Activation of manipulation and function knowledge during visual search for objects.

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ACTIVATION OF MANIPULATION AND FUNCTION KNOWLEDGE DURING VISUAL SEARCH FOR OBJECTS

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Abstract

This study aimed at comparing the time course of the activation of function and manipulation knowledge during object identification. The influence of visual similarity and context information was also assessed. In 3 eye-tracking experiments, conducted with the Visual-World-Paradigm, participants heard the name of an object and had to identify it among four pictures. The target object (e.g., “shopping cart”) could be presented along with objects related by (a) function (e.g., “basket”), (b) manipulation (e.g., “lawnmower”), (c) context (e.g., “cash register”), (d) visual similarity (e.g., “toaster”), and (e) completely unrelated objects. Growth curve analyses were used to assess competition effects among semantically (a, b and c), visually related (d) and unrelated competitors (e). Results showed that manipulation- and function-related, but not context-related objects received more fixations than the unrelated ones, with a temporal advantage for the manipulation-related objects (Experiment 1). However, the visually similar objects faded the semantic competition effects, especially for function-related objects (Experiment 2). Finally, no temporal differences appeared when manipulation- and function-related objects were shown within the same visual array (Experiment 3). These results support the idea that both function and manipulation are relevant features of object semantic representations, but in the absence of other semantic competitors the activation of manipulation features appears prioritized during object identification.

Key-words: function, manipulation, visual world paradigm, context and visual similarity

Public Significance Statements

This study evaluates which object’s features are the most relevant for their recognition: functional (what the object is used for), manipulation (how the object is used), contextual (in which context the object is found), or physical characteristics (shape, color of the object).

Results show that once the object physical characteristics have been processed, knowledge about object manipulation is the most relevant for their identification.

The objects with similar manipulation features (for example a spray bottle when searching for a drill with similar trigger action) attract the most of the attention when searching for a given object among others.

Introduction

Imagine you are in front of a messy desk and someone asks you to look for the stapler; your gaze will probably examine different objects before landing on the target one. This search may be guided by the conceptual knowledge you have of the object "stapler". According to the distributed theories of conceptual representations, a concept is activated by multiple representational units (Smith et al., 1974; Barsalou, 1999; Tyler & Moss, 2001; Caramazza & Mahon, 2003; Gallese & Lakoff, 2005; for a review: Kiefer & Pulvermüller, 2012). These units represent different features of the concept which are distributed over a range of brain areas. As a consequence, some conceptual features of the target "object" will be shared also by other objects (e.g., the representational unit "curved handle" is shared by different tools). If we accept this view, then we should expect that in the searching for the stapler, as in the example above, the gaze will land primarily on the objects that share some key conceptual features with the target one. This hypothesis has received support by several eye-tracking studies using the Visual World Paradigm (VWP; Allopenna, Magnuson, & Tanenhaus, 1998; Cooper, 1974; Tanenhaus et al., 1995). When participants are delivered with the name of a target object and have to find in a visual display the corresponding picture of object among distractors, they look more to the distractors that are related in some ways to the target than to the unrelated distractors. This bias reflects the online activation of the features that the target and the related distractors have in common. For example, more looks to the distractor "trumpet" than to the distractor "hammer" when looking for the target "piano" indicates that processing of the target "piano" has activated the categorical feature "musical instrument". Since this feature is shared by the distractor "trumpet", this distractor has competed for attention with the target and has received more looks than an unrelated distractor. Such competition effects have been shown with distractors related by categorical features (with the amplitude of the competition effect varying as a function of categorical distance; e.g., Huettig & Altmann, 2005; Mirman & Magnuson, 2009), phonological features (e.g., Allopenna et al. 1998), visual features (color, shape, e.g., target "snake" and related distractor "rope", Dahan & Tanenhaus, 2005; Huettig & Altmann, 2005; Yee, Huffstetler, & Thompson-Schill, 2011), functional features (e.g., target "broom" and related distractor "vacuum cleaner"), thematic features (e.g., target "broom" and related distractor "dustpan"; Yee & Sedivy, 2006; Kalénine et al., 2012b), and manipulation features (e.g., target "piano" and related distractor “typewriter”; Lee, Middleton, Mirman, Kalénine, & Buxbaum, 2013, Myung, Blumstein,& Sedivy, 2006)”. Overall, these studies demonstrate that “*eye movements are a sensitive measure of overlap between the conceptual information conveyed by individual spoken words and the conceptual knowledge associated with visual objects*” (Huettig & Altmann, 2005, page: B31).

