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RESEARCH ARTICLE

Semantic Priming with Homonymous Nouns: Hints of Clarifying the Issue of Selective vs. Non-Selective Priming

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In this study, ways of accessing information about ambiguous words were tested. The non-selective access hypothesis states that all meanings of an ambiguous word are activated for retrieval. In contrast the selective access hypothesis predicates that only the meaning that fits the semantic context is accessed. To test this, 29 students (Age: 21.7 years [*SD* = 3.09]; 12 males, 17 females) were given a lexical decision task in order to record reaction times. Each trial had three stimuli while the second stimulus consists of a lexical ambiguity (e.g., bank). We found no difference in reaction times and error rates between conditions with and without semantic association, which favours the non-selective access hypothesis.

Keywords: ambiguity; selective access; non-selective access; priming; lexical decision task

Introduction

Languages often contain words that share the same sequence of letters but have different meanings. For example, the word "iron" can be interpreted as a metal which is used to produce steel, or a tool which is heated up to remove wrinkles from clothes, but there are also other meanings. In everyday life, people can easily encode these words by semantic context. If the context is clothing, the "iron" is clearly identified as the object to iron clothes. The question of interpreting ambiguous words gets interesting in cases where the context is unclear or not shown. The previous research on lexical ambiguity, which names the circumstance that a similar spelled word describes two or more distinct meanings, leads to many different hypotheses of how access to ambiguous words works. Two of these theories are the selective access (Garden Path Theory; Lashley, 1951) and non-selective access hypothesis (MacKey, 1966, 1970). While the selective access hypothesis states that only the meaning that fits the semantic context is accessed, the non-selective access hypothesis anticipates that all possible meanings of an ambiguous word are accessed (Black, 2001; Black et al., 2013; MacKey, 1966, 1970; Meyer & Schvaneveldt, 1971; Schvaneveldt, Meyer, & Becker, 1976). The most frequent form of ambiguous words is homonyms, which exhibit more than one distinct meaning of a word (e.g., iron).

A great amount of research already exists that targets the processing of either phonological or lexical ambiguity (De Groot, Delmaarm, & Lupker, 2000; Foss, 1970; Frost, Feldman, & Katz, 1990; Giora, 1999; Libben & Titone, 2009; Schvaneveldt et al., 1976). While lexical ambiguity is described as a word with more than one meaning (e.g., the homograph "iron"), phonological ambiguity means that two differently written words are pronounced similar or the same (e.g., the homophones "see" and "sea"). For an example, Schvaneveldt and colleagues (1976), as well as Black (2001) and Black and colleagues (2013) found evidence, using a lexical decision task, that the access to homographs is selective. In contrast, Foss and Jenkins (1973) showed evidence for non-selective access. They used a phoneme monitoring system, where participants had to press a button if they heard a phoneme to which they should be attentive (Foss, 1970). In this way, they illustrated that a context given ahead of the stimulus presentation did not result in different reaction times. Another technique of testing lexical access is to name the colour of the ink a word is written in (like the Stroop task; Stroop, 1938), then name the presented word and measure the interference via reaction times (Conrad, 1974; Warren, 1972). With this paradigm, Warren (1972) showed that the semantic context (category membership) is relevant for the processing of observed terms. However, studies including those aforementioned and especially those using the colour-naming technique, were criticised and it was suggested that the frequency and length of words as relevant influences should be controlled for (Mehler, Segui, & Carey, 1978). Correspondingly, another example of a more recent finding shows that the access to

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ambiguous words depends not only on the context itself, but also on the frequency of the targeted meaning as well (Bedny, Hulbert, & Thompson-Schill, 2007). Such criticism resulted in the important research task, which is to create standardized norms and corpora for semantic contents. These norms can then be used for controlling word frequency, word length or other semantic contents (Church & Hanks, 1990; Nelson, McEvoy, & Schreiber, 2004).

Within another study, evidence of non-selective access was found. In this example, participants had to learn word pairs whereby the author presented the first word of the pair for 60 ms and measured reaction times for the participant responding to the second word of the pair (Underwood, 1980). No differences in reaction times between context concordant or discordant stimuli were found in this study, thus supporting the non-selective access hypothesis. To summarise, there are many different designs (including priming context with sentences or just words) trying to show how lexical access to homonyms works, but there has been no consolidated answer thus far. It is further important to mention that almost all of the research addressing lexical access of ambiguous words to date has been completed with ambiguity in the English language whereas the present study will examine these effects within the German language. This is an important point as several studies have found evidence for non-selective access in bilingual participants with regards to interlexical homographs (De Groot et al., 2000; Libben & Titone, 2009). In addition, it is also significant as almost all research since the early 2000's on the question of selective or non-selective access has been completed in the field of bilingualism (De Groot et al., 2000; Libben & Titone, 2009; Mishra & Singh, 2014; Moon & Jiang, 2012; Tamaoka, Miyatani, Zhang, Shiraishi, & Yoshimura, 2016; Von Holzen & Mani, 2012; Wu, Christino, Leek, & Thierry, 2013).

Cognitive Models of Semantic Activation and Semantic Association

In order to understand the way of accessing semantic content, it is important to show models of how semantic accessing works. In the following, we will refer to a few models and pieces of work that may have an impact on our study: the search model, the works of Simpson (1984, 1994) and the associative read-out model. The search model (Forster & Bednall, 1976; Rubenstein, Garfield, & Millikan, 1970) states that the access to words depends on the frequency. In a search process, the mental lexicon would be searched until the presented word is found. Forster states that the mental lexicon is built in an order of frequency; this means that in the process of accessing words, the most frequent ones are found fastest because they occur more often. This hypothesis was confirmed many times even in the context of ambiguity (Forster & Bednall, 1976; Hauk & Pulvermüller; 2004; Rubenstein et al., 1970; Stanners & Forbach, 1973). In this instance, if participants decide whether a word is ambiguous or not, reaction times were faster on ambiguous words than on non-ambiguous words. This effect is explained by the need of participants to search the whole lexicon for a second meaning (which does not exist) when a non-ambiguous word is presented (Forster & Bednall, 1976).

