After braking comes hasting: reversed effects of indirect associations in 2nd and 4th graders

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Abstract

The Associative Read-Out Model (AROM) suggests that associations between words can be defined by the log likelihood that they occur together more often in sentences than predicted by their single-word frequency. Moreover, semantic relations can be defined by associative spreading across many common associates. Here, we addressed developmental effects of associative and semantic priming. Thus, we manipulated sentence-co-occurrence-based direct (syntagmatic) and common (paradigmatic) associations between prime and target words in 2nd and 4th graders. Syntagmatic associations decreased response times and error rates in both, 2nd and 4th graders. Paradigmatic associations increased errors rates in 2nd graders, whereas they decreased errors rates in 4th graders. These results suggest that 2nd graders profit from syntagmatic, i.e. contiguity-based associations, while a benefit from paradigmatic-semantic relationship probably develops from generalizing across many of these simple associations.

Keywords: Interactive Activation Model, Associative Read-Out Model, Semantic Priming, Computational Models, Syntagmatic-Paradigmatic shift

Introduction

Starting with pioneer work of Meyer and Schvaneveldt (1971) a wide range of studies revealed that a target word (e.g. "chair") is processed faster and more accurate when a semantically associated prime word (e.g. "table") was presented before (e.g. Bentin et al., 1985; Neely, 1976). Interestingly, studies differentiating between various types of associations (e.g. Becker, 1980; Lucas, 2000; McNamara, 2005) and/or individual differences like age (e.g. review Chapman et al., 1994, McCauley et al., 1976) revealed inconsistent results with regard to the size and direction of the semantic priming effect. From a developmental perspective, the presence (or absence) of the semantic priming effect may be an indicator of the development and organization of semantic knowledge (e.g. Lucas, 2000; McCauley et al., 1976; Meyer & Schvaneveldt, 1971).
On the one hand, recent research revealed greater semantic priming effects (i.e. greater difference between primed and non-primed condition) for younger children and elder people (see review Chapman et al., 1994). On the other hand, various studies, investigating processes of different types of relations in semantic priming tasks, revealed that younger children show priming effects if words are directly associated only, and not if they exclusively provide a category relation (e.g. McCauley et al., 1976). So far, empirical evidence points towards a greater facilitation by functional/associative relations in comparison to pure semantic relations in children, but also an increasing sensitivity for thematic and taxonomic relationships over age (Arias-Trejo & Plunkett, 2013). In line with this, younger children tend to freely associate words that have a syntagmatic relation from mere common occurrence in sentences relation (e.g. "good" and "boy") rather than a paradigmatic relation due to the same form class (e.g. "good" and "bad") in comparison to older children and adults (e.g. White, 1985; Woodrow & Lowell, 1916). This effect is also known as the syntagmatic-paradigmatic shift that occurs in an age range between 5 and 9 years (e.g. Brown & Berko, 1960; Entwisle, 1966, Nelson, 1977).

To our knowledge, however, the relative reliance on syntagmatic and/or paradigmatic information has not yet been addressed during visual word recognition. As German children start reading at the age of 6, we hypothesized that word-decoding abilities sufficient for syntagmatic effects should be apparent around the age of 7 years, i.e. in the 2nd grade, while a stronger reliance on paradigmatic information should be observable around the age of 9, i.e. in the 4th grade. So far, most semantic priming studies used free association performance of adults to predict semantic priming (e.g., Lucas, 2000), though already Jung (1905) stated that free associations are diagnostic for interindividual differences. Therefore, it is questionable whether its usage as an independent variable for the study of children is appropriate (see Hofmann & Jacobs , 2014). To derive a semantic long-term memory structure from experience with a sample of text (Hofmann et al., 2011), a recent interactive activation model (IAM; McClelland & Rumelhart, 1981) relies on co-occurrence statistics. The Associative Read-Out Model (AROM, Hofmann et al., 2011) is the first IAM with an implemented semantic layer. It defines two words as associated, if they co-occur more often together in sentences than predicted by their single occurrence frequency (Dunning, 1993; Quasthoff et al., 2006). Thus, it reflects a symbolic Hebbian learning approach (Hebb, 1949) by suggesting higher association strengths for words that are occurring more often together than predicted by the frequency-driven orthographic activation.

