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Early developmental influences on adult language processing: Exploring the locus of age-of-acquisition effects in producing and comprehending single words

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1 Background

The comprehension and production of single words involve a variety of processing stages. Which stages need to be accessed differs depending on whether objects (pictures in an experimental environment) or words are supposed to be named. Naming tasks are often employed in psycholinguistic studies in order to provide an insight into the function of mental processes during word production. Differences in naming latencies and naming accuracy between words suggest that the retrieval of some lexical items is easier or more difficult in contrast to others. The relative ease of word retrieval has been found to be strongly influenced by properties of these words, such as familiarity and written or spoken frequency.

Exploring which variables affect naming speed and accuracy will allow gaining more information about the storage and processing of words in general. If a variable has a discernable effect on a specific experimental task, the localization of this effect is of interest for psycholinguistic research. This is because finding the locus of the effect can help specify models of speech production with respect to what processes occur at which stage of lexical retrieval. Additionally, identifying which variables influence language processing is inevitable in order to control for these variables when necessary. Otherwise variance in naming latencies could not be explained by the variable that was to be tested because other, uncontrolled variables could have altered the results.

It is widely agreed that factors like frequency, imageability, neighborhood density, familiarity, and word length affect naming latencies and have to be taken into account when investigating single word production. One variable that was not recognized as a possible factor and dismissed as being another form of frequency effect in earlier research has gained more attention in recent years: The age at which a word is acquired has been found to have an effect on a variety of experimental tasks that investigate single word production (for recent reviews see Juhasz, 2005; Johnston & Barry, 2006). Most children will acquire the word “cat” earlier than the word “tiger” and this again will be acquired earlier than the word “leopard”. Studies using the age of acquisition (AoA) of a word as an independent variable have found robust effects on participants naming performances, suggesting that early acquired words, like cat, are named faster and seem to be more resistant to errors than late acquired words, like leopard.

In the literature, this AoA effect has led to very diverse propositions concerning its actual relevance, ranging from ignoring the existence of AoA effects (Balota, Cortese, Sergent-Marshall, Spieler & Yap, 2004) over the reinterpretation of frequency effects as actually being AoA effects (Morrison & Ellis, 1995) to making it an inherent property of any learning mechanism or giving it a central role in the building of semantic networks (Ellis & Lambon Ralph, 2000; Steyvers &

Tenenbaum, 2005). Regarding the locus of AoA effects, different hypotheses have been put forward based on findings of various studies that used different experimental tasks, such as lexical decision, semantic classification, picture and word naming. Considering a range of difficulties that arise with AoA as a variable in experimental setups, I will evaluate these hypotheses with regard to how accurately they can predict experimental evidence.

2 Measures of AoA

The age at which a child acquires a word is influenced by many different external factors that vary across individuals. It can be assumed that children tend to acquire those words early in life that are relevant to their learning environment. Reilly, Chrysikou & Ramey (2007) investigated which variables contribute to AoA, i.e. which factors influence whether a word will be acquired early or late. Using AoA as criterion, they found that the following eight out of ten predictors exerted significant influences on AoA and can therefore be seen as affecting the age at which a certain word will be acquired: etymology, familiarity, hypertext frequency, imageability, phonological neighborhood density, number of consonant clusters, number of syllables and word stress. These predictors accounted for 76% of the variability of AoA.

It is also important to note that whenever AoA effects are examined, the values that can be used are only rough estimates of the actual age at which words are acquired. However, as will be discussed in this section, these estimates do seem to mirror the actual objective AoA reliably. Two different methods can be applied to measure AoA objectively (Schröder, Kauschke & de Bleser, 2003). Both investigate the speech of children. The first method measures the age of spontaneous lexical production of different words. In order to establish this, parents are presented with a list of nouns and are asked whether their children produce these nouns spontaneously. Children are then divided into age-groups with a range of half a year each. The age group in which 70% of the children produce the noun in their spontaneous speech is then selected as representative for the AoA of this lexical item. The second objective measure of AoA employs the method of investigating the naming age for different lexical items. In order to do so, children are presented with pictures and asked to provide a name for the respective entity with a “What do you see here?”, or “What is this?” question. Children are then divided into different age groups. If at least 70% of the children of a particular age are capable of naming the picture, this age is established as being the AoA of the lexical item.

Subjective measures of AoA are adult estimates of when a particular word was acquired. These are the measures that were usually used in many early experiments concerning AoA, as they were easier to obtain than objective measures. Subjective

estimates are rated as follows. Participants are asked to rate the AoA for different words on a scale. They are advised to consider the time at which they acquired the lexical item, understood its meaning and also produced the word themselves as AoA. Though this method raises concerns about the actual capability of adults to rate this age, reliable correspondences of these measures with the objective measures have been found repeatedly (Gilhooly & Gilhooly, 1980; Schröder, et al., 2003). For some items Schröder et al. (2003) found an earlier rating for productive AoA (the age at which children produced a word spontaneously) than for the other estimates (picture naming AoA and subjective AoA). This suggests that children tend to repeat a word based on its phonological features without having established a concept of this word. Except for these outliers, subjective AoA estimates have been shown to reliably correspond to objective measures of AoA and can therefore be used as predictors and independent variables in experimental studies.

3 AoA effects in experimental research: Confounds and other difficulties

In the same way external factors influence the age at which a word is acquired, AoA is also influenced by properties of the words themselves. To locate the stages in word processing on which AoA has an effect it is important to recognize that data obtained in experiments might not reflect an actual AoA effect but an effect of other variables that correlate with AoA. As pointed out above, a word which is acquired early in childhood is probably a word that is in some sense relevant to the child's world. Words that are used often and that are needed to adequately express wishes or give responses have to be acquired early in order to communicate. As these words are necessary for communicating basic needs they will be of higher frequency and less abstract than words that are encountered after years of learning. However, some words that are frequent in child-language do not occur often in adult speech. In the following section I will address the problems that have to be dealt with when examining a highly confounded variable like AoA, which itself is only an estimate of some abstract word property.

3.1 Factorial designs vs. regression experiments

AoA is a highly confounded variable and, additionally, never fully reflects reality because the values that are used represent estimates, not the actual AoA. These facts require consideration when choosing an experimental design.

Psycholinguistic research often employs factorial designs. In factorial designs, factors, i.e. the independent variables (e.g. frequency, AoA), are varied within the experiment. This means that two or more variants (conditions) of these variables are tested against each other with regard to their influence on a dependent variable

(typically naming latencies or accuracy). This way, main effects of specific variables and the interactions of these variables can be evaluated.

Another frequently employed way of investigating AoA effects are regression analyses. Regression analyses are used to evaluate the influence of one or several independent variables on the variance of the dependent variable. This analysis makes use of one, or, in most cases, many predictor variables (e.g. frequency, AoA) and tests how much of the variability within the dependent variable (e.g. naming latencies) can be accounted for by every single predictor.

Both types of experimental design have been employed when studying AoA effects (for a summary of analysis types used in picture naming studies see Juhasz, 2005). Baayen (2010) presented a general comparison of the benefits and disadvantages of the use of regression or factorial designs in experiments. He argued that a factorial design leads to a "severe loss of power" (Baayen, 2010, p.1) when examining frequency effects. This is due to the fact that frequency, as well as AoA, is massively correlated with other features of words such as neighborhood density and imageability. In factorial designs the attempt is made to control for all of the correlated features except for one variable. This is done by selecting words with extremely different values regarding the respective variable and very similar values regarding the correlated variables. This attempt to deconfound the involved variables is problematic because they are embedded in highly complex correlational structures. Baayen (2010) argued that regression analyses can make use of all obtained data which gives them an advantage over a factorial design whenever correlations are high. Inversely, factorial designs should only be used when examining variables that are not involved in highly complex correlational structures. This is particularly important when testing for interactions. As AoA is a highly complex variable, an experiment using a regression analysis would therefore probably be the more adequate approach towards examining its impact than making use of a factorial design.

