzieher	screwdriver	3.45	1.50	4	9	-0.119	989	712
Schreibtischstuhl	desk	3.65	1.85	3	11	-0.786	914	518
Sitzecke	seating area	3.75	2.40	3	7	-0.309	733	380
Strickjacke	cardigan	2.85	2.25	3	9	-0.295	764	405
Strumpfhose	tights	3.10	2.40	3	10	-0.625	906	538

Unterhose	underpants	2.10	2.25	4	8	0.373	774	377
Wäscheschrank	linen cupboard	3.10	2.35	3	9	-0.380	798	462
Mean		3.07	2.05	2.90	7.53	-0.19	751.93	419.58
(SD)		(0.52)	(0.43)	(0.93)	(2.01)	(0.61)	(146.44)	(134.21)
typical / late acquired (n = 40)								
Ananas	pineapple	4.10	1.40	3	6	0.077	755	359
Aubergine	aubergine	5.95	2.50	4	8	-0.582	844	336
Blaumeise	bluetit	4.20	1.32	3	7	-1.133	877	441
Blutorange	blood orange	5.00	2.15	4	10	-1.786	853	455
Chicoree	chicory	5.89	2.40	3	6	-1.485	701	324
Clementine	clementine	5.61	2.40	4	10	-0.543	790	448
Cocktailtomate	cocktail tomato	6.30	2.70	5	12	None	1118	595
Grünkohl	green cabbage	4.30	1.95	2	7	-0.249	660	462
Habicht	goshawk	4.35	2.45	2	6	0.249	618	405
Honigmelone	honeydew melon	5.70	2.10	5	11	-1.610	450	421
Mango	mango	5.95	2.45	2	5	-0.690	633	354
Nektarine	nectarine	5.05	2.10	4	9	None	543	483
Pampelmuse	grapefruit	5.20	1.75	4	10	-0.569	832	228
Sittich	parakeet	4.22	2.55	2	5	-0.454	605	388
Sperber	sparrowhawk	5.53	2.67	2	6	-0.133	793	575
Stieglitz	goldfinch	5.53	2.61	2	7	-0.288	845	523
Strauchtomate	vine tomato	4.95	2.40	4	11	None	1013	498
Zaunkönig	wren	4.15	2.32	3	8	-0.496	1025	536
Zeisig	siskin	5.39	2.56	2	5	-0.434	763	422
Zucchini	courgette	5.95	2.00	3	6	-2.088	694	322
Anrichte	sideboard	4.95	2.70	3	7	0.163	699	350
Anzug	suit	4.45	1.40	2	5	1.286	552	498
Beistelltisch	occasional table	5.55	2.70	3	9	-1.088	919	535
Bohrmaschine	drill	4.35	1.30	4	9	-0.425	908	440
Couchtisch	coffee table	4.15	1.75	2	7	-0.745	796	438
Einbauschrank	fitted cupboard	5.20	2.65	3	9	-1.242	890	535
Harfe	harp	4.80	2.65	2	5	0.249	843	458
Jeans	jeans	4.20	1.40	1	4	0.214	813	329
Kettensäge	chainsaw	5.25	2.40	4	9	None	675	459
Kommode	chest of drawers	4.00	1.65	3	6	0.516	544	465
Meißel	chisel	5.15	2.00	2	5	0.030	888	439
Oboe	oboe	5.35	2.65	3	4	0.009	870	392
Ohrensessel	wing chair	5.44	2.42	4	9	-0.531	554	462
Orgel	organ	4.65	1.95	2	5	1.006	851	307
Querflöte	flute	4.89	1.85	3	9	-0.832	840	466
Saxophon	saxophone	4.45	2.15	3	8	-0.034	763	371
S-Bahn	city train	4.15	1.10	2	5	0.189	658	354
Spachtel	scraper	4.75	2.65	2	7	-0.309	560	339
U-Bahn	underground railway	4.40	1.25	2	4	0.182	585	278
Weste	waistcoat	4.10	2.55	2	5	0.690	546	407
Mean		4.94	2.15	2.88	7.15	-0.36	754.15	422.43
(SD)		(0.65)	(0.49)	(0.97)	(2.17)	(0.75)	(153.14)	(82.85)

atypical / early acquired (n = 40)