The AROM already successfully predicted behavioral and electrophysiological data for tasks, in which memory is explicitly required. Hofmann et al. (2011) showed that the correct identification of studied words as well as the false recognition of non-studied words is significantly higher for words with many associations in a recognition memory task. This result has recently been extended by Stuellein et al. (2016) in an EEG study by showing significant response time, P200 and N400 effects for words with many associations. It was an open question, however, to what extend these results were induced by pure direct associations and/or indirect associations like semantic feature overlap (Stuellein et al., 2016). As the AROM defines words as associated by the frequency of their common occurrence, it is in line with localist theories proposing direct associative links between symbolic representations to capture the meaning of a word (e.g., Anderson, 1983; Collins and Loftus, 1975). Whereas distributed models define the meaning of a word by a distribution across subsymbolic 'hidden' units (e.g. McClelland and Rogers, 2003), this assumption is in line with other co-occurrence based models, defining the meaning of a word by latent factors determining with which words they co-occur (e.g. Landauer and Dumais, 1997). In the tradition of distributed models, one can assume that words that often occur together in similar sentence contexts might share similar semantic features. In line with the idea, that the meaning of a word is determined by its surrounding context (Firth, 1957; Harris, 1951), common associates of two words can possibly be considered as common features (Hofmann and Jacobs, 2014). As a consequence, a more complex AROM, that would be able to simulate the dynamic co-activation of such semantic features, was discussed to be a plausible option to accommodate both perspectives (Stuellein et al., 2016).

In a recent study, Roelke et al. (2016, subm.) also tested the AROM in an implicit memory task. During primed lexical decision, a full factorial manipulation of direct association (strong/no) and the number of common associates (many/no) of prime and target revealed strong effects in adult participants. Prime and target words with direct and many common associates facilitated visual word recognition. In contrast, we also have preliminary evidence of inhibitory priming effects at a very long SOA (Schmidt, 2015). These results are in line with recent studies, showing *only* facilitating effects for pure associative relations and inhibitory *or* facilitatory effects for semantic relations that are dependent on the time that the prime is processed (e.g. see Plaut & Booth, 2000).

The present study

To investigate whether the AROM can be used to address the syntagmatic-paradigmatic shift by relying on direct (associative, syntagmatic) and indirect (semantic, paradigmatic) relations, we tested 2nd and 4th grade students from two German elementary schools, using primed lexical decision. In line with recent results, we expected smaller semantic priming effects for younger children for semantic (indirect) relations. Furthermore, we expected greater semantic priming effects for associative (direct) relations in comparison to semantic (indirect) relations for all children, because these depend on an abstraction of experience-based knowledge.

Methods

Subjects

For all participating students, parents signed written consent in advance.

Second grade. Behavioral data were collected for 95 2nd grade students of two primary schools in Solingen, Germany. Two students did not complete the experiment due to the task difficulty. Another eleven participants had to be excluded because of reading/writing disorders and two participants because of lacking German skills. The mean age of the remaining 75 students (female=45) was 7.46 years (*SD*=.502). According to their parents, 62 (82.7%) participants had learned German as their first language. Three children (4%) learned Turkish as their first language, followed by Italian (N=2, 2.7 %) and Russian (N=2, 2.7%). The remaining students came from a variety of linguistic background. For one student, data for the native language was missing.

Fourth Grade. Behavioral data were collected for 86 4th grade students of two primary schools in Solingen, Germany. Ten students had to be excluded because of reading/writing disorders. The mean age of the remaining 76 students (female=52) was 9.54 years (*SD*=.738). According to their parents, 62 participants (81.6%) had learned German as their first language. Five children (6.6 %) learned Turkish as their first language, followed by Italian (N=4, 5.3%) and Polish (N=2, 2.6 %). The remaining students came from a variety of linguistic background.