With specific focus on AoA, the question what type of experimental design should best be used was discussed by Lewis (2006). He evaluated common methods employed in AoA experiments, namely semi-factorial and factorial as well as multiple and stepwise regression designs. Semi-factorial designs make use of two different experiments with two lists of words each, one experiment controlling for AoA and one for frequency (in contrast to factorial designs in which these factors are both manipulated within one experiment). Therefore, this method cannot reveal interactions between the variables. Lewis (2006) argued that when using multiple regression analysis, the correlation of AoA and frequency remains within the stimuli and can therefore lead to non significant results because it does not reveal independent effects. He demonstrated the problems with using multiple regression analyses by conducting an example simulation. He generated data in which frequency affected

AoA and AoA, in turn, affected naming latencies. Afterwards a regression analysis was performed, revealing independent effects of frequency and AoA. Thus, the actual factor that influenced naming latencies, i.e. AoA, was not correctly discovered by the regression analysis. Lewis claimed that the term "effect" cannot be used for the impact AoA has on naming because the variables are not actually manipulated. Rather, the predictors are random variables themselves. He pointed out that fast naming times of a word are not fast because the word is estimated to be learned early in life (AoA) or because it occurs often in a corpus (frequency), but that the fast naming latencies originate in some property of the mental representation of this word. This property correlates with frequency or AoA norms and these norms correlate with, rather than affect, reaction times (Lewis, 2006, p. 1018). In short, when examining AoA effects, the potential danger of confusing causation and correlation seems to be higher than with other variables. After evaluating different types of analyses and experimental design, Lewis (2006) concluded that the only reliable results would be those that can be obtained by training participants on new, fully manipulatable stimuli and testing the effects of order of acquisition (OoA). This was done in a variety of studies (Stewart & Ellis, 2008; Izura et al., 2011), all showing significant effects for AoA or OoA, respectively.

3.2 Confounds with other variables

Words that are acquired early tend to occur more often in speech than words that are acquired late. In fact, this high correlation with frequency is one of the reasons why AoA effects have not been investigated as independent factors influencing language production for a long time (Lewis, 1999). The absolute frequency of occurrence of a lexical item can, once measured, be controlled by selecting stimuli with relatively equal frequency but diverging AoA estimates. However, there are two variants of frequency that must be distinguished from absolute frequency.

3.2.1 Cumulative frequency and frequency trajectory.

One theory about the origin of AoA effects interprets them as simply being effects of cumulative frequency (Lewis, 1999; also see Rastle, 2007). Cumulative frequency is the sum of all encounters with a word over the life-span. An early-acquired and a late-acquired word that share the same absolute frequency do have different cumulative frequencies. Early acquired words will still be heard more often than late ones, as they are introduced earlier and the exposure accumulates. The cumulative frequency hypothesis discards all AoA effects as being frequency effects. It predicts that, as cumulative frequencies adapt, the facilitative effect of AoA should decrease. This was not found by Barry, Johnston & Wood (2006) who investigated AoA effects in older and younger participant groups. According to the cumulative

frequency hypothesis, AoA effects should be smaller for older participants than for younger participants, assuming that, over a life-span, cumulative frequencies equalize. Using a repetition priming experiment, in which pictures and words that have been named before are supposed to be named again, Barry et al. tested the effects of AoA (early/late) and age group (younger/older) on naming latencies. The crucial finding was that the interaction of AoA and age group did not reach significance by participants. It was significant in the item analysis, however with the result that the effect of AoA by items was larger for older people. The cumulative frequency hypothesis predicts a larger AoA effect for younger people. Even though these findings show that cumulative frequency does not suffice as an explanation for the effect of AoA, both variables are highly correlated and cumulative frequency should be controlled for in studies investigating AoA effects.

Another frequency effect that is different to that of absolute frequency and has to be considered whenever dealing with effects of AoA, is the effect of frequency trajectory. Zevin and Seidenberg (2002) coined this term in order to describe the influence of the time course of exposure to a specific lexical item. Many words with high frequency in earlier stages of life become less frequent as age increases. Likewise many words that do not occur in early years will become very frequent in language production and reception once they are introduced. Zevin and Seidenberg (2002) defined AoA effects as the independent effect of frequency trajectory when cumulative frequency is controlled. According to them, the AoA effect consists in a facilitating effect of words that have a high frequency early in life in contrast to those that are of high frequency later in life (this theory will be discussed further in section 4.1).

3.2.2 Imageability.

Other variables are confounded with AoA as well, one of which is imageability. Abstract concepts are acquired later. Inversely, early acquired words tend to be of higher imageability. Funnel, Hughes & Woodcock (2006) showed this by examining naming and knowing (knowledge of the function and properties of items) of objects by children. Their results revealed qualitatively different learning experiences in different age groups such that early words were acquired based on shape and perceptual features whereas late words were acquired by generalizing the functional knowledge of these items. Knowing was tested by asking five questions regarding an item's function and properties. Some words that were named early were not known at this point of time. Some known items were not named until much later.

Early words are learned in connection to the picture that shows the entity or in connection to the entity itself. Thus, these words are named easier early in life as the learning process takes place with strong connection to the necessity of naming

an object. In language acquisition later words are not necessarily learned by direct exposure to visual stimuli but more indirectly. Thus learning experience changes and the differences between the types of learning lead to a high correlation of AoA with imageability. This correlation consists in higher imageability of early words.

3.3 Discussion

It is important to keep in mind that testing for AoA effects is more difficult and results are less reliable than with other variables. There are several reasons for this. In most studies AoA is not actually manipulated but words are chosen out of lists containing estimated norms of this variable. There is no measure to account for individual variances of AoA between different participants. Additionally, the question which experimental design should be used when investigating AoA effects cannot be answered in general, as there are some deficiencies in all designs. Following the argument put forward by Baayen (2010), a regression analysis would be best suited. However, in many studies factorial or semi-factorial designs have been employed and it would be problematic to exclude all of the results obtained that way. In fact, this would lead to a huge loss of data that can be useful in determining the locus of AoA effects. Juhasz (2005) argued that the best way to deal with the inadequacy of statistical analyses when investigating psycholinguistic variables is to compare various studies that used different types of analysis. Thus, I will draw on studies that used different designs and keep in mind that evaluating the methodical details of an experiment can be more important when dealing with AoA than it is with other variables.

Another aspect that needs to be considered when investigating AoA effects is that AoA confounds with other variables, such as different forms of frequency and imageability. It is therefore important to control for these variables and use adequate measures. Many studies that examined AoA effects used the Kučera and Francis (1967; and Francis & Kučera, 1982) frequency norms (e.g. Brown & Watson, 1987; Assink, van Well & Knuijt, 2003; Morrison, Ellis & Quinlan, 1992). Brysbaert and Cortese (2011) recently compared various frequency measures and found that these frequency norms are the least predictive ones, only accounting for 6,1% of the variance in word naming times and 32,3% in lexical decision times. More suitable frequency measures that have also been used in AoA studies (e.g. Cortese & Kanna, 2007; Gullick & Juhasz, 2008) were for example Zeno educator's word frequency and Sublex (word frequencies extracted from movie subtitles). These were found to explain more of the variance. Thus, when trying to evaluate studies and hypotheses that are concerned with locating the stage at which AoA effects operate, it is import to keep in mind that inconsistent results may be

caused by deficient experimental design or a lack of sufficient control of correlated variables, such as frequency or imageability.

4 AoA effects in language processing tasks

When exploring the locus of AoA effects, it is necessary to examine on which tasks AoA actually has an influence. As different tasks require access to different stages of language production, an effect that is observed in a particular task can be assumed to affect a specific stage in the production of a single word.

There is some dissent in the psycholinguistic literature regarding the structure of the mental lexicon, the processes that are involved in language processing and especially the connections that exist between the different stages from accessing a semantic representation to articulating a single word. Models of speech production vary from assuming a strictly serial information flow between the stages of language production, except for the conceptual and early lexical processing stages (Levelt, Roelofs & Meyer, 1999), to proposing cascaded processing (Caramazza & Miozzo, 1997) or advocating for a fully interactive account (Dell & O'Seaghdha, 1991). This paper is concerned with the locus of a single effect and not with determining the order of events in language processing per se. I will therefore provide a basic model that illustrates the main stages involved in producing single words in reading and picture naming in a simplified way, without focusing on the ongoing debate on the temporal coordination of the relevant processing steps.