Biber	beaver	2.95	3.05	2	4	0.189	476	438
Dachs	badger	3.60	2.85	1	4	0.385	487	256
Eidechse	lizard	3.15	3.20	3	6	0.411	719	417
Flusspferd	river horse	3.90	2.90	2	8	None	790	333
Hagebutte	rosehip	3.45	4.71	4	8	-0.261	741	353
Käfer	beetle	1.70	3.11	2	4	0.766	506	337
Kreuzspinne	garden spider	3.80	4.45	3	9	-0.673	948	585
Lama	llama	3.85	2.80	2	4	0.040	649	434
Libelle	dragonfly	3.85	3.58	3	6	0.259	585	362
Marder	marten	3.75	2.90	2	5	-0.201	527	337
Pelikan	pelican	3.90	3.00	3	7	-0.153	703	236
Pfau	peacock	3.80	3.00	1	2	0.255	463	150
Preiselbeere	cranberry	3.95	2.75	4	10	-0.406	894	520
Pute	turkey	3.40	3.20	2	4	-0.249	489	328
Regenwurm	earthworm	2.45	3.05	3	9	0.316	756	506
Schildkröte	tortoise	2.60	2.90	3	9	0.454	930	570
Seepferdchen	seahorse	3.25	3.75	3	8	-0.543	1036	354
Uhu	eagle owl	2.20	2.95	2	3	-0.001	533	292
Warzenschwein	warthog	3.90	3.20	3	10	-0.883	968	480
Wespe	wasp	2.35	3.21	2	5	0.296	599	426
Badeanzug	swimsuit	2.40	3.15	4	9	-0.019	940	501
Blechtrommel	tin drum	3.60	3.89	3	10	-0.138	746	487
Brotschrank	bread cupboard	3.35	4.50	2	9	-2.088	771	510
Haarband	hairband	3.40	5.82	2	7	-1.046	713	501
Hosenträger	braces	2.95	5.25	4	10	0.235	813	478
Kutsche	carriage	2.45	3.75	2	4	0.529	455	292
Latzhose	dungarees	3.05	2.75	3	8	-0.883	781	385
Lederhose	leather gloves	3.20	3.95	4	8	-0.143	831	586
Motorboot	motorboat	3.70	2.95	3	8	0.187	893	571
Mundharmonika	harmonica	3.05	3.40	5	13	0.133	987	329
Quirl	whisk	3.45	5.19	1	5	-0.281	469	297
Rassel	rattle	3.10	4.90	2	5	0.106	598	400
Rollschuh	roller blade	3.55	5.50	2	5	None	612	419
Schaukelstuhl	rocking chair	2.85	2.75	3	9	0.030	891	680
Schuhschrank	shoe cupboard	3.25	3.05	2	7	-1.389	679	347
Sieb	sieve	2.55	4.25	1	3	0.443	502	404
Stoffhose	cloth trousers	3.40	2.85	3	8	-2.088	908	513
Traktor	tractor	2.35	3.84	2	7	0.490	676	410
Triangel	triangle	3.55	3.65	3	8	-0.268	639	358
Truhe	chest	3.00	2.95	2	4	0.555	485	168
Mean		3.20	3.57	2.58	6.80	-0.15	704.70	408.75
(SD)		(0.57)	(0.85)	(0.93)	(2.50)	(0.67)	(174.63)	(116.40)

atypical / late acquired (n = 40)

Auerhahn	wood grouse	4.89	3.40	3	5	-0.236	754	460
Bison	bison	4.80	3.00	2	5	-0.153	528	180
Dattel	date	5.05	4.35	2	5	-0.190	455	194

