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## Judging the animacy of words: The influence of typicality and age of acquisition in a semantic decision task

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### 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.

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### KEYWORDS

Age of acquisition; Animacy decision; Semantic classification task; Typicality

Word processing has been shown to be influenced by various psycholinguistic variables that are naturally highly intercorrelated (e.g., Hernández-Muñoz, Izura, & Ellis, 2006; Kuperman, Stadthagen-Gonzalez, & Brysbaert, 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, van Wijnendaele, De, & Deyne, 2000), whereas frequency effects are assigned to lexical-phonological processing stages (Levelt, Roelofs, & Meyer, 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.

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, Pastore, Valentini, & Peressotti, 2015), and picture naming (Barry, Morrison, & Ellis, 1997; Carroll & White, 1973; Chalard & Bonin, 2006; Cuetos, Ellis, & Alvarez, 1999; Hodgson & Ellis, 1998; Johnston & Barry, 2006; Johnston, Dent, Humphreys, & Barry, 2010; Morrison & Ellis, 1995) as indicated by faster response times for early- than for 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 than in tasks demanding spoken responses<sup>1</sup> (see also Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2009). Tasks that do not involve speech production are, for instance, lexical

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decision (e.g., De Deyne & Storms, 2007; Morrison & Ellis, 2000; P. T. Smith, Turner, Brown, & Henry, 2006), semantic categorization (e.g., Brysbaert et al., 2000; Ghyselinck, Custers, & Brysbaert, 2004; Holmes & Ellis, 2006), or animacy decision using printed words (De Deyne & Storms, 2007; Menenti & Burani, 2007; Morrison & Gibbons, 2006) or pictures (Catling & Johnston, 2006).

There are different theoretical accounts explaining the age of acquisition effects found in offline<sup>2</sup> 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 network. In contrast, multiple-level theories assume age of acquisition effects to be located at several levels of language processing (Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2006, 2009). Catling and Johnston (2006, 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 that 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, Lewis, & Brysbaert, 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 grapheme–phoneme 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, Cree, Westmacott, & De Sa, 1999). As has been emphasized 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, Ntourou, & Eubank, 2007; Kiran & Thompson, 2003; Rips, Shoben, & Smith, 1973; Rosch & Mervis, 1975; Sandberg, Sebastian, & Kiran, 2012; E. E. Smith, Shoben, & Rips, 1974), in animacy decision tasks (Morrison & Gibbons, 2006), and in tasks requiring spoken responses such as picture naming (Dell'Acqua, Lotto, & Job, 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, Råling, Holzgrefe-Lang, Schröder, and Wartenburger (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 event-related potential (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 Råling, Schröder, & Wartenburger, 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 (e.g., Caramazza & Shelton, 1998; Moss, Tyler, Durrant-Peatfield, & Bunn, 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 that 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 versus non-living concepts (Laws, 2000; Laws & Neve, 1999), which might be due to the evolutionary importance of living objects (Caramazza & Shelton, 1998). Without focusing on the semantic domain as a factor, some of the above-mentioned animacy-decision-tasks also revealed faster response times for living than for non-living items (Catling & Johnston, 2006; 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 (2006) 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, 2006, 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, Richard, & Soulieres, 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, Holzgrefe-Lang et al., 2015; Räling, Schröder 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, 2006; 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, Holzgrefe-Lang et al., 2015; Räling, Schröder 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, Holzgrefe-Lang et al. (2015) with a different but comparable item set in a different group of participants. Hypothesizing 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).

## Experimental study

### Method

#### 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.

#### Stimuli

Words were chosen from a German database including rating norms for typicality, age of acquisition, and familiarity (Schröder, Gemballa, Ruppig, & Wartenburger, 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

**Table 1.** Varied and matched variables of the four item sets used in the animacy decision task.

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

Note: Total number of items,  $n = 156$ .

(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,<sup>3</sup> 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:  $t(76) = 2.18$ ,  $p < .05$ ; typical/early acquired vs. atypical/late acquired:  $t(76) = 3.36$ ,  $p < .05$ ] (see Table 1 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.

### 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-randomized 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 min.

### 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 ( $-1/RT$ , where  $RT =$  response time) 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

**Table 2.** Mean response times of correct responses and accuracy 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

Note: Proportions in parentheses.

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 generalized 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, and 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.

## Results

### Accuracy

The accuracy data in the animacy decision task are provided in Table 2.

Participants generally performed at ceiling in all of the four conditions (between 98% and 99% correct).

The generalized 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  $\times$  age of acquisition interaction:  $b = 0.434$ ,  $SE = 0.35$ ,  $z = 1.26$ ,  $p > .05$ ).

### Response times

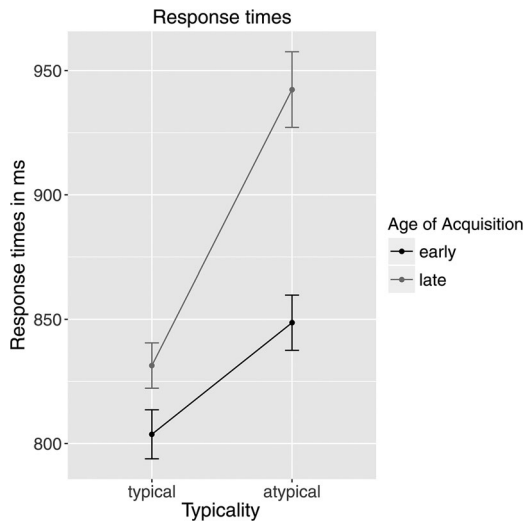
Table 2 also depicts the mean response times for the four different conditions. Within early- and late-acquired words, response times were higher for atypical than for typical items, and, in addition, within typical and atypical items, response times were higher for late-acquired than for early-acquired items. Moreover, participants took longer to respond to items of the non-living than to those of 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% confidence interval, 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  $\times$  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 1.

## 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





**Figure 1.** 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.

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 than to atypical items and to words that are acquired earlier than to those acquired later in life. In addition, response times were faster for words in the living than for those in 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 are 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, 2006; 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 evolutionary 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 than for 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; Råling, Holzgrefe-Lang 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, 2006; 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 (Brybaert et al., 2000; Ghyselinck, Custers 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.<sup>4</sup> 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, Cholewa, & Tabatabaie, 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 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 (Brybaert & Ghyselinck, 2006). Brybaert 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 Råling, Holzgrefe-Lang et al. (2015; see also Råling, Schröder 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 (Råling, Holzgrefe-Lang et al., 2015; Råling, Schröder 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 (2006, 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.

## Notes

1. But see Cortese & Khanna (2007) for larger effect sizes in lexical decisions than in 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.
2. 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.
3. 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.
4. 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 us to overcome 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 that we recently conducted (Råling, Holzgrefe-Lang et al., 2015; Råling, Schröder 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.

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