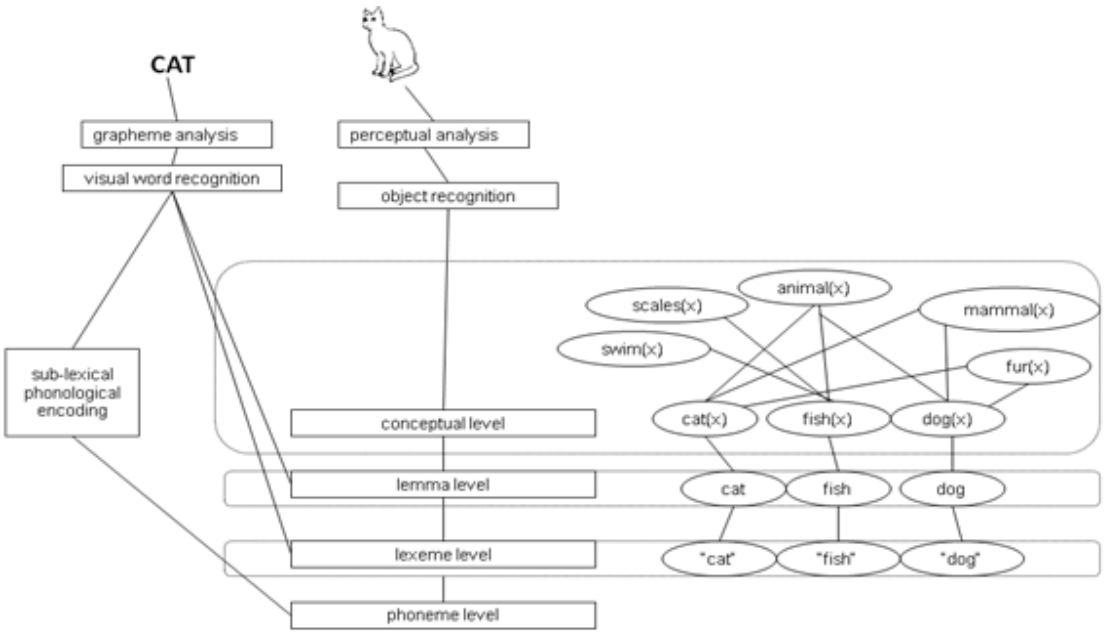

Figure 1: Processing stages for word and picture naming with focus on lexical encoding at the conceptual, lemma and lexeme levels. Based on models by Barry, Hirsh, Johnston & Williams (2001), and Levelt et al. (1999).

All models of speech production assume two processing stages: one that involves accessing lexical-semantic representations (conceptual and lemma level in Figure 1) and one that involves encoding morphophonological information (lexeme level in Figure 1). Production of a single word then takes place as follows. In word naming the single letters of a word and the word as a whole must be recognized (grapheme analysis and visual word recognition in Figure 1). Analogously, in picture naming the object must be recognized (perceptual analysis and object recognition in Figure 1).

In picture naming this leads to the activation of the concept and related feature nodes at the conceptual level. This activates the corresponding lemma. The lemma is the representation that contains syntactic, but not yet morphological or phonological information. During lexical access, several conceptually related lemmas compete for selection. In the model, co-activation takes place at the conceptual level and competition at the lemma level. Presenting a conceptually related word at this stage will cause priming at the conceptual level and lexical competition at the lemma level. The effect depends on the ratio of conceptual facilitation on lexical inhibition. When the activation of one single candidate exceeds the sum of activation of its competitors, the lemma will be selected (according to "Luce's ratio", see Levelt et al., 1999). After the selection of a lemma, the corresponding word form, containing its morphophonological features, is encoded (lexeme level in Figure 1). I will also refer to this level as the 'phonological level' in the following, as it is here that phonological representations are stored). In the next step the word is articulated. Going through all of these stages is indispensable in picture naming.

By contrast, word naming has been shown to function accurately without the involvement of semantics (the conceptual level). There are two routes that can be used instead: a direct lexical and a sub-lexical route, both not requiring access to any conceptual representations. Retrieval of a word's phonological form via the sub-lexical route happens solely through grapheme-phoneme-conversion, which means that, after the word has been recognized, each letter is assigned its phoneme and the word is articulated. The direct-lexical route retrieves a word's entry in the phonological output lexicon based on its entry in the orthographic input-lexicon. Within Figure 1, this means that after the visual recognition of the word, the lexeme level gets accessed directly, without involvement of the conceptual and lemma level (for a more detailed discussion of these routes and a computational model, see Coltheart, Rastle, Perry, Langdon & Ziegler, 2001).

Different tasks require access to different stages. Thus, if AoA effects can be found in some tasks but not in others, this indicates a locus at those levels that are accessed in the tasks that show sensitivity to AoA effects and that are not involved in tasks that are not influenced by AoA. For example, if an AoA effect was observed in a task that did not require access to semantics but not in tasks that re-

quired selective access to this level only, this stage could be excluded as a locus of AoA effects. In the following, I will investigate in which tasks AoA effects have been reliably observed, whilst taking the difficulties in interpreting experimental data of AoA effects into account. In order to do so, I will first focus on tasks that are regularly employed in psycholinguistic research and therefore often used in exploring AoA effects, namely lexical decision, word naming, semantic classification and picture naming. More specific tasks will be considered when evaluating evidence regarding different hypotheses of the locus of AoA effects.

4.1 Lexical decision

In a lexical decision task, participants are faced with deciding whether a word is an existing lexical item in the vocabulary of a language or not. During an experimental session, real words and pseudowords are presented. The latter are letter-strings that could be actual words in a specific language, considering its phone inventory and its phonotactical constraints. Participants then have to decide which of the stimuli are real words, and indicate their decision by pressing one of two buttons (left/right for yes/no).

In lexical decision tasks participants are assumed to match the letter-string that is presented against the entries in their mental lexicon. Thus, the word form of a stimulus is accessed because written words have to be recognized. The speech output system is not involved, as no verbal answer has to be generated. The access to the semantic level has been found to be optional (see Rastle, 2007): Semantic priming leads to faster decision latencies. However, patients with impairment in accessing the semantic level have been found to nevertheless be able to give correct answers in lexical decision tasks. Balota et al. (2004) found that semantic variables contributed to speeded word naming and lexical decision tasks but that they had more impact on lexical decision speed, thus suggesting a larger involvement of the semantic level in the latter task than in word naming.

If AoA affects lexical decision latency and accuracy this suggests that the effect is not located within the speech output level as no verbal answer needs to be generated. A semantic or lemma locus cannot be excluded as these levels are sometimes accessed in lexical decision.

Significant effects of AoA on lexical decision speed have been found and replicated in a number of studies (Assink et al., 2003; Burani et al. 2007; Morrison and Ellis, 1995; Turner, Valentine & Ellis,1998; Weekes, Chan & Tan, 2008). Turner et al. (1998) found AoA effects in lexical decision tasks using visually as well as aurally presented stimuli. Cuetos, Herrera & Ellis (2010) used a slightly modified version of the lexical decision task with Alzheimer's patients, in which only one of four presented letter strings was an actual word. This was done so that the patients'

attention would not be lost. They found that accuracy was better for early acquired words than for late acquired words. There was a significant interaction between group (patient/control) and AoA: Patients made significantly less errors when presented with early acquired words than when presented with late acquired words, and this difference was larger than the one in the control group. Cuetos et al. (2010) account for this finding by the progressing semantic impairment in Alzheimer patients that affects late acquired words more then it affects early acquired ones.

Thus, there is no doubt that AoA affects lexical decision tasks. This suggests that it cannot be located within the speech output system because no verbal answer has to be given in most lexical decision tasks.

4.2 Reading aloud

In reading aloud, or word naming, participants are asked to read words that are presented on a computer screen. This task generally involves the recognition of graphemes, the selection of a lemma, and morphophonological encoding and articulation. As explained above, there are two other routes that can be used when reading aloud: a lexical-semantic route and a sub-lexical route. The sub-lexical route requires the translation of graphemes to phonemes and is therefore assumed to be rather slow. It is unlikely that it is used in reading aloud. The lexical-semantic route accesses the meaning of the word, which is not necessary for completing this task.

The observation of an AoA effect in word naming tasks would, first of all, suggest the involvement of the speech output system or the phonological level, as the semantic system is typically bypassed and the response is generated by relying on the orthophonological code alone. Assuming that the AoA effect was located at the conceptual level, word reading would not be sufficient to provide meaningful observations because the presence as well as the absence of AoA effects could be explained under this assumption. The same applies to a locus at the lemma level as the sub-lexical route can bypass this stage as well. However, if differences are found when contrasting the reading of irregular words (or reading in languages with deep orthography) with reading of regular words (or languages with shallow orthography), this can provide some evidence against or in favor of involvement of the semantic or the lemma level. This is because reading in languages with deep orthography and reading of irregular words both probably rely more on the semantic-lexical route as phonology cannot be predicted by orthography in both cases.

Morrison and Ellis (1995) tested for an effect of both frequency and AoA on word naming speed when the other variable was controlled for. They found a reliable effect of AoA when frequency was controlled, but none for frequency when AoA was controlled. There was no effect of either of the two variables in a delayed word naming task. Thus, it can be assumed that AoA does not evolve during articulatory

encoding, which is the only processing stage that cannot be prepared by participants in a delayed naming task. However, Morrison and Ellis (1995) included the absolute written word frequency of their stimuli in their analysis, thus neither controlling for cumulative frequency, nor taking spoken word frequency into account. It can therefore not be excluded that the findings were due to insufficient control of frequency.

