Neurophysiological Correlates of Thematic and Functional Knowledge Activation during Object Conceptual Processing

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Abstract

Behavioral studies suggest that manipulable artifact concepts are largely organized around action-based knowledge with thematic and functional relations being privileged ways to group objects together. Moreover, recent eye tracking studies have shown that thematic and functional knowledge are activated with different temporal dynamics during object conceptual processing. In order to assess the neurophysiological correlates of thematic and functional knowledge activation, we used a priming paradigm in which Event-Related Potentials were recorded during object identification. The neural response was analyzed as a function of the type of semantic relation shared by prime and target objects: Thematic [saw-wood], Specific Function [saw-axe] and General Function [saw-knife]. Results revealed graded priming effects on the N400 component that could be related to processing time course differences. Findings support the hypothesis of distinct cognitive and neurophysiological mechanisms underlying thematic and functional knowledge.

Keywords: EEG, Semantic priming, Thematic and Functional Knowledge, Manipulable artifacts.

Introduction

Increasing evidence indicates that action-related information is a central part of our knowledge about manipulable artifacts (i.e., manipulable manmade objects). For example, damage to functional/motor feature information has been associated with selective deficits in artifact knowledge (Farah & McClelland, 1991). In property generation tasks, functional/motor properties are produced relatively more frequently in response to artifact than natural object concepts (Cree & McRae, 2003; Garrard, Lambon Ralph, Hodges, & Patterson, 2001; McRae, Cree, Seidenberg, & McNorgan, 2005). Moreover, object recognition and categorization can be facilitated by the prior presentation of another object that shares action-related features (Helbig, Graf, & Kiefer, 2006; Labeye, Oker, Badard, & Versace, 2008; Myung, Blumstein, & Sedivy, 2006). These behavioral data, in addition to numerous neuroimaging findings showing activation of the visuo-motor system during processing of manipulable artifact concepts (Martin, 2007; Noppeney, 2008), are generally consistent with the proposal that object conceptual knowledge is grounded in sensory and motor systems (Barsalou, 1999, 2008; Borghi, 2005; Gallese & Lakoff, 2005).

The relevance of action-related information for manipulable artifact concepts is also consistent with previous work in the categorization domain. Categorization studies have shown that thematic and functional relations are particularly relevant for manipulable artifacts. In the case of manipulable artifacts, thematic relations typically correspond to tool-recipient relationships (e.g., screwdriver-screw), and are more quickly processed than categorical relations (e.g., screwdriver-hammer; Kalénine & Bonthoux, 2008). Moreover, recent neuroimaging evidence (Kalénine et al., 2009) indicates that identification of thematic associations selectively activates brain regions associated with the visuo-motor system (temporo-parietal areas), further supporting the close link between thematic relation processing and some aspect of object use experience. In addition, contrary to natural object categories (e.g. animals), manipulable artifacts are largely characterized by functional attributes associated with object use (Cree & McRae, 2003; Garrard et al., 2001; McRae et al., 2005), suggesting that functional similarities play an important role in object semantic structure. For example, hammer and screwdriver are assumed to belong to the same category because they are both used to repair things. Taken together, these findings suggest that manipulable artifact concepts are largely organized around action-based knowledge, with thematic and functional relations being privileged ways to group objects together. Yet little is known about how these two types of information can be articulated in object semantic structure.