Echse	saurian	4.50	3.30	2	4	-0.128	492	199
Esskastanie	sweet chestnut	5.32	4.53	4	10	None	965	364
Fenchel	fennel	5.15	3.59	2	6	0.089	599	231
Flamingo	flamingo	4.65	3.15	3	8	-0.434	817	419
Granatapfel	pomegranate	6.00	3.74	4	10	-0.556	997	508
Graugans	graylag goose	4.41	3.30	2	7	-0.339	751	553
Kobra	cobra	4.00	3.30	2	5	-0.485	611	256
Kolibri	hummingbird	4.90	3.00	3	7	-0.230	731	398
Kranich	crane	4.60	2.95	2	6	-0.158	623	431
Luchs	lynx	4.10	3.05	1	4	-0.019	486	230
Mirabelle	mirabelle	5.82	3.50	4	8	-0.640	772	390
Olive	olive	5.63	3.39	3	5	0.226	571	326
Rettich	white radish	4.60	2.85	2	5	0.153	636	316
Sauerampfer	sorrel	4.26	4.88	4	7	-0.434	984	496
Seeadler	sea eagle	4.70	2.75	3	6	-0.138	781	534
Wildente	wild duck	4.75	3.05	3	8	-0.230	840	591
Wildkatze	wild cat	4.10	2.90	3	8	-0.302	907	650
Bettkasten	bed drawer	4.40	4.72	3	9	-0.883	844	422
Bratsche	viola	4.95	3.05	2	5	-0.079	627	360
Cembalo	harpsichord	5.67	3.00	3	7	-0.031	614	167
Fagott	bassoon	5.45	3.35	2	5	-0.038	659	309
Gabelstapler	forklift truck	4.80	4.94	4	11	-0.673	873	660
Kajak	kayak	5.35	5.05	2	5	-0.974	536	190
Kellerregal	basement shelf	4.10	4.94	4	9	None	844	342
Krawatte	tie	4.75	3.50	3	7	0.802	638	410
Kutter	cutter	4.35	4.55	2	4	0.322	423	242
Lederjacke	leather jacket	4.20	2.75	4	8	0.065	786	469
Luftschiff	airship	5.11	4.53	2	7	0.409	932	702
Pelzmantel	fur coat	4.15	3.35	3	10	0.114	816	601
Rechen	rake	5.00	4.05	2	5	-0.249	547	366
Reibeisen	grater	5.42	4.18	3	7	-0.508	767	325
Schraubstock	vice	4.85	2.89	2	8	-0.110	844	607
Sichel	sickle	4.65	3.89	2	5	0.196	618	406
Spültisch	sink unit	4.95	4.00	2	7	-0.569	975	634
Stirnband	headband	4.16	4.82	2	9	-0.372	952	599
Vierkant	square box wrench	5.42	3.63	2	7	-0.786	857	542
Yacht	yacht	5.05	4.10	1	4	-0.168	574	209
Mean **(SD)**		4.83 (0.52)	3.68 (0.72)	2.60 (0.84)	6.70 (1.90)	-0.20 (0.36)	725.65 (162.79)	407.20 (154.36)

INCONGRUENT CONDITION *(n = 80)*

typical / early acquired (n = 20)

Aprikose	apricot	3.35	1.80	4	8	0.191	858	380
Buntspecht	spotted woodpecker	3.65	1.60	2	9	-0.596	838	448
Bussard	buzzard	3.95	2.00	2	6	-0.242	583	116
Drossel	thrush	3.85	1.83	2	6	-0.153	563	215
Elch	elk	3.95	2.35	1	3	-0.249	481	237
Pinguin	penguin	3.10	2.40	3	7	-0.168	621	238