It is also important to point out that there is already some research that shows the possibility of an activation of more than one meaning of ambiguous words, without stating non-selective access (Simpson, 1984, 1994). These pieces of research show that first, there is no consolidated answer to the research question as to whether selective or non-selective access provides a better explanation; and second, that two meanings of an ambiguous word can be activated. To sum it up, Simpson (1994) states that one meaning can be activated by the (relative) frequency of that meaning, while the second meaning can be activated because of its meaning in the sentence context. Following that explanation, it can be suggested that the predictability of a (target) word plays an important role in the context of comprehending and interpreting a sentence (Simpson, 1994).

Additionally, according to the associative read-out model (AROM; Hofmann & Jacobs, 2014; Hofmann, Kuchinke, Biemann, Tamm, & Jacobs, 2011) cognitive processing has four layers of activation: a feature, letter, orthographic word, and semantic layer. The first three layers correspond to an interactive activation and competition model (IAM; Burton, 1994) and describe how a word is recognised. The fourth layer represents the recognised word, activating associated words and increasing the activation of the primary word (Hofmann et al., 2011). It is important to note that there is no need for a situational context, as associated words (which can also give context) will increase the activation level. All these models and suggestions make it important to define what an association between a word or a sentence and a target is.

Associated words are defined by Quasthoff, Richter, and Biemann (2006) as occurring significantly more often together within 43 million sentences, as would be expected by their single frequency. This is consistent with the Hebbian learning theory, which states that, on a neuronal layer, two neurons that are activated at the same time probably belong together (Hebb, 1949). Evidence of co-activated neurons that emerge in the learning process was found, thus showing that the co-occurrence of words can be associated with the co-occurrence of the activation in neurons (Garagni, Wennekers, & Pulvermüller, 2009; Kotz, Cappa, von Cramon, & Friederici, 2002; Milner, 1996).

Associations can be direct or indirect: first-order co-occurrences are the direct associations between two words (e.g., "bee" and "honey"), whereas when two words are second-order co-occurring they are indirectly associated if they have few or many mutual associations but no direct association (e.g., "bee" and "bread"; Hofmann & Jacobs, 2014). To stay with the example of the word "bee", it could be associated with the word "bread" in a second-order co-occurrence with the connection between these words potentially being the word "honey", so as the association is not directly but indirectly via another directly associated term.

In an experimental setting in which participants learn words in a first phase and in a second phase and decide if a presented word was learned before or not, the authors predicted according to the AROM (Hofmann & Jacobs, 2014; Hofmann et al., 2011), that participants would respond with "yes" (the word was learned) more often if the particular word had many co-occurrences with words in the presented stimulus set and controlled frequency. In contrast, "yes" would be responded less often if the particular word had few or no co-occurring words in the learned stimulus set (Hofmann et al., 2011). This showed evidence that this prediction can be confirmed and that co-occurrences (or associates) are important for further research.

As such, the AROM may be used to explain both the selective and the non-selective access to lexical units. On the one hand, for selective access a presented context could activate only one meaning of a homonym via spreading activation (see spreading activation theory by Collins & Loftus, 1975). In short, this theory states that the mental lexicon in humans is based on a neural network, and so activation of one word would lead to the activation of associated words by activating the specific neuronal network (Collins & Loftus, 1975; Garagni et al., 2009; Hutchison, 2003; Kotz et al., 2002; Milner, 1996). It is thought that this is because the given context shares many co-occurrences with the target, while the other meaning either does not reach the activation threshold within the network or is inhibited (Collins & Loftus, 1975; Hutchison, 2003). On the other hand, a given situational context could also be unimportant if the target has many single co-occurrences. These co-occurrences would activate the semantic "context" within the mental lexicon, represented by co-occurring other words in the stimulus set, and as such, trigger the thresholds of more, related meanings (the context-prime meaning and the target meaning) via spreading activation. This afore mentioned case would lead to the assumption that context through co-occurrences are more important to predict the access of homonymous words than the completely situational semantic context is. As such, this is the theoretical speculation which has led to the present study.

Current Study

This study will examine whether the selective or non-selective access hypothesis to homonyms can be supported with second-order co-occurrence associations in a lexical decision task. To the best of our knowledge, this is the first study which uses second-order co-occurrences for semantical associations between prime, target, and homonym. While we examine exclusively single words as primes and no sentences, the associations between the presented words (meaning second order co-occurrences) will give the context and predictability to the presented words following this. In a case of showing three words (prime – ambiguous word – target) in a context congruent condition, the target shares the same semantic association with the ambiguous unit as the prime does. While in a context incongruent condition, the target has a different association with the ambiguous unit as the presented prime (see **Table 1**). Targets in a non-prime condition (no context) are not associated with either the homograph or the prime. In a non-word condition, the target is not an existing word and can be orthographically legit and pronounceable or a random letter string (see **Table 1**). Further details are provided in the procedure and stimuli section.

Following the Search Model (Forster & Bednall, 1976; Rubenstein et al., 1970), selective access would be predicted to occur if primes of only the most frequent meaning of the homonyms are used and the meanings are not equally frequent. It should take longer for the participants to access the less frequent meaning in the context incongruent condition, and so the reaction times would be higher in comparison to the context congruent condition. Similarly, if the findings of Simpson (1984, 1994) are considered (activation of one meaning because of its frequency and one because of its relevance to the context), one could assume that the same effect would occur when the most frequent meaning of a homograph is primed. Whereas if two meanings are activated, one by their relative frequency and one by the predictability within the distinct context, the less frequent meaning should take longer to access (selective access). Such an effect should occur regardless of the way a lexical decision task uses words or sentences as primes.

Both predictions work with the given context to primes and predictability or the frequency to targets. However, there is one more prediction that can be offered with the help of the AROM. In the present study, the aim was to test the access of ambiguous words with associates in second order co-occurrences. Predictions of the Search Model (Forster & Bednall, 1976; Rubenstein et al., 1970)

Table 1: Examples of the study conditions.