Materials

Corpora. The word stimuli were taken from the word corpus "childLex", which is based on approximately 5000 German books for children between 6 and 12 years (Schroeder et al., 2015; status: September 2014). The books vary in length and content with about 5000 to 15,000 words per book. We used words that were among the list for 6 to 10 year old children. As the childLex corpus is not openly available for analyses, co-occurrence statistics were taken from the German corpus of the "Wortschatz" project (status: December 2006; Quasthoff et al., 2006). This corpus is largely composed of online newspaper (1992-2006). Based on 800 million tokens and 43 million sentences, two words were considered to be directly associated when they co-occurred more often together in sentences than predicted by their single occurrence frequency (Dunning, 1993). Indirect associations were defined as the number of common direct associates.

Stimuli. The stimulus set consisted of 160 primes and 160 targets. The 160 primes and 80 targets were German nouns. The remaining 80 targets consisted of 40 pronounceable pseudowords and 40 random letter strings. Pseudowords were created by changing one to three consonants of real nouns. 80 targets were German nouns that were split into four word conditions in a 2x2 design with the factors direct association (high vs. low) and indirect relation (high vs. low). Prime and target were considered to provide a low direct association, when they were not associated at all (association strength=0) and as high directly associated, when they were beyond a 2,5%-quantile criterion (association strength > 3) of all possible stimuli (N=6,975; cf. Hofmann et al., 2011, for a formal definition of association strength). They were considered to provide a low indirect relation, when they had less than 65 common associates (below a 2,5%-quantile criterion of all possible stimuli) and were considered to provide a high indirect association, when they had more than 300 common associates (beyond a 2,5%-quantile criterion of all possible stimuli; cf. Bordag, 2007, for counts of common associates). From the childLex corpus, the word features frequency, word length and Orthographic Levenstein Distance (Yarkoni et al., 2008) were counterbalanced between the four word conditions for prime and target words to rule out confounding effects (condition differences $p > .05$). Raw Lemma-Frequency was log10 transformed and words below and beyond a 2,5%-quantile frequency criterion of all possible stimuli were excluded. Word and nonword length was limited from 3 to 6 letters. Before counterbalancing to rule out confounding variables, a manual examination of the stimulus set excluded inappropriate words for children (e.g. those with sexual content), prime and target pairs with the same first letter and compounds (e.g. "snowball").

Procedure

Cover story. The instruction was embedded in a cover story, adapted from a children's lexical decision task by Richter et al. (2013). Children were asked to help an extraterrestrial named Reli, who came to earth to learn the language of the earthlings, to distinguish between real words and nonwords (Target). To further explain the appearance of the prime words, students were told that another extraterrestrial named Gudra also wanted to learn the language of the earthlings (Prime). Students were told that other children were helping Gudra, so that they had to read her word but that they did not have to react.

Semantic Priming Task. The semantic priming task was performed by groups of eight to ten students at the same time in a quiet room, separated from the rest of the class. Before the experiment started, the time course of the experiment was written on the blackboard and the task was explained to the children in front of the class. Each student worked on his/her own on a separate laptop. Students were asked to put on headphones and to leave on the headphones during the whole task. Before the task started, a detailed instruction was presented once more in a videoclip with the extraterrestrial Reli.

First a fixation cross was presented for 1000 ms on the screen. Then a prime word was presented in grey letters for 600 ms. The students were asked to read the prime but not to press a button. After the prime word, a blank screen appeared for 200 ms, after which the target word was presented in black letters. Students were asked to press a green button with their right forefinger on the keyboard ("K"), if the presented stimulus was a real word and to press a red button with their left forefinger on the keyboard ("D") if the presented stimulus was a nonword. The target word stayed on the screen until the student pressed one of the two buttons. Following another blank screen for 500 ms, the word "Bereit?" ('ready?') was presented in red letters on the screen and students were asked to press a yellow button ("space") with one of their thumbs on the keyboard, if they wanted to go to the next trial (s. Figure 1).
To get used to the task, five exercise trials were presented at the beginning. For the exercise trials, feedback was provided whether the response was correct or not. For the main task, no feedback was provided. During the main task, two breaks were included, each after 56-57 trials. The students decided on their own by pressing the yellow button when to continue with the main task.