Porree	leek	3.50	2.15	2	4	-0.038	427	189
Sauerkirsche	sour cherry	2.85	1.70	4	8	-0.389	923	557
Wal	whale	2.75	2.65	1	3	0.341	496	271
Zebra	zebra	2.50	2.10	2	5	-0.224	664	343
Esstisch	dining table	2.95	1.35	2	5	None	654	353
Hubschrauber	helicopter	2.65	2.30	3	8	0.484	782	244
Moped	moped	3.55	2.30	2	5	-0.195	643	385
Nachtschrank	bedside cabinet	3.20	2.50	2	9	-1.088	957	580
Säge	saw	3.65	1.25	2	4	0.449	579	390
Schlafanzug	pyjamas	2.00	2.35	3	9	-0.008	1065	656
Schlagzeug	drumkit	3.45	1.95	2	7	0.424	883	586
Socke	sock	2.10	1.35	2	4	-0.531	426	271
Unterhemd	vest	2.20	2.05	3	8	-0.224	750	413
Unterwäsche	underwear	2.85	1.90	4	8	0.175	716	374
Mean		3.10	1.99	2.40	6.30	-0.11	695.45	362.30
(SD)		(0.61)	(0.40)	(0.88)	(2.05)	(0.40)	(182.78)	(146.52)
typical / late acquired (n = 20)								
Blattsalat	leaf salad	4.15	2.35	3	9	-0.832	858	365
Brokkoli	broccoli	5.53	1.70	3	7	-0.765	663	332
Buchfink	chaffinch	4.40	2.40	2	7	-0.707	716	397
Eichelhäher	jay	5.16	2.37	4	7	-0.556	889	507
Feldsalat	lamb's lettuce	4.10	2.65	3	9	-0.415	882	515
Grünspecht	green woodpecker	4.17	2.60	2	9	-0.941	924	520
Kanarienvogel	canary	4.10	2.05	6	13	0.165	1129	632
Kohlmeise	great tit	4.15	1.30	3	7	-1.485	829	377
Weißstorch	white stork	5.15	2.63	2	8	None	940	540
Wirsingkohl	savoy cabbage	4.53	2.25	3	9	-0.454	888	530
Blazer	blazer	6.00	2.25	2	5	-0.745	673	142
Cello	cello	5.00	2.30	2	4	0.006	482	286
Feile	file	4.05	2.05	2	4	-0.034	569	419
Klarinette	clarinet	5.20	2.25	4	9	0.145	556	313
Kreuzschraubenzieher	Phillips screwdriver	5.75	1.85	5	12	None	1269	822
Pauke	kettledrum	4.20	2.35	2	4	0.470	497	281
Posaune	trombone	4.10	2.25	3	6	0.397	704	256
Sakko	sports jacket	5.21	1.80	2	4	-0.105	476	275
Shorts	shorts	4.55	2.55	1	4	-0.347	595	403
Vitrine	display cabinet	4.30	2.00	3	7	0.187	739	523
Mean		4.69	2.20	2.85	7.20	-0.33	763.90	421.75
(SD)		(0.63)	(0.34)	(1.18)	(2.63)	(0.53)	(214.16)	(155.18)
atypical / early acquired (n = 20)								
Aal	eel	3.05	2.79	1	2	0.505	393	359
Ameise	ant	2.00	2.75	3	5	0.731	644	238
Fledermaus	bat	3.60	2.75	3	8	0.644	973	334
Hecht	pike	3.45	3.21	1	4	0.512	449	397
Kürbis	pumpkin	3.15	2.74	2	6	0.143	650	294
Lachs	salmon	3.95	3.05	1	4	0.352	411	246
Maulwurf	mole	2.50	3.00	2	7	0.366	834	462

Raubkatze	big cat	3.50	2.95	3	8	-0.610	820	542
Schwarzbär	black bear	3.95	2.75	2	8	-1.786	833	623
Seehund	seal	3.60	2.90	2	6	-0.050	702	340
Dreirad	tricycle	1.90	5.11	2	6	-0.569	704	368
Fäustlinge	mittens	3.17	4.00	3	9	None	802	453
Gartenstuhl	garden chair	3.25	4.10	3	10	-0.406	827	570
Kopftuch	headscarf	2.70	3.95	2	6	0.481	734	452
Lätzchen	pinafore	1.80	4.79	2	7	None	647	211
Laufroller	scooter	3.67	6.00	3	7	None	736	414
Segelschiff	sailing ship	3.25	3.65	3	8	0.263	865	573
Seilbahn	cable car	3.75	3.60	2	6	-0.406	733	390
Sonnenhut	sun hat	3.35	4.45	3	8	-1.242	888	495
Umhang	cloak	3.55	5.21	2	5	0.153	493	260
Mean		3.16	3.69	2.25	6.50	-0.05	706.90	401.05
(SD)		(0.65)	(0.98)	(0.72)	(1.91)	(0.70)	(163.57)	(120.21)

atypical / late acquired (n = 20)