Conditions	Word examples		
	prime	**ambiguous unit (homograph)**	**target**
Context congruent	money	bank	coin
Context incongruent	money	bank	duck
Non-prime	money	bank	cake
Non-word legit	money	bank	loqib
Non-word random	money	bank	lwqbp

Note. For a better understanding, the examples are not in the German language; the stimuli used were in German. Bank has the two dominant meanings of a financial institution and a resting place (bench).

and the work by Simpson (1994) do not fit in for second-order co-occurrences exhaustively. This is intensified by the used paradigm, which induces context not by sentences but by single words as second-order associations to the targeted homographs. Accordingly, the predictability and hence the reaction times should depend on the (relative) frequency and the number of associated words.

In contrast to first-order co-occurrences, the second-order co-occurrences are not directly associated with each other and according to the AROM the order of co-occurrences should not provoke a difference. If the single lexical associations were to be more predictive than a whole context of sentences, it would be an important finding. Such evidence would underscore our prediction, as we expect non-selective access to occur, predicting no facilitation by context given through second-order associated words and resulting in similar reaction times for a context congruent and context incongruent condition. According to these hypotheses of non-selective access, responses in the primed conditions will be faster than in the non-prime condition and the orthographical legit non-word condition; whereas reaction times for random string non-words should be fastest because no search in the mental lexicon is needed or initiated. For additionally measured error rates, we expect non-primed words and orthographical legit non-words to score highest, while random string non-words are expected to show the lowest error rates.

Methods

Participants

Subjects in this study were 29 (12 males and 17 females) students from the University of Wuppertal. Participants were recruited via social media and announcements in lectures. Non-German native speaking was an exclusion criterion since German word recognition was a requirement of the experiment. As exclusively university students participated, we did not check the individual reading level of each participant but assumed it to be acceptable for the purposes of the present study. A second exclusion criterion was an age lower than seventeen and higher than thirty years to prevent a potential effect of ages. These cut-off values (17-30 years) were chosen at random but with regards to some literature on age differences in reaction times (Howard, McAndrews, & Lasaga, 1981; Hultsch, MacDonald, & Dixon, 2002; Klein, Fischer, Hartnegg, Heiss, & Roth, 2000; Pierson & Montoye, 1958). The mean age of participants was 21.7 years (SD = 3.09) and all participants gave written consent for their participation. For taking part in the experiment the participants were given course credit and a bar of chocolate.

Materials

For programming and running the experiment, the software PsychoPy (Version 1.81.03) was used (Peirce, 2009). Tasks were completed by a maximum of three participants at a time, in three discrete laboratories, on three identical computers with a display size of 19" and

Table 2: Means and standard deviations of the number of co-occurrences, word length, frequency and syllable of primes and targets for the conditions context congruent, context incongruent and non-prime.

Variable	Conditions					
	Congruent		Incongruent		Non-prime	
	M	*SD*	*M*	*SD*	*M*	*SD*
Primes						
Co-occurrences	16.566	6.207	10.600	5.642	14.400	8.548
Word length	5.967	1.160	6.267	1.507	6.267	0.935
Frequency	11.233	2.107	12.267	2.107	12.533	2.240
Syllable	2.100	0.662	2.067	0.583	2.000	0.643
Homographs						
Co-occurrences	–	–	–	–	–	–
Word length	5.533	1.391	5.267	1.391	5.233	1.455
Frequency	11.200	2.326	10.567	2.326	11.033	2.326
Syllable	1.633	0.556	1.667	0.479	1.667	0.479
Targets						
Co-occurrences	16.533	8.299	14.067	7.455	0.000	0.000
Word length	6.200	0.887	6.200	0.961	6.200	0.761
Frequency	12.033	1.027	12.067	1.027	12.033	1.129
Syllable	2.100	0.403	2.133	0.571	2.133	0.507

Note. Context congruent, incongruent, and non-prime conditions had 30 trials each. Hyphens indicate a non-determinable number (homographs number of co-occurrences with the homograph).

a display resolution of 1280 × 1024. The average viewing distance was 65 cm and was kept as constant as possible during the experiment. Moreover, due to natural light variance, shutters were closed before the arrival of participants. For the purposes of demographics, participants completed a questionnaire providing information about age, sex, and native language. After completing the experimental task, participants were asked to guess the aim of the experiment and to agree to usage of their data anonymously and exclusively for scientific purposes.

Stimulus Selection

Since we have not had access to a tested set of stimuli, a new stimulus set had to be created. Like Schvaneveldt and colleagues (1976), in the present study, word triplets were used for a lexical decision task in which the second stimulus presented in each trial was a homograph (for examples see **Table 1**). All prime and target words were extracted from the Projekt Deutscher Wortschatz (Project German Lexicon; Quasthoff et al., 2006) and were selected by face validity; all targets were controlled for length, frequency and syllable (for an overview see **Table 2** and **Table 3**), while orthographical regularity was not controlled.

Out of 100 frequently used homonymous German nouns, 90 were used for the experimental phase and 10 for a practising phase completed directly prior to the experimental phase. The homographs for the practising phase were words that had too few co-occurrences or their frequency did not fit in the stimulus set. To test the hypothesis, second order co-occurrence nouns for each homograph were utilized as targets and primes. We decided to consistently prime the homographs with the more frequent of its meanings. The selected primes and targets covered up to two dominant semantic meanings of each homograph and represented second-order co-occurrences of the homograph. An example is the German word “Arme”. The two dominant semantic meanings are “der Arm” (“arm”, as a body part) and “der Arme” (“the poor one”). A prime could be the word “help” which should semantically activate the meaning of “the poor one”; a target in this context could be “addiction” for the same meaning or “legs” for the meaning as a body part.

The 90 trials with real words as targets each contain one-word triplet consisting of a prime, a homograph, and a target word. The 90 trials were divided into three conditions, so that each condition provided 30 trials. In the first condition, the first and third word were semantically related to the one same meaning of the homograph in between (context congruent; e.g., money [prime] and coin [target] for bank [homograph]). In the second condition, the first word was linked to one meaning of the homograph while the third word was linked to another distinct meaning of the homonym (context incongruent; e.g., money [prime] and duck [target] for bank [homograph]). Finally, in the third condition the first word was linked to one distinct meaning of the homonym while the third word was not associated with the respective homonym in any common way (non-prime; e.g., money [prime] and cake [target] for

Table 3: Means and standard deviations of the number of co-occurrences, word length, frequency and syllable of primes and targets for both non-word conditions.