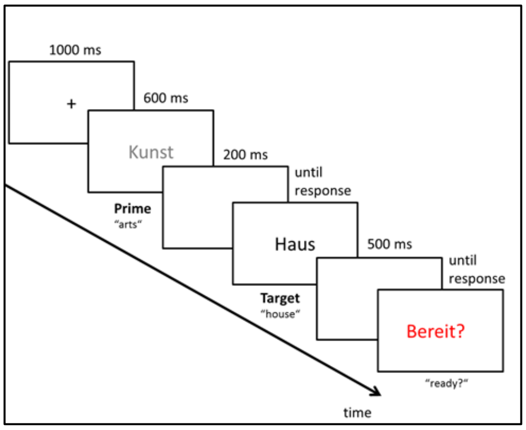

Figure 1: Time course of the experiment

At the beginning of the main task and after every break two "icebreaker trials" were included, that were excluded from data analyses. For every participant, the order of the presented prime-target pairs was randomized. Students were asked to react as fast and as accurate as possible.

Data Analysis. Results were analyzed using general linear mixed-effect models with the fixed effects *grade* (2^{nd} vs. 4^{th} class), *direct association* (low vs. high) and *indirect association* (low vs. high), their interaction terms and the random intercepts *subject* and *item*. The dependent variables were *accuracy* and *response times*. For accuracy analysis we used binary logistic regression and for response time analysis we used linear model. Because the degrees of freedom are not exactly known in LMM analyses, we chose 2 standard errors as significance criterion (i.e. $t >= 2$; cf. Baayen et al., 2008, footnote 1; Masson & Kliegl, 2013). Incorrect responses and those plus/minus a 3 standard deviation criterion from average for each subject and condition were excluded from response time analyses. We only report main effects and interactions between the experimental factors that are significant. When models revealed significant interactions between at least two of the experimental factors, post-hoc t-tests were conducted.

Results

Accuracy

Grade and *direct association* and the significant interactions *grade*direct association* and *grade*indirect association* led to significant contributions to the model (all *t*'s>= 2). The positive effects of *grade* (β=1.273, *t*=7.08, *SE*=.18) and *direct association* (β=1.191, *t*=3.12, *SE*=.382) indicate that direct associations increased accuracy, and that 4^{th} grade students made fewer mistakes than 2^{nd} grade students (s. also Figure 2). The analysis also revealed a significant interaction between *direct associations* and *grade* (β=-0.360, *t*=-2.95, *SE*=.122). Moreover, we obtained an interaction of *indirect association* and *grade* (β=-0.395, *t*=-3.33 *SE*=.119).
Post-hoc t-tests revealed that for 2^{nd} graders words that were high directly associated (*M*=3.50, *SD*=1.90) led to fewer errors (*t*=-9.89, *p*=.000) than words that were low directly associated (*M*=5.71, *SD*=2.60). For 4^{th} graders high directly associated words (*M*=1.74, *SD*=1.24) led also to significantly fewer errors (*t*=-12.32, *p*=.000) than words that were low directly associated (*M*=3.95, *SD*=2.08). Furthermore, for 2^{nd} graders words with many common associates (*M*=4.84, *SD*=2.29) led to significantly more errors (*t*=2.481, *p*=.015) than words with few common associates (*M*=4.37, *SD*=2.16). Whereas for 4^{th} graders words with many common associates (*M*=2.68, *SD*=1.82) led to significantly fewer errors (*t*=-2.116, *p*=.038) than words with few common associates (*M*=3.01, *SD*=1.48).