Importantly, the above-mentioned studies indicate that we mentally represent objects by using different kinds of features, from the more “abstract” (i.e. knowing an object’s category of general function) to the more concrete/sensory-motor ones (i.e. knowing an object’s shape and how to manipulate it), and that these sources of knowledge, once activated, guide the visual search of the target object. In the case of manipulable manufactured objects for which motor experience and functional knowledge have an important weight (Cree & McRae, 2003; McRae et al., 2005), the question that arises is about the respective roles of manipulation or function features in accessing those object concepts. In fact, these two types of features have been often separately explored. As a consequence, it is still unclear whether these features have the same importance, or if some of them are prioritized in the access to object knowledge.

In the neuropsychology literature, a double dissociation has been shown between function and manipulation knowledge. The term “function knowledge” usually refers to the goal achievable by using an object (e.g., the function of a screwdriver is to insert or remove screws). The term “manipulation knowledge” refers to gestures one has to perform to use an object appropriately (e.g., a screwdriver is held by the handle, the hand moves forward to insert the tip into a screw and then it makes different turns) and implies motor-based simulation, that is the re-enactment of perceptual and motor states acquired during experience with the objects (Decety et al., 1994, 1997; Stephan et al., 1995; Barsalou, 1999; Bartolo et al., 2007 ; Gallese & Lakoff, 2005). Some studies reported cases of left brain damaged patients with impaired capacity to select among three objects presented (e.g., stapler, cellophane tape and pen) the two that were similar in function (i.e. stapler and cellophane tape) coupled with spared abilities to select those that were similar according to their manner of manipulation (e.g., select the eggbeater and the pencil sharpener in the presence of the distractor ‘hedge clipper’), whereas some apraxic patients exhibited the opposite pattern (Buxbaum et al., 2000; Buxbaum & Saffran, 2002). By contrast, Sirigu and colleagues (1991) showed that patient F.G., affected by severe multimodal amnesia and agnosia was able to correctly manipulate certain objects, in spite of his difficulty to define their functions. The idea of distinct neuroanatomical networks supporting function and manipulation knowledge respectively has been also supported by several fMRI studies (Canessa et al., 2008; Chen et al., 2016, 2018). In the study by Canessa and colleagues (2008), participants were presented with pairs of objects and had to decide whether they were manipulated in the same way (to assess manipulation knowledge) and whether they were used in the same context (to assess function knowledge). In the studies by Chen and colleagues (2016; 2018), participants were asked to pantomime the use of an object (to assess manipulation knowledge) or to think about the function of the same object (to assess function knowledge). Regardless of the adopted procedure, results from these studies coherently showed that manipulation knowledge (in perception or production) is supported by a frontoparietal network whereas object function knowledge relies on the inferior and medial temporal cortices (but see Boronat et al. 2005).

Moreover, behavioral studies in healthy adults have shown that activation of manipulation features on one hand and function features on the other hand participate in object identification. In a VWP study, Myung and colleagues (2006, Experiment 2) found that when participants were asked to identify a target picture (e.g., “piano”) among distractors, the distractors related in terms of manipulation to the target picture (e.g., “typewriter”) were also fixated. The distractors merely related by visual similarity (e.g., “couch”) or the unrelated distractors (e.g., “bucket”) did not provoke significant fixations. This effect emerged quite early (i.e. around 300 ms after target onset) thus suggesting that manipulation knowledge is incidentally and rapidly activated in a simple conceptual task such as a word-to-picture matching task. This is also in line with what has been found by Lee and colleagues (2013). In their VWP study, participants heard a target word and had to select the corresponding picture in a visual array of four objects. The experiment dissociates activation of “grasp-to-move” actions (i.e. based on the general structure/shape of the objects, e.g., a “stapler” and a “hammer” require a similar grasping action to be moved) versus “grasp-to-use” actions (i.e. based on the knowledge of the use of the objects, e.g., a “remote control” and a “key fob” are manipulated in a similar manner). Results showed that participants were more likely to fixate both action competitors than unrelated objects. Importantly, the structure/shape-based action competition effect ramped up faster and peaked more steeply than did the use-based action competition effect. In other words, manipulation features showed a slower but more persistent activation than action features based on object shape. Together, these two studies support the idea that object identification is mainly driven by activation of manipulation knowledge related to object use (Lee et al., 2013; Myung et al., 2006), which lasts longer than activation of action features based on object shape (Lee et al., 2013).