Variable	Conditions			
	Non-word orthographically legit		Non-word random strings	
	M	*SD*	*M*	*SD*
Primes				
Co-occurrences	6.778	13.628	8.067	11.529
Word length	5.733	1.684	5.755	1.171
Frequency	11.222	3.323	11.289	3.293
Syllable	1.800	0.757	1.867	0.548
Homonyms				
Co-occurrences	–	–	–	–
Word length	5.467	1.254	5.800	1.307
Frequency	10.600	2.490	10.533	2.332
Syllable	1.800	0.694	1.778	0.599
Targets				
Co-occurrences	–	–	–	–
Word length	6.178	0.778	6.267	0.986
Frequency	–	–	–	–
Syllable	2.267	0.618	–	–

Note. The non-word condition had 45 orthographically legit and 45 orthographically non legit words. Hyphens indicate a non-determinable number (e.g., frequency or co-occurrence of a non-word).

bank [homograph]). Further to this, 90 non-words were created for a fourth condition (distractors) of the lexical decision task, where half (45) of these non-words were pronounceable and orthographically legit (e.g., RODGAF) and half were random letter strings (e.g., RPSCH). In the non-word trials, the first and second word were semantically linked (especially with first order co-occurrences) but the second word was not necessarily a homograph. All non-word trials were used as filler trials. Overall, each participant completed 180 lexical decision trials.

Procedure

The experiment took place in the laboratory rooms of the University of Wuppertal and potentially influencing environmental factors, such as light and temperature, were controlled. Participants were informed of the procedure and the anonymity of their data. The opportunity to withdraw from the study at any time was offered and written consent was obtained. A demographic questionnaire was also completed by the participant. The experiment began with a standardized oral instruction with which the participants were informed about the practising phase, to become familiar with the task, followed by a short pause, leaving time to ask possible questions before starting the experimental phase. Afterwards, the experimenter left the room and the experiment started.

First, the participant was presented with a display of written instructions, informing them about the progress of the experiment. The lexical decision task was initialised by the press of a button (space bar) by the participant. A white fixation cross was shown at the beginning of each trial for 1.5 seconds. Each stimulus was presented solely in the middle of a black screen for 250 ms with 30 ms of black screen between the stimulus presentations (see **Figure 1**).

Measurement of reaction time started after the third stimulus of a word triplet disappeared from the screen and participants had to decide whether the third word of the presented triplet had been a word or a non-word. The decision was made by pressing the “D” key on a standard QWERTZ computer keyboard for a word and the “K” key for a non-word. After each decision, the fixation cross appeared again and the next trial started. All trials (in the practising and the experimental phase) were presented in the same order to all participants; as such, possible effects of position would be similar for all participants and not confounding for the results. The constant order was created randomly by usage of the random number command in Microsoft Excel. After the practise phase, a screen appeared introducing the experimental phase and offering the opportunity to ask questions. Alternatively, the experiment could begin if the participant pressed the space bar. After the experimental phase, participants were informed about the purpose of the study, remunerated, and thanked.

Results

Statistical Analyses

Reaction times and error rates were analysed only for the experimental phase; the practise phase had been ignored because of its function to allow the participants to become familiar with the given task. For each participant, the mean reaction time for the context congruent, context incongruent, the non-prime condition and the two non-word conditions was calculated. Reaction times were removed from statistical analysis if these differed by more or less than two standard deviations from the participant and condition specific mean reaction times. Reaction times of trials that were not answered correctly (e.g., a non-word classified as a word) were removed and were also not included in calculations of the participant and condition specific mean reaction times; only correct answers were considered. Furthermore, four participants were excluded completely from analysis because for one participant the error rate was near chance (48.8%), while for the other three participants the mean reaction times were higher than two standard deviations of the conditions mean reaction times. Data for 25 participants was analysed. For mean comparisons on the level of participants, an alpha level of 0.05 was used for global testing. For post hoc between group testing, a Bonferroni alpha correction was used. The adjusted alpha level was $\alpha = .005$.

The probability of error was estimated by overall errors within groups. Tested by binomial tests, seven words (three congruent/two incongruent/two non-prime) had to be excluded from the analysis because of higher error rates than estimated under binomial distribution $B(n, p)$,

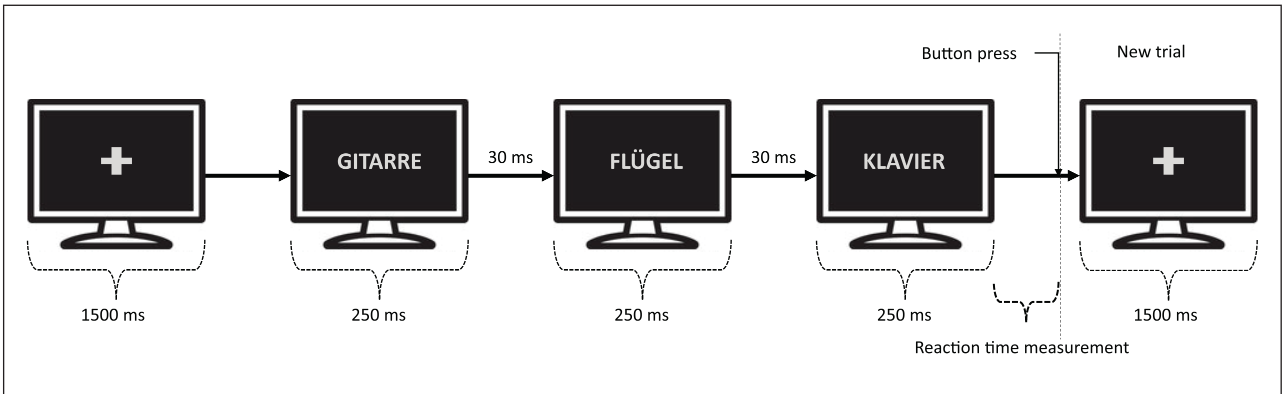

Figure 1: Overview of the procedure.

where 'n' is the sample size and 'p' the empirical probability of errors in the condition. For the context congruent condition the distribution was *B*(28, .032), for the context incongruent condition *B*(28, .046) and the non-prime condition *B*(28, .067). At least 27 trials remained for the congruent, 28 trials for the incongruent and 28 trials for the non-prime condition. For the non-word conditions, four non-words (three orthographical legit, one random string) had to be excluded from the analysis for the same reason. The binomial distributions were *B*(28, .053) and *B*(28, .014) for the orthographical legit and the random string non-words, respectively. 42 trials remained for the orthographical legit and 44 trials for the random string condition. The error rates were computed to percentages in order to make the different trial quantity between the four conditions comparable.