Antilope	antelope	4.00	2.95	4	8	0.049	798	601
Büffel	buffalo	4.05	2.80	2	5	0.257	422	107
Eisvogel	kingfisher	5.17	3.16	3	7	-0.397	741	389
Fasan	pheasant	4.65	3.05	2	5	0.175	693	327
Feige	fig	5.30	3.45	2	4	0.209	605	395
Holunderbeere	elderberry	4.00	3.85	5	11	-1.008	900	598
Ingwer	ginger	6.16	3.94	2	5	-0.212	520	92
Reiher	heron	4.21	3.05	2	3	0.074	533	129
Steinbock	ibex	4.45	2.90	2	7	-0.054	742	640
Zecke	tick	4.80	5.42	2	4	-0.268	490	272
Inbusschlüssel	allen key	6.13	2.94	4	11	None	916	537
Kanu	canoe	4.25	5.20	2	4	-0.268	475	312
Kimono	kimono	5.83	4.84	3	6	-0.332	567	222
Korsett	corset	5.68	4.75	2	6	0.040	522	245
Mieder	bodice	5.11	4.26	2	4	0.068	564	325
Safe	safe	4.85	6.13	1	3	-0.230	540	171
Schelle	bells	5.44	4.25	2	4	0.228	507	359
Trikot	tricot	4.21	4.60	2	5	0.100	582	261
Walze	roller	4.60	4.25	2	5	0.564	672	490
Xylophon	xylophone	4.70	3.80	3	8	-0.174	763	356
Mean		4.88	3.98	2.45	5.75	-0.06	627.60	341.40
(SD)		(0.70)	(0.96)	(0.94)	(2.31)	(0.34)	(142.47)	(164.77)

Notes: TYP: typicality; AOA: age of acquisition; SYL: number of syllables; PHON: number of phonemes; LogFREQ: normalized logarithic lemma frequency; DUR: duration in ms; UP: uniqueness point in ms; SD: standard deviation.

Table A 2 IWA background information

IWA	Sex	Syndrome	Age	PO	TT	CS	N	WL	aud. WPM	vis. WPM	aud. SJ	vis. SJ
			y;m	y;m	percentile	percentile	percentile	percentile	% correct	% correct	% correct	% correct
A01	M	Anomic (f)	48;11	11;09	65	99	82	79	100	100	77[a]	90[a]
A02	M	Broca (nf)	59;00	1;03	81	66	44	56	95	90[a]	80[a]	95[a,*]
A03	F	Wernicke (f)	70;11	2;08	60	83	77	91	100	95	72[b]	90[a]
A04	M	NC (f)	71;01	12;00	70	97	88	89	95	95	87[a]	55[a]
A05	M	Wernicke (f)	68;08	0;09	72	93	63	90	95	95	92[a]	80[a]
A06	M	Broca (nf)	70;01	2;06	60	61	42	43	100	100	70[b]	50[a]
A07	M	Anomic (f)	61;09	12;11	93	75	72	84	95	95	72[b]	65[a]
A08	F	Broca (nf)	47;07	3;06	95	68	87	43	100	100	90[a]	90[a]
A09	M	Anomic (f)	73;08	1;02	81	75	91	99	95	95	87[a]	85[a]
		Mean	63.2	5.4	75.2	79.6	71.8	74.9	97.2	96.1	81.1	77.8

Notes: M: male; F: female; NC: not classifiable; f: fluent; nf: non-fluent; PO: time post-onset; TT: AAT (Huber, Poeck, Weniger, & Willmes, 1983) - Token Test; CS: AAT – Comprehension Score; N: AAT – Naming; WL: AAT written language; WPM: auditory and visual word-picture matching (LEMO 2.0 Tests 11 and 12, Stadie, Cholewa, & Bleser, 2013); SJ: auditory and visual synonym judgement with semantic distractors (LEMO 2.0 Tests 15 and 16); a: impaired performance as determined by LEMO 2.0 (task-specific cut-off: 90 %); b: severely impaired performance (chance level) as determined by LEMO 2.0; *: A02 was tested with LEMO Test 14 instead of Test 16: visual synonym judgement without semantic distractors (task-specific cut-off for impaired performance: 95 %).

ERKLÄRUNG

Gemäß § 4 (2) 7. der Promotionsordnung der Humanwissenschaftlichen Fakultät der Universität Potsdam vom 15. Mai 2013 erkläre ich, Romy Räling, die vorliegende Dissertation selbstständig und ohne Hilfe Dritter verfasst habe. Ich erkläre ferner, dass ich nur die in der Dissertation angegebenen Hilfsmittel benutzt, sowie alle wörtlich oder inhaltlich übernommenen Stellen als solche gekennzeichnet habe. In der Abfassung der Arbeit wurden stets alle Regelungen guter wissenschaftlicher Standards eingehalten.

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