Thematic and functional similarity relation processing has been the focus of a few previous behavioral studies. One of them used an explicit forced-choice task (Kalénine et al., 2009) in order to compare identification speed of thematic and categorical relations. Results showed faster explicit identification of thematic compared to categorical relations in the case of artifact concepts. This result suggests different time courses of activation for thematic and functional knowledge, since categorical relations are largely based on functional similarities for artifacts (i.e., tools, kitchen utensils, etc.). In order to extend this finding to situations in which explicit judgment of the semantic relations is not required, a second line of work has used eye tracking in the visual-world paradigm (VWP) (Kalénine, Mirman, Middleton, & Buxbaum, 2012, Pluciennicka, Coello, & Kalénine, 2013). In the basic version of the paradigm, four pictures are presented to a participant, and eye movements are recorded while the participant identifies a target object. The principle of the VWP is that distractor objects that are related to the target attract more looks relative to distractors that are unrelated to the target. For example, when participants hear the target word "saw" and have to identify the object saw among 4 pictures including pictures of saw, wood, feather and piano, they tend to look more to the wood than to the semantically unrelated distractors before clicking on the saw. This competition effect between target and distractor objects is assumed to reflect incidental activation of specific semantic information (e.g., "saw is used to cut wood") during object identification. In the two studies, competition effects of similar amplitude were observed for 3 different types of semantic relation: thematic relations (e.g., saw–wood), specific function relations (saw-axe; cutting wood) and general function relations (saw-knife; cutting). However, the timing of the competition effect appeared to be dependent on the type of semantic relation present in the display. Competition effects with thematic distractors were early and transient while competition effects with general function distractors were late and long-lasting. Competition effects with specific function competitors exhibited an intermediate pattern. Thus, previous behavioral findings have highlighted hierarchical activation time courses for thematic, specific function and general function knowledge during object conceptual processing.

The present study was designed in order to specify the brain correlates of thematic and functional processing. In particular, we aimed at examining whether differences between thematic, specific functional and general functional knowledge processing previously observed at the behavioral level (Kalénine et al., 2012, Pluciennicka et al., 2013) could be related to differences in neurophysiological correlates. To this aim, a priming paradigm was used and EEG was recorded while participants named object pictures that could be preceded by related (thematic, specific function and general function) or unrelated primes. A similar paradigm had been used to assess priming effects driven by manipulation similarity between objects (Kiefer, Sim, Helbig & Graf, 2011). Following Kiefer et al. (2011), we measured two ERP components (P100 and N400) evoked by target object pictures in central and parietal regions. On each component, priming effect amplitude was compared between the different types of semantic relation between object prime and target (thematic, specific function and general function). Based on behavioral results (Kalénine et al. 2012, Pluciennicka et al., 2013), we expected to find graded priming effects in the Thematic, Specific Function, and General Function conditions.

Methods

Eighteen adults (mean age 25.6; age range 19–37; 10 women) participated in the experiment. All participants were right-handed (handedness quotients 50–100%; mean 90%; Oldfield 1971), had normal or corrected-to-normal visual acuity and had French as a native or primary language. None of the participants reported history of dyslexia or any neurological diseases. The experimental procedure was approved by the local ethical committee in accordance with the Helsinki declaration. All participants signed an informed consent form prior to their participation.

Stimuli

Stimuli were 105 color photographs of common objects (200 x 200 pixels), including 15 target and 90 prime objects. Among the prime objects, 45 were semantically related to the target (15 Thematic, 15 Specific Function, 15 General Function), and 45 were unrelated to the target (15 visually similar and 30 visually dissimilar). The type of semantic relation was manipulated in three conditions. In the Thematic condition, the prime object could be used to act upon/with the target (e.g., saw–wood). In the Specific Function condition, the prime and the target were functionally similar at a relatively specific level (saw-axe; cutting wood). In the General Function condition, the prime and the target were functionally similar at a relatively general level (saw-knife; cutting). Unrelated pictures were neither semantically nor phonologically related to the target, but fifteen of them were visually similar, either in shape or in color (saw-feather). A corpus-based similarity measure (LSA) was used to assess overall semantic relatedness between target and prime objects. As expected, related object noun pairs were more semantically related than unrelated noun pairs. Importantly, overall semantic relatedness between target and prime object nouns was equivalent between conditions.

Procedure

After a brief presentation of the EEG materials and general goal of the study, participants were informed that they would have to name a series of object pictures. During the whole experiment, participants were seated in front of a computer screen (1920 × 1080, 60 Hz) in a dimly illuminated room.

Familiarization Session Prior to the EEG experiment, all objects pictures were presented to the participant and named by the experimenter. This was done to avoid possible interference caused by hesitation between different object nouns during the actual experiment and ensure that all participants use basic-level names to identify objects.