Reaction Times

A repeated measures analysis of variance (ANOVA) was applied to test mean differences in reaction times. The within subject factor was the condition type (context congruent, context incongruent, non-prime, non-word legit, non-word random string). The requirement of normal distribution of the residuals is met as evidenced by Kolmogorov-Smirnov Tests (see **Table 4**).

Mean reaction times and their standard deviations are displayed in **Table 5** and **Figure 2**. Sphericity could not assumed to be given, tested by Mauchly's sphericity test ($p < .001$; Greenhouse-Geisser epsilon: $\varepsilon = .517$). Therefore, the Greenhouse-Geisser correction for degrees of freedom was used (Greenhouse & Geisser, 1959). The repeated measures ANOVA for within subject comparison indicated a significant main effect for conditions, $F(2.070, 49.674) = 14.503$, $p < .001$, partial $\eta^2 = .377$ Post hoc t-tests with Bonferroni alpha-adjustment were used to identify differences between the within subject conditions. Results indicate that the mean reaction time of congruent triples was significantly lower than the mean reaction time of non-prime triples ($p = .001$). Furthermore, the mean reaction time of the incongruent trials was significantly lower than the non-prime condition ($p = .002$). The comparison of the congruent with incongruent condition revealed no significant difference ($p = .334$).

The reaction times for the orthographical legit non-words were significantly higher than the context congruent condition ($p = .021$) and the random string non-word condition ($p < .001$). Lastly the random strings non-words had significantly faster reaction times than the non-prime words ($p = .002$).

Error Rates

For the analyses of the error rates, the absolute error rates were transformed into percentage error rates to facilitate comparisons. The requirement of normal distributed residuals is not met (see **Table 4**) and so, for the overall comparison, data were analysed with Friedman's test (Friedman, 1940). For post-hoc comparison of all groups, Wilcoxon signed-rank tests were computed as well (Wilcoxon, 1945). For mean error rates in percent see **Table 5** and **Figure 3**.

Table 4: Statistics of the Kolmogorov-Smirnov tests for each condition for reaction times and error rates.

Conditions	Reaction time			Error rate		
	Test-statistic *d*	*df*	*p*	Test-statistic *d*	*df*	*p*
Context congruent	.123	25	.200	.282**	25	.001
Context incongruent	.149	25	.157	.200*	25	.010
Non-prime	.150	25	.150	.198*	25	.027
Non-word legit	.138	25	.200	.229***	25	<.001
Non-word random	.127	25	.200	.373***	25	<.001

Note. Level of significance: $\alpha = .05$. $p < .05$*, $p < .01$**, $p < .001$***. Abbreviations: *df* = degrees of freedom, *p* = level of probability of more extreme values of the test-statistic.

Table 5: Means, standard deviations and standard error of reaction times in milliseconds and error rates in percent.

Conditions	Reaction time			Error rate		
	M	*SD*	*SE*	*M*	*SD*	*SE*
Context congruent	461.774	122.462	24.492	3.556	3.292	0.658
Context incongruent	482.272	142.748	28.549	5.143	4.384	0.878
Non-prime	554.868	194.969	38.993	6.857	5.249	1.050
Non-word legit	532.547	145.608	29.121	3.238	3.819	0.764
Non-word random	428.185	85.241	17.048	1.091	1.751	0.350

Note. All reaction times are measured in milliseconds and error rates in percent. Abbreviations: *M* = mean; *SD* = standard deviation, *SE* = standard error.

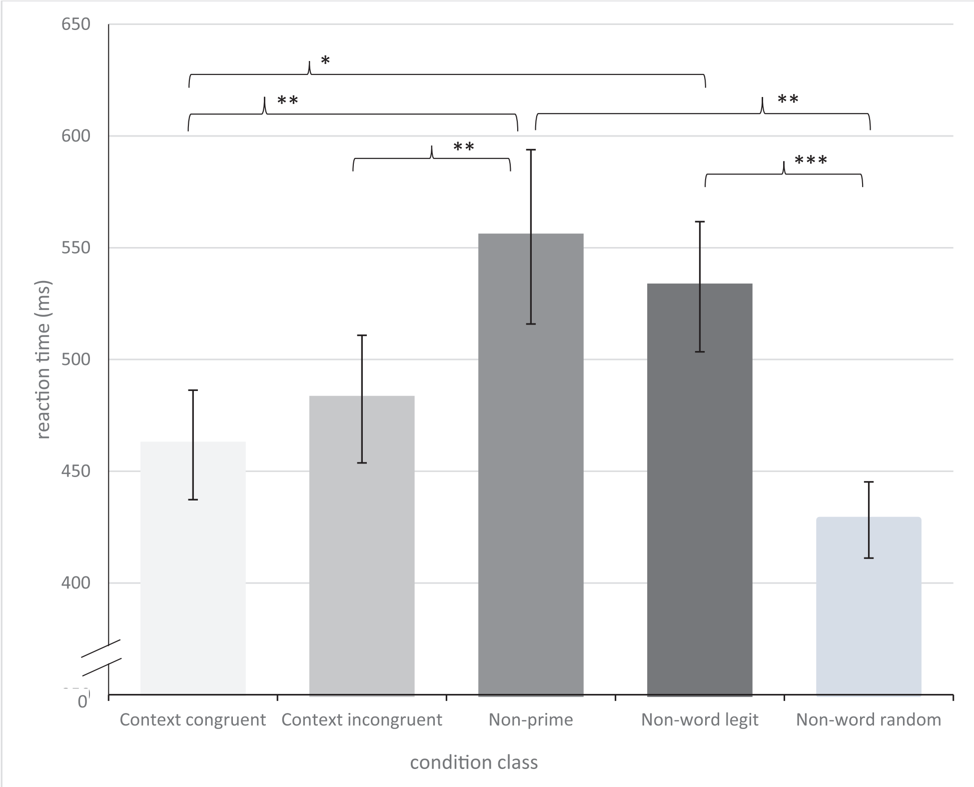

Figure 2: Mean reaction times for context congruent, context incongruent, non-prime and the two non-word conditions. Error bars represent one standard error. $p < .05^{*}$, $p < .01^{**}$, $p < .001^{***}$.