Response time

Grade and *direct association* led to a significant contribution to the model (all *t* 's>=2). The positive effects of *grade* (β=1.103,*t*= 8.99, *SE*=.12) and *direct association* (β=0.19, *t*= 3.06, *SE*=.08) indicate that 4^{th} grade students responded faster than 2^{nd} grade students and in general students responded faster for words that were directly associated (s. Figure 3).

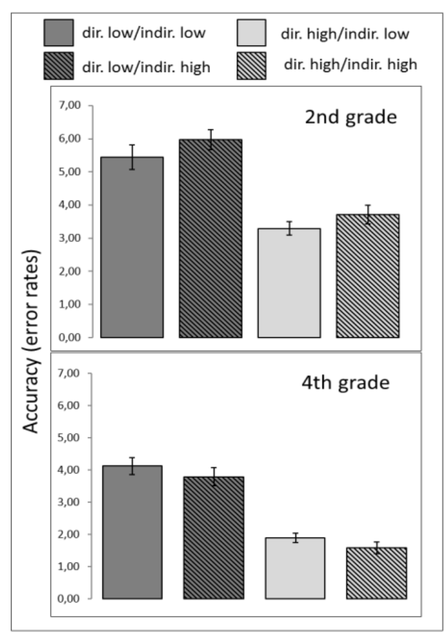

Figure 2: Mean accuracy (error rates) in 2^{nd} and 4^{th} grade students
Note: Error bars are standard errors.

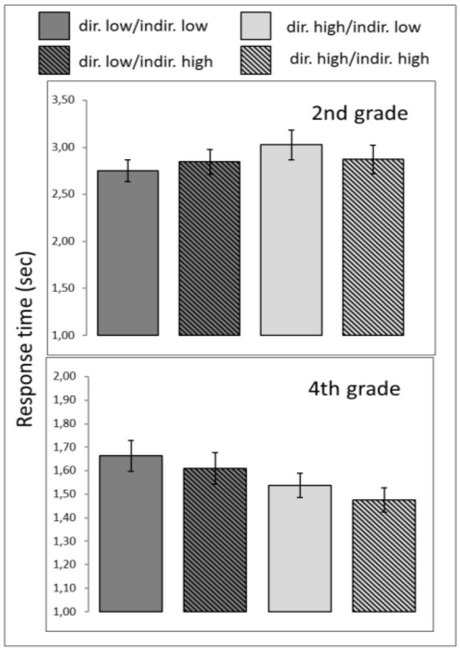

Figure 3: Mean response times in 2nd and 4th grade students
Note: Error bars are standard errors.

Discussion

To test whether the AROM can account for a developmental shift from associative-syntagmatic (direct) to semantic-paradigmatic (indirect) relations during visual word recognition, we analyzed the performance of 75 2nd grade and 76 4th grade children of two German elementary schools in a semantic priming task. Direct (syntagmatic) associations decreased errors in 2nd graders as well as in 4th grade students. The analysis of indirect (paradigmatic) relations revealed a significant interaction of grade and paradigmatic associations: while paradigmatic associations led to inhibitory effects in 2nd graders (more errors), they led to facilitating effects in 4th graders (fewer errors). Thus, children may develop the ability to generalize across common associations between the second and the fourth grade.

Our results fit into a reading development model, in which category knowledge is gradually abstracted and develops from functional, event-based knowledge. Response differences may result from the addition from new structures within an associative network, instead of a complete reorganization (e.g. McCauley et al., 1976). Consistent with this, Nelson (1977) assumed that children first represent semantic knowledge as spatial or temporal scripts (e.g. "eating lunch") and gradually abstract and define categories from this script-based knowledge.
Our results also show that the Associative Read-Out Model (Hofmann et al., 2011) is sufficient to define both, associative-syntagmatic and semantic-paradigmatic perspectives by co-occurrence statistics, and thus provides a computational window into developmental effects of visual word recognition. Future more explicit simulations with an AROM thus may capture individual differences such as age by differential associative excitation and inhibition scaling parameters within the semantic representation layer.