Using a computational approach, Zevin and Seidenberg (2002) trained a model to produce a phonological output, given an orthographical input. They manipulated frequency trajectory and held cumulative frequency constant. The model produced 98% correct output after 10 epochs with most errors on low frequency words. If naming of words with the frequency trajectory early-high to late-low was facilitated in contrast to those with other trajectories after the cumulative frequencies were matched, this would be analogous to an effect of AoA. However, this prediction was not borne out in the study by Zevin and Seidenberg (2002): There was an effect of frequency trajectory early in training, which, as cumulative frequencies were not yet aligned at this point of time, equaled a frequency effect. This effect disappeared as cumulative frequencies equalized. Zevin and Seidenberg (2002) argued that AoA effects occur when what is learned about early patterns cannot be carried over to later ones. This is not the case in English word naming, as English grapheme-phoneme correspondence for regular words is mostly predictable. The study by Zevin and Seidenberg (2002) showed that there is an effect of AoA in word naming. However, they argue that this effect cannot be detached from the effect of frequency but rather is a part of the superordinate variable cumulative frequency.

In contrast to the proposition made by Zevin and Seidenberg (2002), Raman (2006) found evidence that the reduction of AoA effects in word naming cannot be explained by the small degree of arbitrariness in the mapping between the stimuli and the output. He found that an AoA effect was present in Turkish word naming, when frequency, imageability, length and initial phoneme had been controlled for. Turkish is a language with very shallow orthography. This means that pronunciation can be predicted almost entirely by orthography. It should be noted that Raman (2006) used subjective frequency norms and tested AoA for high frequency words but did not test frequency independently. That was due to the fact that no objective frequency word norms exist for the Turkish language. It is possible that participants who are asked to rate word frequency and AoA for the same words are influenced by their rating of the other variable and unknowingly include errors by linking these norms. In contrast to the results obtained by Raman (2006), Burani, Arduino & Barca (2007) found no effect of AoA but one of frequency on word reading in Italian, which also is a language with regular letter-to-sound mapping.

As seen, the studies investigating AoA effect on word naming yielded inconsistent results, which makes it impossible to derive a valid hypothesis concerning the locus of AoA effects from this task.

4.3 Picture naming

In a picture naming task, participants are asked to name a picture that appears on a computer screen. Succeeding in this task involves access to the conceptual level, as the semantics of the picture has to be activated, and also requires access to the lemma and phonological level as the correct name has to be selected, encoded and produced.

All previous studies using a picture naming task revealed significant effects of AoA (e.g. Barry et al., 2001; Chalard & Bonin, 2006; Zevin & Seidenberg, 2002; see Juhasz, 2005, for a compilation). Those effects were generally larger than the AoA effects in any other task. Perez (2007) analyzed picture naming latencies using a regression design with objective AoA measures. As predictors he included the following variables: familiarity, visual complexity, image variability, AoA, adult written frequency, cumulative frequency, frequency trajectory, orthographic neighborhood, phonological neighborhood and word length. Using a multiple regression analysis he found a high correlation between frequency and AoA. However, AoA was the predictor that accounted for the most variance, followed by written word frequency.

The repeated observation of AoA effects in picture naming first of all strongly suggests the general existence of an effect of AoA. With regards to its localization, results cannot exclude any locus within the process of word production. However, the finding that the effect of AoA in this task is larger than in others needs to be considered when trying to locate this effect.

4.4 Semantic classification

In semantic classification tasks, participants are asked to categorize picture stimuli (e.g. “living”/”non living”). This task requires the recognition of an objects as well as access to the conceptual level because semantic features of the pictures need to be considered in order to make a decision. In contrast, it is not necessary to access the phonological level as it is possible to make a decision simply by recognizing the object’s semantic category. An effect of AoA in this task would suggest an involvement of the semantic level as the stage at which AoA effects operate because none of the other levels has to be accessed necessarily.

Morrison et al. (1992) found an effect of semantic category and prototypicality when letting participants categorize pictures into natural or man-made objects. They found no significant effect of AoA and argued that this variable thus does not

operate at the level of object recognition. In contrast to these results, Catling and Johnston (2006) applied a similar picture classification task, in which participants again were supposed to distinguish between manmade and naturally occurring objects. To rule out the possibility of participants judging the stimuli by non-semantic features, such as shape (natural objects tend to have less sharp lines than manmade ones) stimuli were selected to have untypical shapes with respect to their category (e.g. balloon and globe as manmade objects). The effect of AoA was significant by items and participants, as was object type by participants. There was no interaction between object type and AoA in the analysis of response latencies. However, in the analysis of errors, the interaction was significant, showing that AoA had an effect on the categorization of natural objects but not on that of manmade objects. In a second experiment, using a picture naming task, Catling and Johnston again yielded a significant effect of AoA. The combined analysis of AoA and task type revealed faster latencies in classification than in naming and an interaction of AoA and task: The AoA effect was greater for picture naming than for semantic classification. Catling and Johnston (2006) argued Morrison et al. did not include enough items per predictor, which might have obscured the effect. Also, when the participants were supposed to rate how prototypically manmade or natural the items were, they were presented with the written names of the objects in Morrison et al.'s study in contrast to the pictures in the study by Catling and Johnston. Thus, the evidence regarding the influence of AoA on semantic classification tasks appears to be inconclusive. However, considering the improvement of stimulus selection and analysis by Catling and Johnston (2006) in comparison to Morrison et al. (2002) the results obtained by Catling and Johnston seem to be more reliable. Additionally, effects of AoA on semantic classification tasks have been observed in other studies as well (Izura et al, 2011; Catling & Johnston, 2009).

It can be assumed that, despite the null-effect of AoA in Morrison et al.'s study, an effect of AoA is present in semantic categorization. This suggests that the semantic level is the, or one of the, stages which are affected by AoA.

4.5 Discussion

Other tasks than the aforementioned ones have also been employed in order to trace the locus of AoA effects. I will elaborate on some of these when evaluating different hypotheses regarding the localization of effects of AoA. The findings so far suggest that AoA effects cannot be located within the speech output system (given the absence of the effect in delayed word naming). None of the other levels of word production can be excluded so far, as AoA can be found in tasks that require access to the semantic and to the lemma level (picture naming, semantic classification) as well as to the lexeme level (picture naming, lexical decision, word naming). How-

ever, hypotheses about where and how AoA effects arise during word processing need to account for the differences in magnitudes of these effects depending on task. In addition, the finding of an effect of AoA in all the tasks listed above must be explicable in these hypotheses. Inversely, if a hypothesis cannot explain the observed absence or existence of an AoA effect in a specific task, it can be excluded.

5 Locus of AoA effects

In the following I will evaluate the existing hypotheses regarding the locus of AoA focusing on how well they can explain obtained results. Drawing on studies that have employed different tasks, I will show the implications of these hypotheses in order to find weak points of, or more evidence for, the different approaches.

5.1 AoA and frequency effects: related or independent?

AoA affects word naming, picture naming, semantic classification and lexical decision. In some of these tasks the effect of AoA can be separated from that of frequency, however, in others this is not possible.

Brysbaert and Ghyselinck (2006) proposed that instead of dealing with one single AoA effect it is possible that what has been taken to be a single-locus effect might in fact reflects two different effects of AoA. One of these is frequency related and the other one frequency independent. Using two naming tasks Brysbaert and Ghyselinck found that when they presented words as stimuli, AoA and frequency were fully correlated. However, when presenting pictures to be named, AoA had a much stronger effect on reaction times than frequency did. Brysbaert and Ghyselinck (2006) compared the magnitudes of the effects of AoA and frequency on different tasks and postulated that AoA effects were "partly frequency related, partly frequency independent" (cf. the title of their study). According to their argument, frequency related AoA effects, which are AoA effects that are of the same magnitude as frequency effects, are those found in tasks that do not require a semantic analysis of the input in order to produce a single word. In generating a specific word, whilst accessing the semantic level, a frequency independent AoA effect can be found.

5.2 Phonological completeness hypothesis

5.2.1 Theory.

One early hypothesis that tried to make sense of the AoA effect on tasks that required a verbal output was the phonological completeness hypothesis. Brown and Watson (1987) found a significant effect of AoA on word familiarity ratings and word naming. They interpreted their results in favor of the phonological output as

the locus of AoA effects. According to their argument, phonological representations of early and late acquired words are stored qualitatively different. The phonological forms of early acquired words are stored more completely in the mental lexicon, whereas late acquired words must be assembled from a segmental representation. Therefore, retrieving a late acquired word will take longer than retrieving an early acquired word.