Naming Task Participants were instructed to fix the center of the screen where all events appeared in order to minimize artifacts generated by gaze motion. The following task specific instructions were delivered: "On each trial, after a fixation cross presented in the center of the screen, two successive object pictures will be briefly presented (300 ms each) before a question mark. Your task will be to name both objects in the presentation order after the appearance of the question mark" (Figure 1). A delayed naming task was used in order to prevent EEG signal contamination by EMG signal of mouth muscles mobilized during naming. After participant's response, the question mark was replaced by a hash mark until initiation of the next trial. Instructions stressed the importance of accuracy but did not set any constraint on response times. The same trial procedure was used for the 360 trials: 4 sessions x 2 prime categories (related, unrelated) x 3 types of semantic relation (thematic, specific function, general function) x 15 targets.

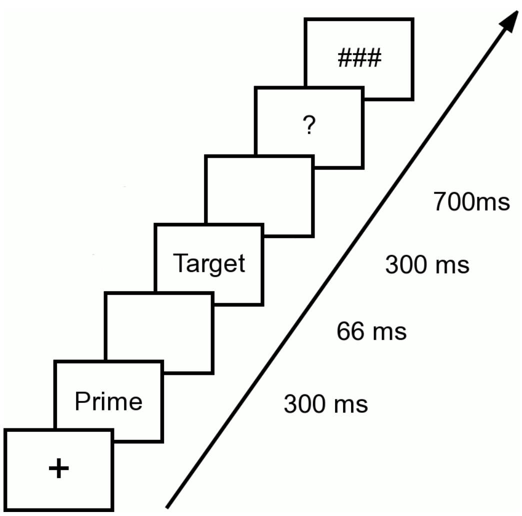

Figure 1: Typical trial sequence used during naming task

Data Analysis

EEG was recorded continuously during the naming task from 128 active electrodes mounted on an elastic cap (10-20 International system Electro-Cap Inc) with an Active Two Biosemi system (Biosemi, Amsterdam, the Netherlands). The impedance of all electrodes was kept below 20 kΩ. Two additional electrodes were used to monitor eye movements and blinks (one placed at lateral canthi and one below the eyes). Continuous EEG was digitized at 512 Hz and filtered offline (1-20 Hz) using EEGLAB software (Delorme & Makeig, 2004) and recalculated to mastoid reference. ICA-based artifact correction was used in order to correct blink artifacts (Delorme, Sejnowski, & Makeig, 2007). Epochs consisting of 1000 ms pre-target and 800 ms post-target were processed. Epochs contaminated by muscular contractions or an excessive deflection (± 75 µV) were detected by a visual inspection of the data, and excluded from the averaged ERP waveforms. ERPs were computed for each condition using a 200 ms time-window before fixation cross as baseline.

Following Kiefer et al. (2011), we respectively collapsed ERPs across 14 and 11 electrodes (A1, A2, B1, B2, B18, B19, B20, B21, B22, D14, D15, D16, D17, D18 on the one hand and A5, A8, A17, A18, A19, A20, A21, A30, A31, A32, B5 on the other hand; see Figure 2). Activity recorded in central and parietal regions is assumed to reflect the activation of large temporo-parietal network involved in manipuable object processing (Kiefer et al., 2011; Gerlach, 2007; Martin & Chao, 2001). Then, Mean Peak Amplitude for P100 and N400 components was computed by averaging the signal according to 85-115 and 370-510 ms time windows, respectively.