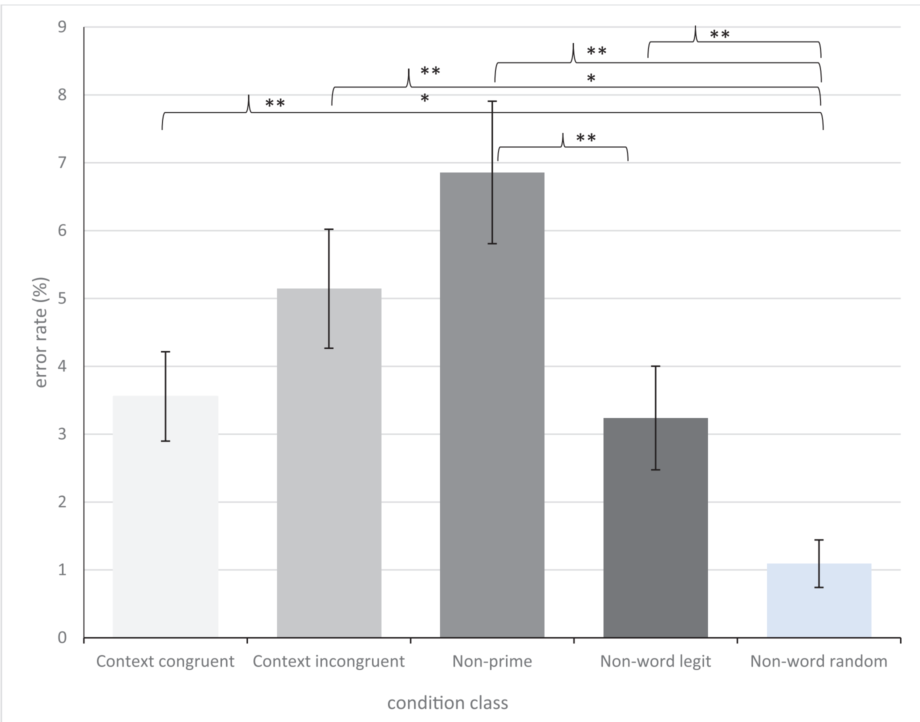

Figure 3: Mean error rates in percent for context congruent, context incongruent, non-prime and the two non-word conditions. Error bars represent one standard error. $p < .05^{*}$, $p < .01^{**}$, $p < .001^{***}$.

The Friedman test for nonparametric analysis showed a significant main effect of the factor condition on the error rate, $\chi^2(4) = 34.362$, $p < .001$. The Wilcoxon comparison tests showed significant lower error rates for random string non-words than for the congruent condition ($p = .002$), the incongruent condition ($p < .001$), the non-prime condition ($p < .001$) and the orthographical legit non-words ($p = .002$). The error rates for the orthographical legit non-words was significantly lower than the non-prime condition error rates ($p = .008$).

Discussion

The aim of the present study was to show whether the processing of homonymous words, primed with second-order co-occurrences, was of selective or non-selective nature. Following the implications of the associative read-out model (Hofmann et al., 2011), we generated the hypotheses that lexical access in a lexical decision task (Meyer & Schvaneveldt, 1971) would be non-selective, if second-order co-occurrences were used as prime stimuli. This non-selective access would be mediated by the activation of both associated meanings of an ambiguous word (Collins & Loftus, 1975; Hutchison, 2003). Furthermore, it was predicted that targets in the non-prime condition and orthographical legit non-words would be processed slower, for the reason of not having any associations, so that no priming effect occurs. According to the search model of lexical access (Forster & Bednall, 1976; Rubenstein et al., 1970), it would take longer to search for a less frequent, non pre-activated word in the mental lexicon. It would also take longer if an exhaustive search is initiated in mental lexicon, which would be necessary during the nonexistence of the presented letter strings of the non-word. Besides, without associated meanings, no semantic network would be activated and the facilitative process of spreading activation would not be triggered.

In the present study, the difference between the context congruent and incongruent conditions was not significant, which indicates that both distinct meanings of the presented homonyms were activated and represent evidence for the favoured non-selective access hypothesis. In addition, the shorter reaction times of the context congruent and context incongruent conditions provide evidence that these conditions were processed faster than the non-prime and orthographical legit non-word condition, in which the targets were not associated with the presented homonyms. These findings also support our hypothesis of non-selective access to both distinct contexts of homonyms. However, it is important to point out that participants in this study are moderately dispersed in their reaction times in combination with a small sample size. That might have an impact on the results and could be a limitation to this study, a circumstance that will be discussed in a later section.

Our hypothesis concerning the error rates was also confirmed as the nonparametric Friedman test showed a main effect on error rates. In comparison, participants showed the highest accuracy with random string non-words whereas, in all other conditions, significantly more errors occurred. The non-prime condition showed significantly more errors in percent than the orthographical legit non-word, which we did not expect. Error rate in this non-word condition is as high as in the primed conditions and this effect was not found in published literature and is not plausible as far as we can see. While statistics are working with probabilities, it is possible that sometimes effects can occur that are not true to the population (alpha-error). Our only suggestion therefore, would be a result of a possible but improbable outcome in the process of recruiting participants.