As regards the function knowledge, Yee and colleagues (2011) used the VWP to directly compare the activation of shape and function features of object concepts. Shape features were assessed independently of the surface visual features of the image (e.g., target “pizza” and shape distractor “frisbee”, both typically round, but the pizza is presented a triangular slice in the picture). Function features did not overlap with shape features (e.g., target “glue” and function distractor “tape”). They found that the activation of object shape features was earlier than that of function information. Therefore, they concluded that “*shape is critical for recognizing an object … once an object is recognized, other attributes, such as what it is used for* (i.e. function knowledge), *become more important*” (p. 362). In another VWP study, Kalénine and colleagues (2012b) asked participants to identify manipulable artifact targets (e.g., broom) among distractors objects that were thematically (e.g., dustpan) or functionally related (e.g., vacuum cleaner). Analysis of the time course of gaze fixations revealed an earlier and shorter lasting activation of thematically related objects as compared to functionally related ones. According to the authors, this could reflect the close connection between thematic knowledge and action experience. Together, the two studies show that object identification is also incidentally driven by activation of object function knowledge (Kalénine et al. 2012a, Yee et al., 2011), which is longer lasting than activation of object shape features (Yee et al., 2011) and object thematic knowledge (Kalénine et al., 2012a). Although both may relate to object functional use, to what extent object thematic knowledge overlaps with manipulation knowledge remains an open question.

In summary, previous eyetracking studies using the VWP have clearly demonstrated that object function and manipulation features are independently activated during object identification in an incidental manner. They further suggest that the activation of function and manipulation knowledge shows a different time course than activation of knowledge of object shape or thematic relations. However, the temporal dynamics of activation of function and manipulation knowledge have never been directly contrasted in the VWP. This is the aim of the present study.

To our knowledge, only two behavioral studies have directly compared access to object manipulation and function knowledge in healthy adults (Garcea & Mahon, 2012; Collette et al., 2016). Garcea and Mahon (2012) used an explicit forced-choice task in which participants were asked to decide which two of three visually or verbally (written) presented objects shared the same manipulation or the same function. Results showed that participants were faster for function than for manipulation judgments, especially for the verbal material. In line with this, in Collette and colleagues (2016), participants were first primed with an image of an object that could be related (e.g., “knife-scissors” for function; “key-screwdriver” for manipulation), unrelated but visually similar (e.g., “glasses-scissors”; “baseball bat-screwdriver”), or purely unrelated (e.g., “die-scissors”; “tissue-screwdriver”) to the target object. Participants’ task was to name the target object. Results showed a priming effect (facilitation) when the prime and the target shared the same manipulation and not when they were similar in function in their youngest group of children (8 year-old). This pattern diminished with development (10 year-old) and reversed in adulthood, with the emergence of facilitative priming effects when the prime and the target were similar in function and interference priming effects when similar in manipulation. In adults, when controlling for visual similarity, results showed that manipulation and visual similarity played a similar role in the priming effect the authors found, whereas function was not affected by visual similarity.

In summary, results from both studies suggest an easier access to function knowledge in comparison to manipulation knowledge when adults identify manipulable manufactured objects, in accordance with the claim that activation of motor information is not necessarily required to access object function (Garcea & Mahon, 2012; Chatterjee, 2010). Yet several factors could explain the advantage of function knowledge in these two studies. First, the effect is associated with the explicit processing of object names in both studies (words as stimuli or naming as task), which may have emphasized the relevance of function knowledge (Chua et al., 2018; Egorova et al., 2016; Geng & Schnur, 2016). Second, the comparison between function and manipulation processing may be sensitive to the potential confound of visuo-perceptual similarity (not controlled in Garcea and Mahon’s study and accounting for manipulation priming effects

Collette and colleagues' study) and contextual similarity (not controlled in the two studies and partially overlapping with function similarity in Kalenine et al., 2012b). Finally, the two protocols used do not provide any dynamic information about the implicit activation of manipulation and function knowledge. In brief, the use of an explicit task in Garcea and Mahon (2012) or of a unique prime duration in Collette and colleagues (2016) did not allow detecting potential differences in time course between function and manipulation knowledge. Also, in Collette and colleagues (2016) the priming effects were visible in both function (facilitation) and manipulation (interference), reinforcing the idea that the time course of these two sources of knowledge remains to date not clearly defined.