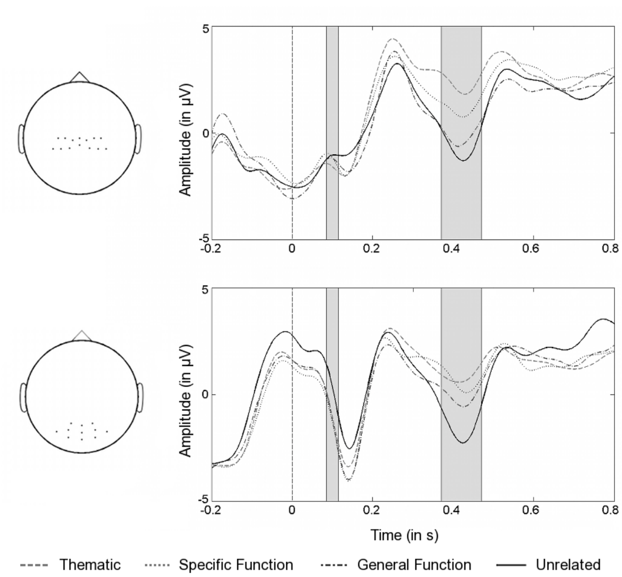

Figure 2: Electrodes Position and Event-Related Potentials measured in the central (top) and parietal (bottom) Regions of Interest (ROIs). Periods represented in grey on the ERP plots correspond to the time windows used to compute Mean Peak Amplitude for our two components of interest (85-115 ms for P100 and 370-510 ms for N400)

For each component, an Analysis of Variance (ANOVA) was conducted on the priming effect amplitude, namely the difference between semantically related and unrelated (but visually similar) object pairs, with Type of Semantic Relation (Thematic, Specific Function, General Function), and Region (Parietal, Central) as within-subject factors. Semantically unrelated but visually related pairs were used as baseline for computation of the priming effects for a better control of the potential visual similarity between semantically related object pairs.

At the neural level, facilitation for processing objects preceded by related compared to unrelated primes should be reflected by a diminution of the neural response for related compared to unrelated pairs (Kiefer et al., 2011, Helbig et al., 2006; Bentin, McCarthy, Wood, 1985). Thus, smaller priming effect amplitude corresponds to greater response of the brain to semantically related objects. Overall, we expected a main effect of Type of Semantic Relation on priming effect amplitude. Following behavioral results (Kalenine et al. 2012), we predicted that with limited object prime processing (i.e with a Stimulus Onset Asynchrony of 366 ms, see Kiefer et al. 2011), priming effect amplitudes should be ranked with thematic pairs < specific function pairs < general function pairs. This hypothesis was further tested with specific contrasts. Finally, significance of the priming effect in each condition was verified by comparing the amplitude of the related-unrelated pair difference with 0 in each condition using t-tests.

Results

P100 component

The ANOVA revealed a significant main effect of Region on the P100 priming effect amplitude ($F_{1,17} = 6.96$; $p < 0.05$). There was also a significant interaction between Region and Type of Semantic Relation ($F_{2,34} = 5.09$; $p < 0.05$). However, planned comparisons did not show any significant difference between the 3 Types of Semantic Relation in the two Regions considered. Besides, comparison to 0 in each condition indicated that none of the priming effects reached significance. Thus, P100 amplitude during object identification did not differ as a function of whether objects were preceded by semantically related pictures (thematic, specific function and general function) or visually similar pictures.

N400 component

The ANOVA showed significant main effects of Region and Type of Semantic Relation on the N400 priming effect amplitude ($F_{1,17} = 8.42$; $p < 0.01$ and $F_{2,34} = 5.81$; $p < 0.01$, respectively). There was also a significant interaction between Region and Type of Semantic Relation ($F_{2,34} = 7.95$; $p < 0.01$). As shown on Figure 3, planned comparisons revealed that, in each region, Thematic and General Function priming effects were significantly different ($F_{1,17} = 4.60$; $p < 0.05$ and $F_{1,17} = 11.40$; $p < 0.01$ for central and parietal region, respectively) while Specific Function priming effect did not differ from the average of the priming effects in the two other conditions (for both regions, $F_{1,17} < 1$). This result demonstrates graded priming effects on the N400 component in both central and parietal regions with the Thematic condition showing maximal priming and the General Function condition showing minimal priming[1].

Besides, comparison to 0 in each condition indicated that in the parietal region, priming effects reached significance in the Thematic ($t_{17} = 4.31$; $p < 0.001$) and Specific Function conditions ($t_{17} = 3.19$; $p < 0.005$), but not in the General Function condition ($t_{17} = 0.38$; $p = 0.71$). In the central region, the priming effect reached significance in the Thematic condition only ($t_{17} = 2.52$; $p < 0.05$). Thus, N400 amplitude during object identification was influenced by semantic priming beyond visual similarity and was sensitive to the Type of Semantic Relation between prime and target.