A necessary condition for obtaining an AoA effect under the assumption of the phonological completeness hypothesis is the access to phonological representations. AoA effects should not be observed in tasks that do not require access to the phonological level, for example semantic classification.

5.2.2 Evaluation.

The phonological completeness hypothesis can be discarded very quickly. The prediction that no AoA effect should be observable in a semantic categorization task because this task does not require access to phonology was not borne out. As seen in section 4.4, reliable AoA effects have been observed in a number of studies employing this task. In addition, direct evidence against the phonological completeness hypothesis comes from a study by Assink et al. (2003). They found significant AoA effects in a lexical decision task that compared a group of English native speakers with one of non-native speakers. Assink et al. argued that, if the phonological completeness hypothesis was correct, naming latencies of the non-native speakers, whose phonological representations of the later learned language would be stored in segments throughout, should not be affected by AoA. In contrast to this prediction no interaction of AoA and first language (English/Dutch) was found in an English lexical decision task. AoA had an effect of the lexical decision times of speakers whose phonological representations of a language could not have been stored completely in the early-acquired condition. This is not explicable in the phonological completeness hypothesis.

Hence, the phonological completeness hypothesis does not provide an adequate approach for explaining AoA effects. It could explain AoA effects in picture naming but the fact that AoA effects are observed in tasks that do not require access to phonology, such as semantic classification, cannot be explained in this hypothesis. Additionally, AoA, or, more specifically, order of acquisition effects in a second language, cannot be explained under the assumption that only early acquired words are stored as a phonological whole.

5.3 Lexical-phonological hypothesis

5.3.1 Theory.

The idea of a lexical-phonological locus of AoA effects was proposed by Barry et al. (2001). Barry et al. (2001) postulated, similar to the phonological completeness hypothesis, that the phonological representations of early acquired words were accessed or retrieved more easily than those of later acquired ones. They argued that this was the case because access to representations of early words does not require as much activation as that to representations of late acquired words. As the AoA effect is located at lexeme level, it predicts an effect of AoA in tasks in which the morpho-phonological representation of a stimulus needs to be accessed but none in tasks in which this is not the case (such as semantic classification).

5.3.2 Evaluation.

Barry et al. (2001) used a repetition priming experiment in order to explore the locus of AoA effects. They asked participants to name pictures. In one group of participants, this was primed by the prior naming of the same picture or the reading of the object's name. In addition, a control group was tested without this priming trial. Barry et al. (2001) argue that the effect of repetition priming is located at the lexical level. In the first experiment of their study they varied the AoA of the stimuli, controlling for frequency. The effect found during the first presentation (reading aloud or picture naming) replicated earlier findings for AoA in reading and picture naming: There was a significant effect of task such that participants were faster in reading than in naming. AoA resulted in faster latencies in the early condition and an interaction was observed, such that AoA had a larger effect on picture naming than on word reading. In the second presentation of the stimuli (picture naming), the effect of AoA was highly significant. The same held for the priming condition: Participants who had been presented with the picture before were significantly faster than the control group. A significant main effect of prime type was observed: Participants who had been primed with a picture were faster in naming than those who had been primed with a word. In addition there was a significant interaction between AoA and priming: The priming effect was larger for late acquired words than for early acquired ones. Barry et al. (2001) interpreted this interaction as evidence that the two effects, priming and AoA, shared the same locus, namely lexical retrieval.

Again, strong evidence against this hypothesis comes from tasks that do not require access to stored phonological representations but are affected by AoA, like semantic classification. These results cannot be explained by the lexical-phonological hypothesis because no lexical selection, the proposed locus of AoA, is required for semantic classification.

5.4 Neural network hypothesis
5.4.1 Theory.

In a number of simulations Ellis and Lambon Ralph (2000) investigated the effect of order of acquisition within a distributed connectionist framework. The network contained input and output layers of 100 units each that were connected to a hidden layer, containing 50 units. The network was trained to learn a large set of words. Critically, the training regime could be adjusted to simulate that some words are acquired earlier than others. Ellis and Lambon Ralph (2000) performed a variety of simulations, for example adding late patterns to early ones or replacing early patterns by late ones. Within the network, weights between input and output units were adjusted during the learning of early patterns. Activation in the intermediate layer had a starting value of 0.5 which was then altered by these adjustments. Late training had a smaller influence on the activation values as the network structure lost plasticity over time and was not able to represent late mappings as efficiently as early mappings. Ellis and Lambon Ralph proposed that this loss of ability to accommodate new material efficiently as time went by was the origin of the AoA effect. They underlined that this effect of order of acquisition should also be observable in other learning processes that do not result in language production (for an evaluation of this prediction see section 5.4.3). Lambon Ralph and Ehsan (2006) summarized this hypothesis and focused on the loss of plasticity (i.e. reduction of the strength of transfer). They argued that early acquired items benefit from the high plasticity of a network. The AoA effect can be explained by a partial reduction of plasticity, which means that late presented items still can be learned but not as efficiently as early ones. If the network underwent a complete loss of plasticity, a "critical period effect", the effect that after a certain period no new information can be learned, would result from this. However, this does not hold for lexical development, as new words can continuously enter the lexicon.

The neural network hypothesis can explain AoA effects by suggesting a reason for their occurrence and proposing an underlying mechanism. It is, however, difficult to test as it does not make as concrete predictions as localist accounts of AoA effects do. Two testable predictions can be derived of the neural network account. The first is that, as AoA and frequency operate similarly, and that these effects will never be observed independently, thus there will be no task that is affected by frequency but not by AoA and vice versa. The second prediction is the arbitrary mapping hypothesis. According to Zevin and Seidenberg (2002) and as found by Ellis and Lambon Ralph (2000) there is a reduced ability to transfer knowledge about early acquired items to late acquired ones whenever the mapping between input and output is arbitrary. The arbitrary mapping hypothesis predicts that AoA effects

should be found in tasks where knowledge about an early acquired word cannot help to produce an adequate output for a late acquired word. Therefore, picture naming should show a large AoA effect as the mapping between an entity and its name is completely arbitrary in most cases. In comparison, word naming, especially in languages with predictable orthography-phonology mapping or in words with regular grapheme-phoneme mapping, should show a reduced AoA effect. As the mapping between orthographic word forms and semantics is arbitrary as well, this hypothesis also predicts an effect of AoA in lexical decision tasks.

5.4.2 Evaluation.

The neural network hypothesis locates the AoA effect in the connections between semantics and phonology and predicts larger effects of AoA when mapping between input and output is arbitrary. Larger AoA effects can indeed be observed in picture naming whereas word naming does not yield a strong effect, especially not for regular mapping.

Chen, Zhou, Dunlap and Perfetti (2007) investigated word naming in Chinese for compound characters that consist of two subcomponents, a semantic and a phonetic radical. Predictability of semantics and pronunciation of these characters differ depending on which family the respective character belongs to. A phonetic radical family has as its members those characters with the same phonetic radical. Some families exhibit high regularity in pronunciation, others contain many irregular characters. Thus, predictability can be manipulated as an independent variable. This was done by Chen et al. (2007). They varied AoA and predictability (highly predictive/ non predictive) in a character naming task. They found significant main effects of both variables (naming speed was faster for early acquired and for highly predictive characters) and a significant interaction in the analysis by participants. This interaction consisted in slower naming latencies for late acquired non predictive characters than for early acquired non predictive characters while this difference was not significant for highly predictive characters. In a second experiment Chen et al. (2007) applied the same design to a semantic category judgment task in which participants were required to categorize characters according to whether their denotation was related to an action, an animal or a plant. They obtained similar results to the first experiment, namely significant effects of AoA and predictability as well as a significant interaction of both factors in the analysis by participants (Chen et al. accounted for the failure to observe significant by-item effects by the small amount of items, namely 14, that were tested). These results strongly support the arbitrary mapping hypothesis, showing a larger AoA effect for unpredictable mappings between input and output than for highly predictable mappings.

More support for the arbitrary mapping hypothesis comes from a study by Cortese and Kanna (2007). They performed a stepwise regression analysis with AoA as predictor for word naming and lexical decision latencies and accuracy. They found that AoA affected response latencies in both tasks but was a stronger predictor for lexical decision times than for word naming latencies. With regards to accuracy it did predict lexical decision accuracy but not word naming accuracy. Cortese and Kanna (2007) interpreted these results as support for the arbitrary mapping hypothesis, as the mapping between phonology and concepts (which, following their argument, would have to be accessed in lexical decision) is more arbitrary than between orthography and phonology.