Therefore, the specific aims of the present study were to: - verify the incidental activation of manipulation and function knowledge during object identification using a VWP (Experiments 1 & 2); - compare the time course of these activations for the same target elements (Experiments 1 & 2); and – test the relative importance of the two sources of knowledge by presenting both manipulation and function competitors at the same time during the visual search for a target object (Experiment 3). Furthermore, the presence of two possible confounding sources of information will be also assessed, that is contextual relationships (i.e. objects used or found in the same context but with different function and manipulation properties; e.g., a "*shopping cart*" and a "*cash register*") (Experiment 1, 2, & 3) and visuo-perceptual similarity between objects (e.g., objects with a similar shape/contour but different function and manipulation properties) (Experiment 2).

Experiment 1

Participants. Twenty participants were involved in the experiment (8 males; age range: 18-30; mean age: 24.13). Considering the amplitude of the competition effect observed with functionally related distractors in a previous VWP study with a very similar design (Kalénine et al., 2012, 3% more fixation on the function competitor than the unrelated distract overall, R^2 = 0.005 for this estimated difference), a sample size of 20 participants was sufficient to ensure a statistical power of 0.82 to detect a semantic competition effect in the present study (calculated from 50 simulations using the powerCurve function of the R package simr, Green & MacLeod, 2016). Participants were recruited among students of the University of Lille (France). Recruitment and testing were in conformity with the requirements of the Ethical Committee of the Behavioural Sciences of the University of Lille and of the 2013 Declaration of Helsinki (Ethical Protocol Reference Code: FM-PMV 2017-4-S51). Informed consent was obtained from all participants.

Materials and Methods.

Stimuli. The picture stimuli were 108 color images of objects selected with ad-hoc questionnaires (see Appendixes A and B), including 18 reference object images, 54 semantically related pictures (18 manipulation, 18 function, 18 context), and 36 unrelated pictures. Fifty-two more pictures were used as practice and filler stimuli. For each reference picture, three semantically related pictures and two unrelated pictures were selected. The type of semantic relationship was manipulated in three conditions. In the function condition, the competitor and the reference object were functionally similar (e.g., a “shopping cart” and “basket” are both used to carry food). In the manipulation condition the competitor and the reference object were manipulated in the same way (e.g., a “shopping cart” and a “lawn mower” are used similarly). Finally, in the context condition the competitor and the reference object were experienced as belonging to the same spatio-temporal context (e.g., a “shopping cart” and a “cash register” are both experience in a supermarket during shopping).

Control measures on the stimuli. Unrelated pictures were neither semantically nor phonologically related to the reference object. All 18 reference images were named with the same noun by at least 11 out of 12 participants (see Name Agreement in Appendix B/1). Furthermore, in order to ensure that the competitors in each condition (i.e. manipulation, function and context) were highly related to their reference object, we asked to 12 participants to rate on a 7-point Likert scale the functional, manipulation and context similarity between the reference object and the different competitors. Results showed that the degree of specific semantic similarity between reference and competitor did not differ among the three conditions (mean score for function = 5.71, for manipulation = 5.35; for context = 5.74; χ^2 = 3.63, p= .16). Importantly, all the three competitors received lowest scores on the others dimensions (e.g., the objects related for manipulation received a mean score of 0.68 for function, 1.23 for context; the objects related for function received a mean score of 0.89 for manipulation, 4.86 for context; the objects related for context received a mean score of 0.66 for function, 1.15 for context; see Appendix B/2 for all the statistical details). Finally, other 26 participants were asked to rate on a 7-point Likert scale the degree of overall semantic relatedness between each object (related and unrelated) and the reference. Specifically, participants had to indicate how much they thought the two objects were related in meaning while not taking into account visual similarity. Results showed that functional similarity relations were rated as the most related (M= 6.17, SD= 0.82), followed by Context (M= 4.55, SD= 1.46) and Manipulation (M= 2.46, SD= 1.13). No differences were found between the two unrelated relations and the relations of visual similarity (unrelated 1 M= .83, SD= .40; unrelated 2 M= 1.33, SD= 0.93; visually similar M= 1.53, SD= .90) (see Appendix B/4 for statistical details).