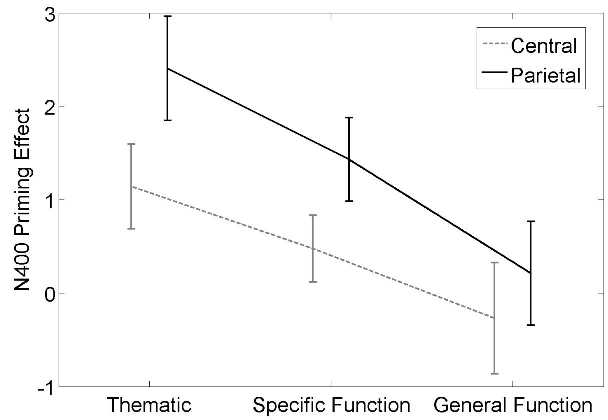

Figure 3: N400 priming effect (i.e. N400 amplitude difference between related and unrelated object pairs) as a function of Type of Semantic Relation (Thematic, Specific Function, General Function) and Region (Parietal, Central). Bars represent standard errors.

Discussion

The present experiment highlights two main findings. First, we found that the N400 component was sensitive to the type of semantic relation between prime and target. Such result is indicative of differences in activation of thematic and functional knowledge during object conceptual processing. Second, and contrary to what was suggested by previous data (Kiefer et al., 2011), we did not observe any difference between the different types of semantic relation on object early visuomotor processing (P100).

In our paradigm, when we compared object processing preceded by semantic primes with object processing preceded by semantically unrelated but visually similar primes, priming effects were observed on the N400 component only. It is not surprising to observe semantic priming effects on the amplitude of the N400 component. Indeed, N400 component is known to be involved in semantic processing, since N400 is sensitive to semantic deviation (Eddy et al., 2006; Deacon et al., 2000; McPherson et al., 1999; Kutas et al., 1998). More importantly, we found graded semantic priming effects on the N400 component as a function of the type of semantic relation. Compared to semantically unrelated but visually similar primes, a reduction of the amplitude of the N400 component was observed when target objects were preceded by thematically related primes (i.e. wood-saw < feather-saw). Conversely, no similar effect was observed when prime and target shared a general function (i.e. knife-saw= feather-saw). An intermediate pattern of results was visible when prime and target shared a specific function (i.e. wood

[1] Since N400 is a negative component, greater reduction of the neural response following related primes is reflected by greater (i.e. less negative) priming effect amplitude.

saw < axe-saw < knife-saw = feather-saw). Note that it is very unlikely that the absence of semantic priming on the N400 component in the general function condition is due to poor overall semantic relatedness between primes and targets in this particular condition. First, the LSA scores collected in order to obtain a measure of overall semantic relatedness between objects were equivalent between conditions. Second, the amplitude of the competition effects reported in previous eye-tracking studies (Kalénine et al., 2012; Pluciennicka et al., 2013) did not differ as a function of the type of semantic relation between target and distractor objects (thematic, specific function, general function), consistent with similar overall semantic relatedness for the 3 types of relation. Therefore, we suggest that the absence of priming effect on the N400 component for general function primes relates to differences in semantic activation timing rather than differences in overall semantic relatedness between conditions. The gradation of the N400 priming effect amplitude may be related to differences in processing time course, as reported in behavioral studies (Kalénine et al., 2009; Kalénine et al., 2012; Pluciennicka et al., 2013). Indeed, after limited processing of the prime object (366 ms SOA), maximal priming was obtained for thematic relations that are behaviorally processed within the shortest time. In contrast, after only 366 ms of prime possible influence, priming was absent for general function relations that require most time to be processed. Consistent with behavioral results, specific function relations exhibited intermediate priming.

The present finding provides first arguments supporting the hypothesis that thematic and functional knowledge are processed with different temporal dynamics at the neurophysiological level. It is consistent with the claim that processing thematic and functional similarity relations rely, at least partially, on distinct functional and neuroanatomical mechanisms (Kalénine et al., 2012; Mirman & Graziano, 2012; Schwartz et al., 2011). Following behavioral results, future work should increase the SOA between prime and target in order to allocate more time to prime object processing. With longer SOA, the pattern of priming effects should reverse, and the emergence of priming effects for general function relations should be observed.