Comparison of Present and Previous Research

The present study is based on the work of Schvaneveldt and colleagues (1976), who found evidence for the selective access hypothesis, by showing that congruent conditions (the prime and target sharing the same meaning with a homograph) are processed significantly faster than targets of the incongruent condition (the prime having another meaning of a homograph other than the target). This contrasts with our findings, where both congruent and incongruent conditions do not differ significantly in reaction times, thus supporting the theory of non-selective access. However, this disparity may be caused by the modification of the paradigm used in the present study. While Schvaneveldt and colleagues (1976) presented words one underneath the other and requested a response to each word, we presented words one after another and requested a response to the latest presented stimulus. Since various studies have shown that there are differences in the processing of sentences in reaction times as well as in error rates (Byrne, 2002; Yu, Park, Gerold, & Legge, 2010), similar effects could occur here. The visual span (the number of letters that can be recognised with a high accuracy and without moving the eyes) seems to be different in vertical reading and dependent on parameters such as letter spacing (Yu, Cheung, Legge, & Chung; 2007; Yu et al., 2010), and so the style of presentation could have an impact on processing in lexical decision tasks. Moreover, new within this study is the examination of relations between presented stimuli, based on second-order co-occurrences, which provides another distinction between the present study and former research, and is likely to explain discrepancies between findings.

Whilst Simpson (1984, 1994) states that two or more meanings of a homonym can be accessed in different ways without a non-selective lexical access occurring, one meaning by its frequency and one by its relevance to the context, this explanation of our results would be inefficient. In our case, the prime represents the most frequent meaning of the following homograph and the significance of relevance in context should therefore be the same. According to Simpson (1984, 1994), that would lead the assumption that selective lexical access should be the result, but it is not.

With the AROM, it can be stated that lexical access depends on the number of associates. If the primed homograph shares many co-occurrences with the target word, we predicted this target to be activated in mental lexicon as well as all other co-occurring words. In that way, frequency does not predict lexical access exclusively, but the number of associates and the predictability of a word also do. In the context of this study, where only single words were presented rather than whole sentences, predictability should be a function of co-occurrences and frequency. To support this hypothesis concerning the co-occurrences, another study targeting relations of stimuli showed evidence for the importance of associates (Hofmann et al., 2011). The authors demonstrated that participants recognised a tested stimulus as learned more often than if the current stimulus had been presented in a learning phase before and additionally, if the stimulus had many co-occurrences with stimuli presented in the test phase. In contrast, participants recognised stimuli less often if they had few or no co-occurring terms. Accordingly, it can be concluded that reaction times on presented stimuli are faster if a target has more associated terms in a former shown stimulus set. On the other hand, for a target that has fewer associations the reaction times in lexical decision tasks increase. Correspondingly, the results of the present study stand in line with Hofmann and colleagues (2011) by showing that the reaction times of the context related conditions are faster than for the unrelated non-prime or non-word conditions, which had no associations between target and homonym at all.

Being the first study testing the processing of homonyms with second-order co-occurring associations exclusively, it may be an addition to past research, showing evidence for both the selective (Forster & Bednall, 1976; Frost et al., 1990; Schvaneveldt et al., 1976; Simpson, 1984, 1994; Simpson & Kreuger, 1991; Warren, 1972) and non-selective hypothesis (DeGroot et al., 2000; Foss, 1970; Giora, 1999; Libben & Titone, 2009; Underwood, 1980) by using different paradigms.

Suggestions for Future Research

Since Mehler and colleagues (1978) began to provide new norms of testing lexical stimuli by controlling for word length and frequency, several studies have supported that controlling length and frequency is important for the explanation of differences in word recognition (Giraudo & Grainger, 2000; Mehler et al., 1978). Within this area of research, establishing standardised norms and corpora has increased in significance (Church & Hanks, 1990; Nelson et al., 2004). The present findings, however, combine existing standards in research on word recognition and may be compared with former studies as a basis for further research. It is possible that the application of neuropsychological methods such as electroencephalography (EEG) or functional magnetic resonance imaging (fMRI) would be an interesting continuation of former research. For example, studies already exist which have tested lexical access during a reading experiment using EEG (Dambacher, Kliegl, Hofmann, & Jacobs, 2006). They found that high frequency words are accessed fast, resulting in a strong effect of the event related potential (ERP) of P200. Furthermore, associations and predictability showed a reducing effect for low frequency words in the N400. In addition, Kutas and Federmeier (2011) give an overview of the development and findings of the N400 as a dependent variable in many different research questions. For example, it has been shown that if the target stimulus was related to the prime stimulus (no matter if associatively, categorically, phonologically, or semantically) a reduced N400 amplitude appeared in results (Kutas & Van Petten, 1988). The N400 was also found to be a good predictor for an effect of predictability resulting in the smallest amplitudes for predictable endings in sentences (Van Petten, Coulson, Rubin, Plante, & Parks, 1999; for an overview see Kutas & Federmeier, 2011). Research could potentially go a step further and test ERPs in priming lexical decision tasks with homonymous words. With such a procedure, research could try to find additional evidence with regards to the controversy of selective and non-selective access and first or second-order associated words.

In addition, there is already a body of literature that has utilised fMRI for testing the access of ambiguous words. An interesting starting point for further research, therefore, could be the comparison of visual and phonological processing. Both the phonological and visual access to lexical content are related to the activation of the same part of the brain (Poldrack et al., 1999). This was shown by fMRI which was used to examine whether separate regions of the left inferior prefrontal cortex are activated in both types of processing. Thereby, authors could demonstrate that the ventral left inferior prefrontal cortex showed increased activity during the processing of semantic ambiguity compared to the processing of phonological ambiguity. In contrast, the dorsal left inferior prefrontal cortex is activated at both phonological and semantical ambiguity processing. Thus, evidence indicates that for lexical access similar brain areas are activated, even though these brain areas are distinct (Poldrack et al., 1999). This is an important aspect for further research on lexical ambiguity. Another important finding of some recent studies is that the left posterior inferior temporal cortex and the inferior frontal gyri (bilateral but mostly left) also represent regions with importance in processing ambiguity (Bedny et al., 2007; Martin & Chao, 2001; Snijders et al., 2009; Zempleni, Renken, Hoeks, Hoogduin, & Stowe, 2007). The activation in these brain areas, in context with the primed dominant meaning of an ambiguous unit, suggests a rather post lexical semantic mechanism (Copland, de Zubicaray, McMahon, & Eastburn, 2007). Also, there is some evidence that fronto-parietal areas (dorsolateral prefrontal cortex and angular gyrus) might give an inhibitory signal to temporal regions (superior temporal gyrus and right ventromedial temporal lobe) so that a selection between relevant and irrelevant meanings of a homograph can be made (Hoenig & Scheef, 2009). Whilst these findings are not numerous, they are certainly important; however, there seems to be no literature discussing context effects of selective and non-selective access in addressing various meanings of ambiguous terms yet.