As seen in the discussion of AoA effects in the section on word naming tasks, Turkish and Italian are both languages with highly predictable grapheme-phoneme conversion. However, while Raman (2006) did find a significant effect of AoA for Turkish, none was present in the study by Burani et al. (2007), who investigated Italian word naming. This cannot be explained by the arbitrary mapping hypothesis.

5.4.3 Order of acquisition effects as inherent feature of any learning process.

The neural network hypothesis predicts that effects of order of acquisition (OoA) should be found in any learning process in which the mapping between input and output is arbitrary. OoA effects have been investigated in studies that produced these effects under controlled conditions in a laboratory environment, which is what Lewis (2006) proposed after his criticism of factorial and regression experiments.

Stewart and Ellis (2008) presented checkerboards with patterns that belonged either into a category “A” or a category “B”. Participants had to categorize these stimuli over 8 blocks, each consisting of 96 trials. Stewart and Ellis found a significant advantage of those checkerboards that were introduced early in training compared to those that were introduced late. This advantage still remained significant after cumulative frequencies had been adapted. Similarly, Izura et al. (2011) conducted a study in which participants learned foreign words. During the learning sessions they controlled for cumulative frequency. They found significant effects of OoA in picture naming, lexical decision and semantic classification. Likewise, Moore and Valentine (1999) demonstrated significant OoA effects in reading names of celebrities, deciding whether a name referred to a famous person (though in these tasks OoA only reached significance in the analysis by participants), and deciding whether a presented face was that of a celebrity or not. These results support the hypothesis that AoA effects should be observed in any learning process.

Thus, the neural network hypothesis provides a useful account for AoA effects. It can generally explain their underlying mechanism and can also account for the occurrence of AoA effects in reading, picture naming, semantic classification and lex-

ical decision. This is because it predicts that AoA effects occur whenever frequency effects are present. However, findings like those by Raman (2006) are difficult to explain by the arbitrary mapping hypothesis, which is part of this theory.

5.5 Semantic hypothesis

5.5.1 Theory.

The semantic hypothesis was first put forward by van Loon-Vervoorn (1989, cited in Brysbaert, van Wijnendaele and de Deyne, 2000). She assumed the conceptual level as the locus of AoA. Van Loon-Vervoorn argued that in language acquisition the meanings of late acquired words are built on those of early acquired words. In that way the order of acquisition influences word production in so far that representations of early acquired words can be activated faster than those of late acquired ones. Brysbaert et al. (2000) argued that the fact that AoA seems to be highly correlated with semantic variables such as concreteness and imageability supports the idea of a semantic locus.

Steyvers and Tenenbaum (2005) developed a model of semantic growth that demonstrated the development of AoA effects in a network with non-distributed representations. They found a more central position in the network for those words that were acquired early than for those that were acquired late. This difference between early and late acquired words emerges because nodes that join the network early will acquire more connections than nodes that join it later. Within this network, high frequency words also show higher connectivity and the AoA effect on connectivity is more prominent for high frequency words. The difference between this model and that by Ellis and Lambon Ralph (2000) is that later learned items are not accommodated deficiently but rather not as well connected as early learned items. Hills, Maouene, Riordan & Smith (2010), in an analysis of adult associate norms, found that early acquired words are indeed better connected and in addition are the most contextually diverse in the learning environment. This was shown by the impact of AoA on the number of connections from a word to other words in adult association norms.

Locating the AoA effect at a semantic level predicts AoA effects on any task in which the conceptual level has to be accessed. These effects should be larger or smaller, respectively, depending on the amount of involvement of the semantic level.

5.5.2 Evaluation.

The semantic level is accessed in picture naming tasks, semantic classification tasks and it can be accessed in lexical decision and word naming tasks. The effect of AoA is largest in picture naming tasks. All of the results described above are

compatible with the semantic hypothesis. As seen, results from word naming studies are diverging as some studies have obtained significant results for AoA in word naming (Raman, 2006), whilst others did not (Burani et al., 2007). To assure that the semantic level could not be bypassed, as possible in single word reading, Juhasz and Rayner (2006) measured eye fixation duration during a (silent) sentence reading task. Within this task they manipulated frequency (high/low) and AoA (early/late) for target words. Dependent variables were:

- first fixation duration: duration of the first fixation regardless how many fixations followed
- single fixation duration: the duration of fixation if a word only received a single fixation during first reading
- gaze duration: accumulated duration of all fixations before the eyes left the word
- total fixation duration: sum of all fixation durations including regressions back to the word

AoA affected all of these variables significantly: All durations were shorter for early acquired words than for late acquired words (though for first fixation duration this effect was only significant in the analysis by participants). In sentence comprehending the meaning of a word has to be accessed. That distinguishes this task from word naming in which the semantic level can be bypassed. The results of this study are again compatible with a hypothesis that locates AoA effects at a semantic level and are again difficult to explain in a theory that favors the phonological output system.

Another study supporting the semantic hypothesis was conducted by Gullick and Juhasz (2008), who performed a cued recall task. This task investigated the effect of AoA on associated word pairs (pairs of semantically related stimuli that were controlled for frequency). During the experiment one of the words of each pair was given and the other one was supposed to be named. Independent variables were AoA of the cue word and AoA of the target word. Gullick and Juhasz argued that if early and late acquired words were connected differently within the semantic network then the semantic memory should be affected by AoA. They found significant effects of target AoA on response latencies, such that early acquired target words were produced faster than late acquired ones. There was a significant interaction of cue AoA and target AoA that consisted in faster latencies for the combination late cue AoA – early target AoA than for other combinations. Gullick and Juhasz explained this in the model by Steyvers and Tenenbaum (2005): Activation spreads between connected nodes and the lexical search is biased to more connected nodes. When early acquired words are activated the activation spreads more diffusely because they have more connections. When a late cue word is activated, it becomes easier to find an early target.

Brysbaert et al. (2000) also provided strong evidence in favor of an involvement of semantics as the operating stage of AoA. They employed a word-associate generation task as a semi-factorial design in which three lists were compiled, each manipulating imageability, frequency or AoA and controlling for the others. Participants were required to articulate the first word that came to their mind when a cue word was presented visually. All of the independent variables significantly affected naming latencies: Associations were generated faster for low frequency words, highly imaginable words and early acquired words. The inverse frequency effect is explained by the fact that low frequency words have more distinctive representations than high frequency words. The conditions that created longer generation latencies also yielded more different associates. The generation of associates strongly relies on the access to semantic information about a word. Therefore, these results can be considered as strong evidence for a semantic locus of AoA effects. More support for this hypothesis stems from the second experiment within this study, in which participants were supposed to categorize words with definable meanings and given names in a semantic classification task. Both, the effect of AoA and frequency were significant.

Ghyselinck, Custers and Brysbaert (2004) investigated the effect of AoA on a variant of the Simon paradigm that differed from word naming in that it required obligatory access to semantics: Participants decided whether a word appeared in uppercase or lowercase printing and responded by labeling it as “living” or “nonliving”. Response latencies were influenced by the congruity of the response with the stimulus presented (“living” as output for a living stimulus in the congruent, for a non-living stimulus in the incongruent condition and analogously for the “nonliving” output). Ghyselinck et al. (2004) found that the congruency effect was stronger for early acquired words than for later acquired ones. In accordance to the Steyvers and Tenenbaum (2005) model and as pointed out by Ghyselinck et al. (2004) this can stem from the fact that early acquired concepts have more connections within the semantic network and therefore their meaning can be activated faster.

Results from different studies seem to support the semantic hypothesis. Evidence against this locus of AoA does not come from tasks that do not require access to semantics but show an effect of AoA, but rather from a study that showed no effect of AoA when it can be assumed that the conceptual level was involved. Izura and Ellis (2002) performed a naming as well as a lexical decision task with bilingual Spanish-English speakers, whose first language was Spanish. It is assumed that within the bilingual lexicon there is one shared semantic system for both languages (La Heij, 2005). Thus, if AoA effects evolve at the semantic level they should be observed for the corresponding lexical entries in the same way for both languages, depending on AoA in the first language and regardless of AoA in the second lan-

guage. This was not confirmed. Izura and Ellis (2002) tested the naming condition (Spanish/English) between participants. They observed significant main effects of language and AoA as well as a significant interaction that consisted in a smaller difference in response latencies for AoA in Spanish than in English. Results of a second experiment showed the same effects in a lexical decision task (although the condition of language was only significant by items).