Despite the poor spatial resolution of EEG data, the electrode sites behind the reported N400 graded effects (in central and parietal regions) are compatible with a differential recruitment of temporo-parietal areas. Indeed, previous studies using comparable paradigms indicated that N400 source generators could be localized in inferior temporal and somatosensory cortex (Kiefer et al., 2011). Moreover, the idea that thematic priming activates temporo-parietal areas more importantly than functional priming is consistent with previous fMRI results (Kalenine et al., 2009), and suggests a close connection between thematic knowledge and object motor representation.

On early visuomotor processing represented by the P100 component, we did not observe any difference between the three types of semantic relation. If we consider that semantic priming can be visible as early as 100 ms after target onset as Kiefer et al. (2011) suggested, we assume that the effect would be general and would not depend on the type of semantic relation between prime and target. Surprisingly, we did not find any significant semantic priming effect on P100 component when visual similarity between prime and target was controlled, namely when the baseline used for priming effect computation was semantically unrelated but visually similar object pairs. Best-case scenario, this result suggests that prior presentation of a semantically related object has the same amount of impact on object early visuomotor processing (P100) as prior presentation of a visually similar object. Worse case scenario, the semantic priming effect observed on this component in previous studies (Kiefer et al. 2011) is due to visual similarity. In Kiefer et al.'s study, priming effects between objects sharing the same manipulation were assessed at the neural level. In many cases, objects that share the same manipulation tend to be also visually similar. Since visual similarity was not systematically controlled in their study, it is difficult to discriminate effects driven by visual similarity from those driven by semantic relatedness. Further work should evaluate early manipulation priming effects on P100 component while strictly controlling for low level visual differences between stimuli.

Conclusion

To sum up, semantic priming effects on the N400 component of the event-related brain potential response were more important for thematically than functionally related object pairs. Considering that the time allocated to prime object processing was limited in our paradigm, the pattern of priming effects observed could be consistent with different activation time courses of thematic and functional knowledge. In accordance with behavioral results (Kalénine et al., 2009; Kalénine et al., 2012; Pluciennicka et al., 2013), priming neurophysiological correlates suggest that object conceptual processing recruits thematic knowledge first, followed by specific and then general functional knowledge. This pattern has been interpreted in relation to the closer link between thematic knowledge and sensorimotor experience (Kalénine et al. 2012). In contrast, semantic priming was not visible on early P100 ERP component, irrespective of the type of semantic relation, suggesting that "semantic" priming effects on early (P100) and late (N400) ERP components reported elsewhere (Kiefer et al., 2011) actually rely on distinct processes. Future works should further investigate the origin of the discrepancy between priming effects on early and late components.

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References

Barsalou, L. W. (1999). Perceptual symbol systems. *Behav Brain Sci, 22*(4), 577-609.

Barsalou, L. W. (2008). Grounded cognition. *Annu Rev Psychol, 59*, 617-645.

Bentin, S., McCarthy, G., Wood, C.C. (1985). Event-related potentials, lexical decision and semantic priming. *Clin. Neurophysiol. 6*, 343–355.

Borghi, A. M. (2005). Object concepts and action. In D. Pecher & R. A. Zwaan (Eds.), *Grounding Cognition: The role of perception and action in memory, language, and thinking* (pp. 8-34). Cambridge: Cambridge University Press.

Cree, G. S., & McRae, K. (2003). Analyzing the factors underlying the structure and computation of the meaning of chipmunk, cherry, chisel, cheese, and cello (and many other such concrete nouns). *J Exp Psychol Gen, 132*(2), 163-201.

Deacon, D., Hewitt, S., Yang, C. M., Nagata, M. (2000). Event-related potential indices of semantic priming using masked and unmasked words: evidence that the N400 does not reflect a post-lexical process. *Cogn Brain Res, 9(2)*, 137-146.

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. Journal of Neuroscience Methods, 134(1), 9–21.