Whilst the present study solely uses dominant meanings of homonyms as prime and target contexts, it could also be interesting to test reaction times on subdominant meanings. In a context incongruent condition, the variation of dominant and subdominant meanings could provide a better understanding of the processing of ambiguous words. For example, an Italian study showed that the dominance of a meaning might still affect the reaction time outcomes (Tabossi, Colombo, & Job, 1987). These findings of Tabossi and colleagues indicate that if the dominant meaning of an ambiguous word is primed, the resulting lexical access seems to be selective; but if the meaning of a presented prime targets a less dominant context, differences in reaction times on dominant and subdominant targets were not significant, which indicates non-selective lexical access (Tabossi et al., 1987). These findings can be explained by the works of Simpson (1984, 1994) and Simpson and Krueger (1991), who stated the possibility of two meanings being activated. In the case of priming, the frequent (or dominant) meaning access is selective because the most frequent meaning is consistent with the meaning relevant to the given context. As the present study did prime the dominant meaning only, but found evidence for the access to be non-selective, the order of indirect associations (second order co-occurrences) could have an impact on the results, whereas the dominance of the meaning of an ambiguous word could not have a further impact exclusively. As Forster and Bednall (1976) point out in their study and the search model of mental lexicon, the balance of the meanings of ambiguous words is a necessary criterion for further research. As they draw attention to, participants should show decreased reaction times in the decision between ambiguous and unambiguous words in a balanced condition (two meanings having a similar frequency). While reaction times in an unbalanced condition (one meaning is significantly more frequent than the other) should increase (Forster & Bednall, 1976). Even though they did not find a difference in their study, the distinction between balanced or unbalanced homonyms should be an important factor for future studies. However, important replications and further research to include many or all of the different factors is needed.

When focusing on the quantity of associations between prime and homonym or target and homonym, it would be reasonable to test the quality of homonyms by calculating a coefficient. Therefore a possible criterion might be the selectivity on which a homonym differentiates between the meanings it contains. By using first- or second-order co-occurrences, the dominance of a pre-activated meaning could be quantified. With such quantification, future studies might build context congruent and incongruent conditions, controlling the quality of associations. Within a context congruent condition prime and target would both have many associations with each other, caused by the relation to the same meaning. In an incongruent condition prime and target word should have only a few or no associations in order to reach a better differentiation. As an example, the German word “Leitung” may be mentioned, whose most dominant meanings are either a “water or gas pipe” or a “leadership” or “guidance” of people. Both meanings actually have a common origin for the meaning of guiding either people or a substance like water to a desired point (Duden, 2011). According to the hypothesis of the present study, this circumstance should not make a difference to the results if the quantity of the associations is controlled. However, future research may at this point either support or refute our findings.

Besides the research on semantic processing of written language, research focusing on the processing of ambiguous words in spoken language is important as well. Along with the present study for written language, Frost and colleagues (1990) have shown the non-selectivity of processing phonological ambiguity. They describe how, in spoken language, the dominant meaning is strongly activated but the subordinate meaning is alternatively activated as well. The activation of the different meanings does not appear to be parallel. It seems that the activation appears in an order with the most frequent meanings resulting in the strongest activations and the less frequent meanings leading to weaker activations. Overall, several studies on the processing of phonologically ambiguous words suggest non-selective activation, similar to the processing of written homonyms examined in the present study.

Finally, it might be interesting to test access on lexical ambiguity by constructing a more complex paradigm on the recognition of homonyms. Recent research confirmed a pop-out effect in the context of high arousal with emotionally negative connoted terms in a word grid paradigm (Palma de Figueiredo, 2015). In the context of homonyms, it would be interesting to test whether there is a pop-out effect (Treisman & Gelade, 1980) on one meaning of the lexical ambiguous unit or on multiple meanings, if these meanings have different emotional qualities.

Limitations and Final Conclusion

Conclusions of the present research are limited by the exclusive inclusion of psychology students as participants. Furthermore, the present study is the first study to test the processing of German homonyms. As such, although this study may have an impact for future research, replications are needed to support or reject the findings. In addition, research should replicate the findings of the present study with a more representative and larger sample; this would possibly strengthen external validity and therefore generalizability. Even though we excluded participants with slow reaction times (see results section) the reaction times of participants in our study still seem to deviate more than usual (the standard deviations are approximately twice as high as “normal”). A possible explanation for this finding might be a factor in our experimental design, which provoked variance that we cannot explain. It could be a factor of individual associations in words, since we did not use direct associated words, but that seems rather unlikely and makes a replication of this study even more important. In general, more research relying on co-occurrences of different orders is needed in testing the processing of ambiguous words. This is especially needed as the present study is the first of its kind investigating the processing of ambiguous words with second order co-occurrences and results seem to depend partly on method, experimental design, selection of stimulus material and the order of associations of stimuli. Likewise, language seems to play an important role in the findings of research on homonyms as well. These (language, method, stimulus selection, experimental design) are aspects that complicate a distinct review on the question whether selective or non-selective access is a valid theory of lexical processing in homonyms. Therefore, it seems challenging for future research to explain the processing of ambiguity and the effect of different aspects such as method, language, experimental design and selected stimuli.

Nevertheless, it can be stated that for the present investigation non-selective access is the supported theory. As such, both ways of usually interpreting a homonym are accessed in lexical processing. Even if more than two distinct meanings are connected to an ambiguous term, all or even the most frequent meanings are accessed, regardless of the semantic contextualization. Although it cannot be constituted that the theory of selective access is necessarily wrong, the results of the current study point towards non-selective access for German homonyms.

Additional Files

The additional files for this article can be found as follows:

- **Annex 1.** CSV file of the experiments. DOI: http://doi.org/10.5334/jeps.408.s1
- **Annex 2.** Scientific data related to experiments. DOI: http://doi.org/10.5334/jeps.408.s2

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Competing Interests

The authors have no competing interests to declare.

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