In a third experiment Izura and Ellis (2002) tested the effect for words that were acquired early in the first language (Spanish) and late in the second language (English) as well as those that were acquired late in the first but early in the second language. In second language learning, words that are necessary for adult everyday life (for example directions or vocabulary that helps buying things) are acquired early but they are acquired comparatively late in first language acquisition (and vice versa). In experiment 1, Izura and Ellis employed a lexical decision task using English stimuli. Independent variables were AoA of a word in English as a second language, English word frequency, word length and AoA of the word in Spanish as a first language. All had significant effects on decision latencies, except for AoA of the word in Spanish.

In experiment 3 Izura and Ellis varied language of presentation (Spanish/English) in addition to stimulus set (early Spanish - late English/ late Spanish - early English). There was a significant interaction of language and stimulus set: The group presented with Spanish words responded faster to early Spanish – late English words than to late Spanish – early English words. The group deciding on English words was faster responding to late Spanish - early English items than to early Spanish - late English items. This revealed that AoA only affected decision times of the respective language in which AoA was early. These findings cannot be explained by the semantic hypothesis without assuming separate conceptual representations of the two languages within the bilingual lexicon. This is incompatible with the existing evidence about the structure of the bilingual mental lexicon.

Additional evidence against the semantic hypothesis comes from a study by Menenti and Burani (2007). They claimed that the semantic hypothesis predicts larger AoA effects in semantic classification than in lexical decision, provided that the classification task requires extensive access to semantics. Employing a “living”/”non-living”- classification task and a lexical decision task and analyzing their results using a regression analysis they did not find such a difference. They interpreted their results as contradicting the semantic hypothesis and being explicable by the neural network and the lexical-semantic competition hypothesis (see section 5.6). Similarly, Catling and Johnston (2006) argued that a semantic locus of AoA could indeed explain the effects in different tasks but that it could not account for the differences in magnitude between these effects. They proposed an accumulation

of AoA effects, depending on how many stages of word production are accessed. (This account will be discussed in section 5.7).

As seen, a semantic locus could explain the AoA effects in all tasks that are listed in section 4. However, it cannot account for the findings by Izura and Ellis (2002) and it cannot explain the differences in magnitude between the AoA effects in different tasks.

5.6 Lexical-semantic hypothesis

5.6.1 Theory.

The lexical-semantic hypothesis draws on the difference in magnitude between frequency related and frequency independent AoA effects, as discovered by Brysbaert and Ghyselinck (2006). According to the lexical-semantic hypothesis, the frequency independent effect of AoA arises from competition at the lemma level that spreads activation to the conceptual level. In the model by Steyvers and Tenenbaum (2005) early acquired words are better connected within the network than late acquired ones. Therefore, late acquired words will have to face stronger competition at the stage of lemma selection. This theory predicts an AoA effect in tasks that require the selection of a single lemma. Additionally, as Juhasz (2005) pointed out, this theory expects the frequency dependent AoA effect to only occur when a frequency effect is present and to be of similar size. Thus the lexical semantic hypothesis predicts an AoA effect in all tasks. This effect should be of the same size as the frequency effect when the lemma level does not have to be accessed and it should be larger than the frequency effect whenever a lemma has to be selected.

5.6.2 Evaluation.

Belke, Brysbaert, Meyer & Ghyselinck (2005) used the semantic blocking paradigm in order to explore AoA effects. In this paradigm, blocks of pictures are presented that are semantically related or unrelated. A homogenous context involves blocked naming of stimuli belonging to the same category, whereas the heterogeneous context condition requires naming of items with no semantic relatedness. Participants have been shown to be generally slower for the homogeneous condition in this task (Kroll & Stewart, 1994; Damian, Vigliocco & Levelt, 2001). This is explained by the spread of activation and high competition at the conceptual and the lemma level. The variant of the paradigm used by Belke et al. (2005) made use of cyclically presented blocks of pictures (Experiment 1) and words (Experiment 3). There was no significant effect in word naming. In picture naming, by contrast, significant effects for cycle, context, and interaction of context and AoA were

found. The interaction consisted in a larger effect of context for late acquired words than for early acquired words. This is consistent with the Steyvers and Tenenbaum (2005) model: Early acquired lemmas compete with other early acquired words, late acquired ones have to compete with early, as well as late acquired candidates. Therefore, the inhibitory effects of semantic context should be larger in naming late acquired words. Other evidence in favor of this hypothesis comes from the fact that the prediction seems to be met that the effect of frequency and the effect of AoA are of approximately the same size in tasks which do not require access to the lemma level. Juhasz (2005) evaluated different tasks with regards to this prediction and found that, indeed, in tasks like word naming and lexical decision, frequency and AoA effects are of roughly similar size and are smaller than those seen in picture naming.

However, she introduced evidence against the lexical-semantic hypothesis by drawing on experimental results by Turner et al. (1998). They conducted two lexical decision experiments, using visually and aurally presented stimuli. Though the effect of frequency and that of AoA were similar in magnitude in the visual condition, this was not the case when stimuli where presented aurally. Here the effect of AoA was larger than that of frequency. Their study was criticized for the use of Kučera and Francis (1967) frequency norms by Zevin and Seidenberg (2002), who found that when applying Celex norms to the stimuli, early acquired words were of much higher frequency than late ones. Thus, deficient control for frequency cannot be excluded. However, this would not account for the difference between the results of the two experiments. According to Juhasz (2005), trying to maintain the lemma competition theory would mean that the discrepancy between lexical decision with auditory and visual stimuli must be accounted for. That means, as the effects of AoA and frequency differed in auditory lexical decision, it would have to be explained why this task should require selecting a lemma while visual lexical decision does not. Access to semantics is optional in lexical decision. In order to maintain the assumptions of the lexical-semantic hypothesis it would have to be hypothesized that semantics is more involved in auditory than in visual lexical decision.

Despite this weak point, the lexical semantic hypothesis can explain almost all findings of AoA as either being frequency related or evolving during lemma competition: The frequency related effect of AoA should occur in all tasks that exhibit sensitivity to effects of frequency, here lexical decision, semantic classification and word naming. The frequency independent effect of AoA affects tasks like picture naming, in which a specific lemma needs to be selected.

5.7 Two distinct loci, a single locus or accumulation of AoA?

As discussed, the assumption of a single locus of AoA effects can be discarded because of the observation of a frequency-dependent and a frequency-independent effect of AoA. Two different theories have been put forward to account for the varying effects in different tasks. Catling and Johnston (2009) hypothesized that the AoA effect accumulates depending on how many processing stages are involved in a task. For example in picture naming, more stages have to be accessed than in lexical decision or word naming. The magnitude of the AoA effect should vary depending on the number of stages involved in a task. Catling and Johnston (2009) held this hypothesis against the prediction made by the lexical-semantic hypothesis. Following their argument, this theory predicts that a jump in the magnitude of AoA effects should occur depending on the involvement of phonology (as two AoA effects are assumed and the task that required access to phonological representations also required selection of a single lemma). In order to test these predictions, they conducted 4 experiments.

In their experiments 1 and 2, Catling and Johnston (2009) employed tasks that only required access to structural information. A picture-picture verification task required participants to decide whether two pictures were identical or not. The 48 critical stimuli were matched on a variety of variables and were always presented in the 'different' condition. In order to avoid an effect of repetition priming, unrelated filler objects were used in the 'same' condition. In experiment 2, participants were required to decide whether an object presented was a real or an unreal object (with unreal objects being chimeric pictures).The effect of AoA was significant for both tasks, thus showing an effect of AoA at a perceptual level.

In experiment 3, Catling and Johnston (2009) were concerned with the magnitude of AoA effects in tasks that require access to semantic and structural representations. In an object-name verification task they asked participants to indicate whether a given picture was the corresponding one to a presented name. There was a significant effect of AoA (but see Charlard & Bonin, 2006, for different results). The fourth experiment consisted in an object naming task. The same procedure as in experiment 3 was used, except participants now were required to produce a verbal response to the presented picture. AoA had a highly significant effect on this task. Catling and Johnston (2009) then evaluated their results with regards to the differences of AoA effects across tasks. In order to do so, they calculated the effects sizes of each participant for each task and compared those between the separate tasks. Task type affected effect size significantly. The effects observed in naming were significantly larger than those seen in all other tasks. There were no significant differences between the sizes of the effect in picture-picture verification, real/unreal

classification or word-picture verification. According to the accumulation-hypothesis, brought forward by Catling and Johnston (2009), the effect size should have increased continuously. That was not the case; rather a jump of effect size between tasks that did not require access to phonology and those that did was observed. Because of this finding, Catling and Johnston (2009) interpreted their results in favor of the lexical-semantic hypothesis.