Delorme, A., Sejnowski, T., & Makeig, S. (2007). Enhanced detection of artifacts in EEG data using higher-order statistics and independent component analysis. NeuroImage, 34(4), 1443–49.

Eddy, M., Schmid, A., Holcomb, P.J. (2006). Masked repetition priming and event-related brain potentials: a new approach for tracking the time-course of object perception. *Psychophysiology, 43(6),* 564-568.

Farah, M. J., & McClelland, J. L. (1991). A computational model of semantic memory impairment: modality specificity and emergent category specificity. *J Exp Psychol Gen, 120*(4), 339-357.

Gallese, V., & Lakoff, G. (2005). The Brain's Concepts: The Role of the Sensory-Motor System in Reason and Language. *Cognitive Neuropsychology, 22*, 455-479.

Garrard, P., Lambon Ralph, M. A., Hodges, J. R., & Patterson, K. (2001). Prototypicality, distinctiveness and intercorrelation: Analyses of the semantic attributes of living and non living concepts. *Cognitive Neuropsychology, 18*(2), 125-174.

Gerlach, C. (2007). A review of functional imaging studies on category specificity. *Journal of Cognitive Neuroscience, 19*, 296-314.

Helbig, H. B., Graf, M., & Kiefer, M. (2006). The role of action representations in visual object recognition. *Exp Brain Res, 174*(2), 221-228.

Kalénine, S., & Bonthoux, F. (2008). Object manipulability affects children and adults' conceptual processing. *Psychonomic Bulletin & Review, 15*(3), 667-672.

Kalénine, S., Peyrin, C., Pichat, C., Segebarth, C., Bonthoux, F., & Baciu, M. (2009). The sensory-motor specificity of taxonomic and thematic conceptual relations: a behavioral and fMRI study. *Neuroimage, 44*(3), 1152-1162.

Kalénine, S., Mirman, D., Middleton, E. L., & Buxbaum, L. J. (2012). Temporal dynamics of activation of thematic and functional action knowledge during auditory comprehension of artifact words. *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

Kiefer, M., Sim, E.-J., Helbig, H. B., & Graf, M. (2011). Tracking the time course of action priming on object recognition: Evidence for fast and slow influences of action on perception. *Journal of Cognitive Neuroscience, 23*, 1864-1874.

Kutas, M., Hillyard, S.A. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science, 207(4427)*, 03–205.

Labeye, E., Oker, A., Badard, G., & Versace, R. (2008). Activation and integration of motor components in a short-term priming paradigm. *Acta Psychologica, 129*(1), 108-111.

Martin, A. (2007). The representation of object concepts in brain. *Annual Review of Psychology, 58*, 25-45.

McPherson, W.B., Holcomb, P.J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects. *Psychophysiology, 36(1)*, 53-65

McRae, K., Cree, G. S., Seidenberg, M. S., & McNorgan, C. (2005). Semantic feature production norms for a large set of living and nonliving things. *Behavior Research Methods, 37*(4), 547-559.

Mirman, D., Graziano, K. M. (2012). Individual Differences in the Strength of Taxonomic Versus Thematic Relations. *Journal of Experimental Psychology: General ,141(4)*, 601-609.

Myung, J. Y., Blumstein, S. E., & Sedivy, J. C. (2006). Playing on the typewriter, typing on the piano: manipulation knowledge of objects. *Cognition, 98*(3), 223-243.

Noppeney, U. (2008). The neural systems of tool and action semantics: A perspective from functional imaging. *Journal of Physiology-Paris, 102*, 40-49.

Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia, 9*, 97-113.

Pluciennicka, E., Coello, Y., Kalénine, S., (2013). Development of thematic, specific function, and general function relation processing during childhood: An eye-tracking study. *7th Workshop Concepts, Actions and Objects: Functional and Neural Perspectives*.

Schwartz, M. F., Kimberg, D. Y., Walker, G. M., Brecher, A., Faseyitan, O. K., Dell, G. S., Mirman, D., Coslett H. B. (2011). Neuroanatomical dissociation for taxonomic and thematic knowledge in the human brain. *Proceedings of the National Academy of Sciences, 108(20)*, 8520-8524.