The syntagmatic-paradigmatic shift in children is well known (e.g. Entwisle, 1966). De Saussure's (1959) coined the term "syntagmatic" as an associative relation between words that typically co-occur in a linear combination (cf. Hofmann & Jacobs, 2014). He further proposes a second type of relation, i.e. that words are associated when "they have something in common" (1959, p. 123). In computational linguistics, the number of common associates is used to define paradigmatic relations: "For example, the semantic similarity of the words red and blue can be derived from the fact that they both frequently co-occur with words like color, flower, dress, car, dark, bright, beautiful, and so forth" (Rapp, 2002, p. 1). We think that simple within-sentence co-occurrence provides an intelligible, transparent and performance-independent explanation of differential effects during reading development.

We are aware of the fact, that the priming effects might also be driven by factors like positional-syntactic information (e.g. Hofmann, Biemann, & Remus, 2017). Thus, future studies may also investigate the influence of syntactic information by using not only simple nouns from the word corpora, but also words from other syntactic classes or prime-target pairs spanning differential word classes (e.g., verbs, adjectives etc.). Further studies may also investigate whether computational models that reduce the amount of latent semantic dimensions can provide generalization capabilities that may account for more variance than the simple amount of common associates (e.g. Landauer & Dumais, 1997).

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References

Arias-Trejo, N., & Plunkett, K. (2013). What's in a link: associative and taxonomic priming effects in the infant lexicon. *Cognition, 128(2),* 214-217.
Anderson, J.R. (1983). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior, 22*, 261-295.
Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics*. Cambridge: Cambridge University Press.
Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory & Cognition, 8(6),* 493-512.
Bentin, S., McCarthy, G. & Wood, C.C. (1985). Event-related potentials, lexical decision and semantic priming. *Electroencephalography and Clinical Neurophysiology, 60*, 343-355.
Bordag, S. (2007). *Elements of Knowledge-free and Unsupervised Lexical Acquisition*. Unpublished dissertation, Department of mathematics and informatics, University of Leipzig, Germany.
Brown, R. W. & Berko, J. (1960). Word association and the acquisition of grammar. *Child Development, 31*, 1-14.
Chapman, L. J., Chapman, J. E, Curran, T. E., & Miller, M. B. (1994). Do