For each reference object 8 displays containing 4 pictures were created (see Figure 1): - three critical displays (i.e. one for each semantic condition: function, context and manipulation); - three composed filler displays; and - two unrelated filler displays. The critical displays were characterized by the presence of the reference object (e.g., shopping cart) that was the actual target, the object related to the target i.e. the semantic competitor, and the unrelated objects (i.e. both semantically dissimilar from the reference). The competitor was functionally related to the target in the function displays (e.g., basket), shared manipulation information with the target in the manipulation displays (e.g., lawn mower), or shared a general context in the context displays (e.g., cash register). Since in the critical displays the target was always the same, in the composed filler displays the related objects became the reference objects (see Figure 1, and Kalénine et al. 2012a,b for a similar procedure). This assured that participants could not guess in advance the critical target. Instead, the unrelated filler displays were characterized by completely novel objects pictures. Therefore, a total of 144 trials were presented (18 X 8), including 54 critical trials: 18 function displays, 18 manipulation displays and 18 context displays. The practice trials (10 in total) were prepared with the same logic.

The names of the 18 reference objects and 68 noncritical target objects were recorded by a native female French speaker. These represented the audio stimuli. They were recorded and edited (i.e.

digitized at 22 KHz and amplitude normalized) by using Audacity open source software. The critical targets nouns had an average duration of 725 ms (SD = 142 ms).

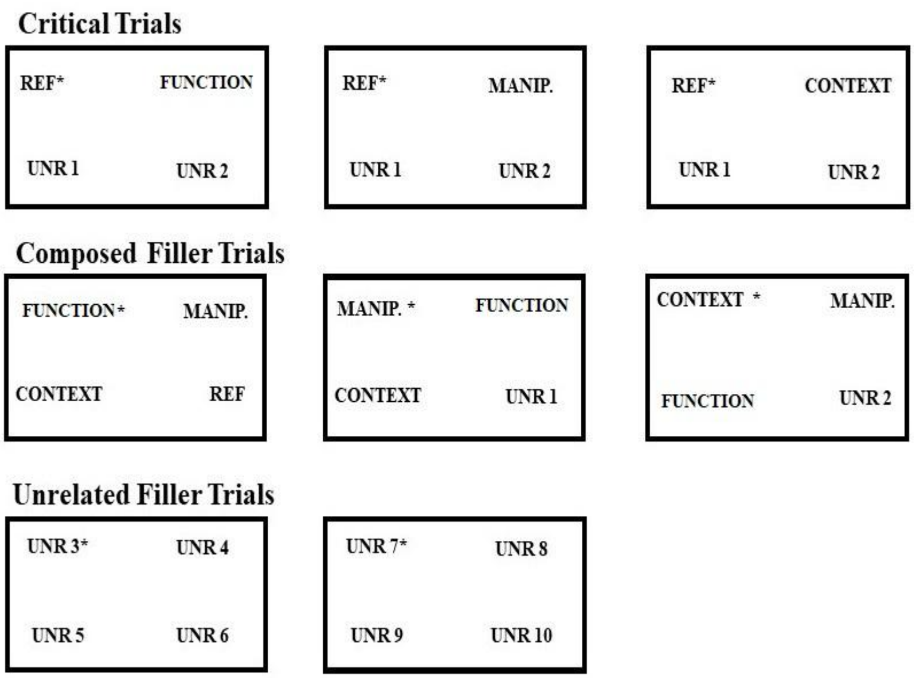

Figure 1. The figure shows the different four-picture displays (8 in total) for each reference object. The asterisks indicate the target picture for each display. The position of the pictures in the display was randomized (it is standardized here for simplicity). Critical and composed filler trials involved the reference object (REF), the semantically related pictures in the function, manipulation, and context (Function, Manip., and Context, respectively) and two unrelated pictures (Unr1 and Un[R2]). Unrelated filler trials involved different unrelated pictures (Unr3–Unr10).

Apparatus. Gaze position and duration were recorded using an EyeLink 1000 desktop eyetracker at 1000 Hz. E-Prime software was used to run the task and to collect responses (Psychological Software Tools, Pittsburgh, PA).