5.8 Discussion

Different hypotheses have been brought forward regarding the locus of AoA effects:

- the phonological completeness hypothesis
- the lexical-phonological hypothesis
- the neural network hypothesis
- the semantic hypothesis
- the lexical-semantic hypothesis.

As seen at this point none of these hypotheses can sufficiently explain all experimental results. However, these theories differ with regards to explicatory power. Assuming one locus of AoA does not seem to suffice to account for all observed effects. Brysbaert and Ghyselinck (2006) as well as Catling and Johnston (2009) provided strong evidence that at least two distinct loci of AoA have to be assumed. Any one-locus account, such as the semantic hypothesis and both the phonological completeness and the lexical-phonological hypotheses would face the problem of failing to explain why AoA effects are systematically observed even if the critical processing stage is not accessed.

The phonological completeness hypothesis and the lexical-phonological hypothesis cannot account for a number of findings of AoA effects without the access to phonological representations. Also the AoA effect in second language learning cannot be explained by the phonological completeness hypothesis because there is no reason to assume that early acquired words of a second language are stored differently from late ones. Similarly, the lexical-phonological hypothesis has to make further assumptions as to how AoA effects in semantic categorization or picture-picture verification tasks can be explained.

The neural network and arbitrary mapping hypotheses, of which the latter derives from the former, provide a good account as to when AoA effects should be observed. The prediction that the more arbitrary the mapping between input and output the greater the magnitude of the effect of AoA seems to hold in most cases. In addition, the neural network account offers a good explanation for the observation of AoA, or rather order of acquisition, effects in tasks that do not include language specific stimuli. However, Raman (2006) provided evidence against this claim by

showing an AoA effect when mapping between phonology and orthography was completely predictable. Thus, in order to maintain the arbitrary mapping hypothesis these findings have to be taken into account, either by identifying features of Raman's experimental design that may have caused the effect or by extending the existing theory so far that these effects can be explained.

The semantic hypothesis can explain the existence of AoA effects across the full variety of tasks. Even in word naming and lexical decision access to semantics is optional and thus might be the stage at which AoA operates in these tasks. However, the semantic hypothesis does not provide sufficient explanation for the differences in the magnitudes of the effects between tasks. In addition, the finding that OoA has an effect in a second language that depends on the OoA of words in this respective language, rather than the first one, cannot be accounted for by the semantic hypothesis without assuming different semantic systems for the two languages of bilinguals.

The lexical-semantic hypothesis can explain all observed effects of AoA as well and makes adequate predictions regarding the magnitudes of AoA effects in different tasks. However, it cannot account for the frequency independent AoA effect in auditory lexical decision tasks.

As seen, the hypotheses that can account for most of the findings of AoA effects, or the absence of these findings, respectively, are the neural network hypothesis and the lexical-semantic hypothesis. Menenti and Burani (2007), favoring the neural network hypothesis, pointed out the importance of directly comparing these hypotheses. Likewise, Juhasz (2005), though discarding the lexical-semantic hypothesis, came to the conclusion that more research needs to focus on the differences between the predictions of the neural network hypothesis and the model by Steyvers and Tenenbaum (2005). To my knowledge no such study has been conducted yet. This would be the next step in optimizing theories about the locus of AoA effects. Ellis and Lambon Ralph (2000) assign AoA effects to differences in quality between the acquisition of early and late presented patterns. In contrast, Steyvers and Tenenbaum (2005) assume quantitative differences between the connections of early and late acquired words, with early words being better connected than late ones due to a more central position within the network.

As seen, the neural network hypothesis does not make many testable predictions. The ones it does make are the co-occurrence of effects of AoA and frequency, and differences of the magnitude of AoA effects depending on the mapping between representations. As Belke et al. (2005) argued, their results are compatible with the arbitrary mapping hypothesis as well, as no effect of AoA was observed in word naming. Likewise, Juhasz (2005) claimed that, according to the lexical-semantic hypothesis, frequency and AoA effects of similar sizes should be found in all tasks that do not require lemma selection. It could be argued that both hypotheses might

be compatible, in so far as the neural network hypothesis might explain the mechanism behind the frequency related AoA effect and the lexical-semantic hypothesis the locus of the frequency unrelated effect. However, both hypotheses differ with regards to their underlying assumptions, namely the idea of loss of plasticity within a network over time (neural network hypothesis) or different positions of early and late words within a network (lexical-semantic hypothesis, corresponding to the model by Steyvers and Tenenbaum, 2005).

As arbitrary mapping, the strong association with frequency effects, and transferability to other learning processes are the only testable predictions of the neural network hypothesis, there is none that would not be consistent with the lexical-semantic hypothesis. One way to deal with this problem could be to further test the strong predictions made by the lexical-semantic hypothesis (as it assumes competition at the lemma level).

Recently, Abdel Rahman and Melinger (2011) found that competition can be induced in cyclically blocked picture naming for blocks of pictures that would not usually cause interference by competition, for example associatively related stimuli. Interference is induced by establishing a context in which the pictures would be semantically related. This context is created by providing a title before the presentation (e.g. “fishing trip” for the items bucket, coffee, river, stool). Abdel Rahman and Melinger found an interaction of title presentation and semantic relatedness in a task in which heterogeneous and associatively related blocks of pictures were supposed to be named. Participants were slower in the associatively related condition than in the heterogeneous condition. Importantly, this was only the case after the prior presentation of a title that created a meaningful context for the presented pictures. This effect was found even after six cycles had passed without a title, showing that semantic context effects can be established ad hoc.

These findings can be useful for testing the predictions made by the lexical-semantic hypothesis. Assuming the argument of this hypothesis, the following predictions can be made. Late acquired words have to face more competition than early acquired ones, based on their less central position in the network (late words have to compete with early as well as late words, whereas early words are stronger competitors and only have to compete against early words). When the lemma of a word is activated, lemmas sharing similar, by then co-activated, features at the conceptual level will also become possible candidates for selection. For early acquired words competition will be less strong than for late acquired words, resulting in faster selection of the former ones, or slower selection of the latter ones, respectively. The findings by Abdel Rahman and Melinger (2011) can be used to test whether the AoA effect is influenced by different levels of competition. This can be tested by adding the independent variable AoA (early/late) to the experiment conducted by Abdel Rahman and Melinger (2011) that had as independent variables context

(heterogeneous/thematically related), title (with title, cycles 6-12 /without title cycles 1-6), and cycle (1-12). The first 6 cycles should show no effect of context and an AoA effect of the same size as it is in picture naming. After the presentation of a title, an effect of context should emerge. Likewise, an interaction should be found. This should consist in a stronger influence of the related context for late AoA than for early. This interaction would suggest the same locus of the effects of context and AoA, namely lemma selection. This has already been shown by Belke et al. (2005), however, in this experiment it would be possible to rule out any other factor than competition as the origin of this interaction. This is because the effect does not occur for the same stimuli before competition is induced. Such results would thus support the model of semantic growth by Steyvers and Tenenbaum (2005) and the lexical-semantic hypothesis.

6 General discussion and future directions

The AoA of a word affects all language processing tasks. The production of single words in picture and word naming is affected by this variable, however, with varying magnitude. In order to gain more knowledge about the storage and processing of language it is therefore important to investigate this effect further and to control for it when trying to locate the effects of other variables.

Future studies will have to take limitations in experiments investigating AoA effects into account. Ideally, a study exploring effects of AoA should do so by training participants on new stimuli that can be controlled and actually be manipulated. During the training, cumulative frequency, imageability and as many other factors that were found to influence AoA (see Reilly, et al., 2007) as possible have to be controlled.

Regarding the locus of AoA effects, any one-locus account can be discarded in favor of a two-loci or multiple-loci approach. This is because two effects of AoA have been observed: a frequency related one and one that is frequency independent (Brysbaert & Ghyselinck, 2006). There are two hypotheses which can explain most findings of AoA effects adequately: the neural network hypothesis (Ellis & Lambon Ralph, 2000) and the lexical-semantic hypothesis (Belke et al., 2005). These would ideally be compared directly by investigating whether a loss in plasticity in the network results in an encoding of late acquired words that is not as efficient as that of early acquired words (Ellis & Lambon Ralph, 2000), or if the position of late acquired words is not as central in the network as that of early acquired ones (Steyvers & Tenenbaum, 2005). However, as the testable predictions made by the neural network hypothesis are also consistent with the lexical-semantic hypothesis, such a direct comparison is not possible. Thus, predictions made by the lexical-semantic hypothesis will have to be tested further. The next step in AoA re-

search will lead to exploring whether the frequency independent effect of AoA actually can be shown to arise of competition during lemma selection or not.

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