children and the elderly show heightened semantic priming? How to answer the question. *Developmental Review, 14*, 159-185.
Collins, A.M., Loftus, E.F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407-428.
Dunning, T.(1993). Accurate methods for the statistics of surprise and coincidence. *Computational Linguistics, 19*, 61-74.
Entwisle, D. R. (1966). *The word association of young children*. Baltimore: Johns Hopkins University Press.
Firth, J. R. (1957). *A synopsis of linguistic theory 1930–1955, in Studies in linguistic analysis*. Oxford, England: Blackwell Publishers, pp. 1–32.
Harris, Z. S. (1951). *Methods in Structural Linguistics*. University of Chicago Press, Chicago, http://archive.org/details/structurallingui00harr
Hofmann, M. J., Kuchinke, L., Biemann, C., Tamm, S., Jacobs, A. M. (2011). Remembering words in context as predicted by an associative read-out model. *Frontiers in Psychology, 2*, 252,1-11.
Hofmann, M.J., Jacobs,A.M., (2014). Interactive activation and competition models and semantic context: from behavioral to brain data. *Neuroscience & Biobehavioral Reviews, 46*,85–104.
Hofmann, M.J., Biemann, C., & Remus, S. (2017). Benchmarking n-grams, topic models and recurrent neural networks by cloze completions, EEGs and eye movements. In B. Sharp, F. Sedes, & W. Lubaszewski (Eds.), Cognitive Approach to Natural Language Processing (pp.197-216). Amsterdam, London: ISTE Press – Elsevier.
Hebb, D., (1949). *The Organization of Behavior*. Wiley: New York.
Jung, C.G. (1905). *In: Ueber das Verhalten der Reaktionszeit beim Assoziationsexperiment.* Ambrosius Barth: Leipzig.
Lucas, M. (2000). Semantic priming without association: A meta-analytic review. *Psychonomic Bulletin & Review, 7(4),* 618-630.
Landauer, T.K., Dumais, S.T. (1997). A solution to Plato's problem: the latent semantic analysis theory of acquisition, induction and representation of knowledge. *Psychological Review, 104,* 211-240.
Masson, M. E., & Kliegl, R. (2013). Modulation of additive and interactive effects in lexical decision by trial history. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39(3),* 898-914.
McClelland, J.L., Rogers, T.T. (2003). The parallel distributed processing approach to semantic cognition. *Nature, 4*, 310–322.
McClelland, J. L., Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88*, 375-407.
McCauley, C., Weil, C. M., & Sperber, R. D. (1976). The development of memory structure as reflected by semantic-primary effects. *Journal of Experimental Child Psychology, 22*, 511-518.
McNamara, T. (2005). *Semantic Priming – perspectives from memory and word recognition*. New York and Hove: Essays in Cognitive Psychology.
Meyer, D.E., & Schvaneveldt, R.W. (1971). Facilitation in recognizing pairs of words: evidence of a dependence between retrieval operations. *Journal of Experimental Psychology. 90(2),* 227-234.
Neely, J. H. (1976). Semantic priming and retrieval from lexical memory: Evidence for facilitatory and inhibitory processes. *Memory & Cognition, 4(5),* 648–54.
Nelson, K. (1977). The syntagmatic-paradigmatic shift revisited: a review of research and theory. *Psychological Bulletin, 84*, 93–116.
Plaut, D. C., & Booth, J. R. (2000). Individual and Developmental Differences in Semantic Priming: Empirical and Computational Support for a Single-Mechanism Account of Lexical Processing. *Psychological Review, 107(4),* 786-823.
Quasthoff, U., Richter, M. Biemann, C. (2006). Corpus Portal for Search in Monolingual Corpora. *Proceeding of the fifth Int. Conf. Language Resour. Eval., LREC, Genova, Italy* (pp. 1799-1802).
Rapp, R. (2002). The computation of word associations: comparing syntagmatic and paradigmatic approaches. In: *Association for Computational Linguistics, Proceedings of the 19th International Conference on Computational Linguistics – Volume 1*, pp. 1–7
Richter, T., Isberner, M., Naumann, J., & Neeb, Y. (2013). Lexical Quality and Reading Comprehension in Primary School Children. *Scientific Studies of Reading, 17(6),* 415-434.
Roelke, A., Franke, N., Radach, R., Jacobs, A. & Hofmann, M. (2016). *Semantic higher order but not direct associations prime ventral visual stream activation*. Manuscript submitted for publication.
de Saussure, F. (1959). *Course in General Linguistics. Philosophical Library, New York* http://books.google.de/books?id=FSpZAAAAMAAJ
Schmidt, U. (2015). *Direkte und indirekte Assoziationen beim semantischen Priming*. Unpublished bachelor thesis, Department of General Psychology, University of Wuppertal, Germany.
Schroeder, S., Würzner, K.-M., Heister, J., Geyken, A., & Kliegl, R. (2015). childLex: Eine lexikalische Datenbank zur Schriftsprache für Kinder im Deutschen. *Psychologische Rundschau, 66*, 155-165.
Stuellein, N., Radach, R., Jacobs, A. & Hofmann, M. (2016). No one way ticket from orthography to semantics in recognition memory: P200 and N400 effects of associations. *Brain Research, 1639*, 88-98.
Yarkoni, T., Balota, D., & Yap, M. (2008). Moving beyond Coltheart's N: A new measure of orthographic similarity. *Psychonomic Bulletin & Review, 15 (5),* 971-979.
White, H. (1985). The Syntagmatic-Paradigmatic Shift and Long-Term Memory Activation. *The Journal of Genetic Psychology, 146*, 561-562.
Woodrow, H. & Lowell, F. (1916). Children's association frequency tables. *Psychological Monographs, 22*, No. 97.