Procedure. The procedure of the current study has been previously used in Kalénine and colleagues' studies (2012a, b). Specifically, participants were seated with their eyes at approximately 50 cm from a 17-in. screen with resolution set to 1.024 X 768 pixels. A chin-and-front-rest apparatus was used to prevent participants' head movements. They were asked to provide their answer by clicking on a computer mouse with their right index finger. Each trial started by clicking on a central fixation cross. On each trial, participants saw four images; each image was presented near the screen corners. Images had a maximum size of about 200 X 200 pixels (min 10° of visual angle). The position of the four pictures was randomized for each trial and for each participant. The display was presented for a 1-s preview to allow for initial fixations driven by random factors or visual salience rather than word processing. Two hundred and fifty milliseconds before the offset of the preview, a red circle appeared in the center of the screen to disengage participants' attention from the different objects before word onset. Then, participants heard the target word through speakers and had to click on the image that corresponded to the target word (see Figure 2). Eye movement recording started when the display appeared on the screen and ended when the participant clicked on the target picture. Once clicked on the target picture, participants were instructed to put back the mouse arrow at center of the screen. The same procedure was followed for the 10 practice trials and the 144 test trials.

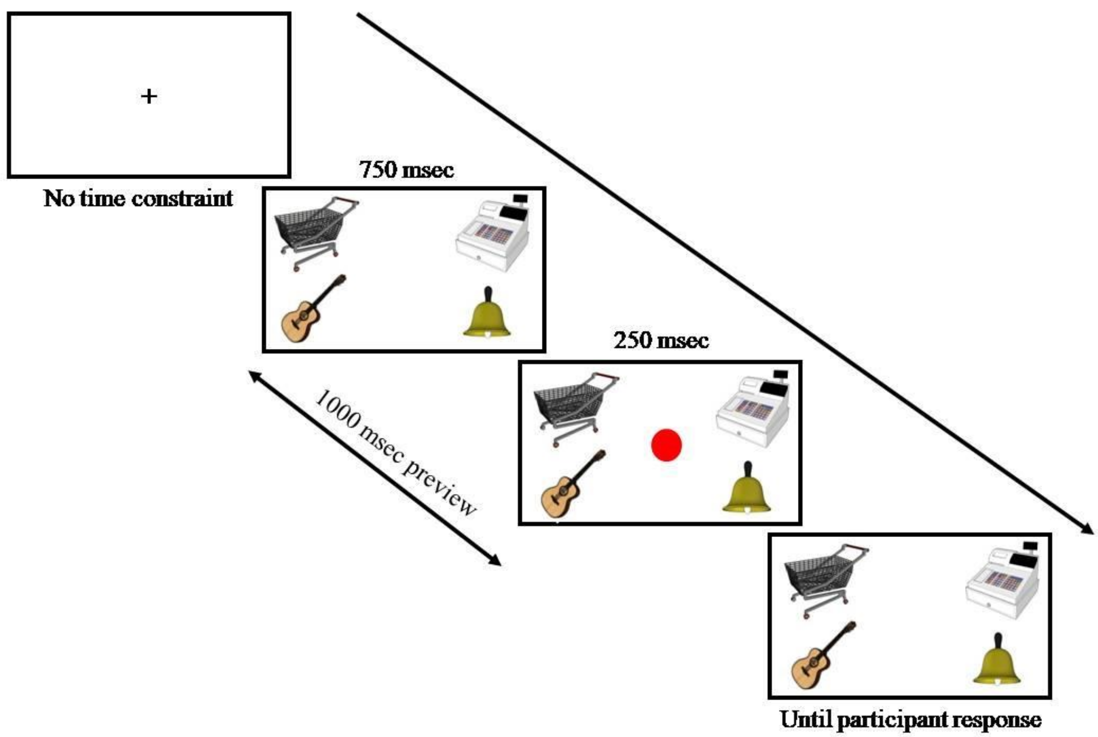

Figure 2. The figure illustrates a schematic overview of the procedure used in each trial. The display presents the target object (e.g., shopping cart), a contextual competitor (e.g., cash register), and two unrelated objects (e.g., guitar and bell). Target words were delivered after a 1,000-ms preview of the display.

Experimental design. In this first experiment, a target/reference image (e.g., "*shopping cart*") was presented with competitors sharing the same function, manipulation or context information with the target/reference. Other two completely unrelated objects were also present in the same visual scenario. The semantic similarity between target/reference and competitor was equivalent between conditions (see Appendix B/2). We analyzed the proportion of fixations on each quadrant of the screen in which an object was present (dependent variable) as a function of the following independent variables: time (continuous variable); distractor object relatedness, that is, the type of distractor object in the area (two levels: competitor vs. unrelated); and display type, that is, the type of semantic relationship present in the display (three levels: function vs. manipulation vs. context).

Overall, we expect to find semantic competition effects, with more fixations for related distractors than for unrelated distractors in the display. In addition, we expect differences in competition effect amplitude between the manipulation and function conditions on one hand, and contextual condition on the other hand, according to the hypothesis that function and manipulation knowledge are central for manufactured objects and cannot be limited to broad contextual contiguities. Finally, semantic competition in the manipulation and function conditions should be mostly visible on timing, with possible earlier activation of function than manipulation (*cf*. Collette et al., 2016; Garcea & Mahon, 2012).

Data analysis

Analysis of accuracy and response time data

Differences in mean accuracy and response times between the three semantic conditions were briefly evaluated using non-parametric Friedman and Wilcoxon signed rank post-hoc tests. Modulation of semantic competition from the related distractor during target identification was not expected to be visible on relatively coarse, non-dynamic measures such as accuracy and response time data in healthy individuals. However, accuracy and response time data might provide complementary results to gaze data in some cases. For example, stronger competition between target and related distractor in a given condition may be reflected by more difficult target identification in this condition, i.e. lower accuracy and increased response times.

Averaging of fixation data

We defined four areas of interest (AOI) for the 4 pictures presented in the display that corresponded to 400 x 300 pixel quadrants in each corner of the computer screen. Fixations falling into one of these AOI were considered object fixations, whereas fixations outside of the AOI were non-object fixations. Although they did not cover the whole screen, AOIs were designed slightly larger than picture size so that fixations falling very close to the object were still considered object fixations. Fixations spatial and temporal coordinates were extracted from EyeLink fixation reports. For each trial of each participant, fixations on each AOI were segmented into 100 ms time bins so that for each time bin, fixation on a given AOI could be either 0 or 1 (in the event of two fixations overlapping over a single bin, the second fixation was taken). The time course of fixations on the target/reference, related and unrelated objects was then estimated by averaging fixation proportions on critical trials over items and participants. Data from filler trials were excluded from the analysis. Fixation proportion on one of the unrelated objects (U1) was considered as baseline in the analysis.

Growth curve analysis (GCA) of fixation data

The time course of fixations on semantically related pictures relative to unrelated pictures in the Function, Manipulation and Context conditions during target identification was analyzed using growth curve analysis (GCA). GCA is a method of multilevel regression particularly well suited to the analysis of time series (see Mirman, 2014 for direct application to gaze data). At level 1, models capture the effect of time on fixation proportion using forth-order orthogonal polynomials. The intercept term reflects the overall height of the curve, the linear term corresponds to the overall slope of curve, the quadratic term reflects the central inflexion of the curve, and the cubic and quartic terms reflect the inflexions at the extremities. As demonstrated in previous studies (e.g., Kalénine et al., 2012; Lee et al., 2013, etc) and illustrated on Figure 3, the magnitude of the competition effect is captured by differences between related and unrelated distractor curves on the intercept. The timing of the competition effect may be captured by differences on the other terms. For example, a central competition bump will be visible on the quadratic term whereas early versus late competition will be evidenced on the linear or cubic terms. Importantly, there was no clear hypothesis on the term(s) that would best capture temporal differences in semantic competition *a priori*. However, early versus late competition was expected to affect each time term in a specific direction. Overall, earlier competition may be reflected by more negative linear and cubic estimates and more positive quadratic and quartic estimates.

At level 2 models capture the effect of the experimental manipulations on level-1 time terms. Each time term is described as a function of population means, fixed effects, and random effects. Fixed effects correspond to the different contrasts related to object relatedness, semantic condition, and the interaction between object relatedness and semantic condition. The random effect structure included individual adjustments according to the effect of object relatedness and semantic condition (random slopes) on each time term.

Models were fit using restricted maximum likelihood estimation using the lmer function of the lme4 package (version 1.1-19) in R (version 3.5.1.). P-value for t-tests on parameter estimates of the fixed effects of the model were calculated based on Satterthwaites's approximations using the LmerTest package (version 3.0-1). R-squared values for the whole linear mixed model (conditional R^2) and the different fixed effects of the model were obtained using the r2beta function of the r2glmm package (version 2.3.0). Plots were all made in R with ggplot2 version 2 3.1.0

Two separate statistical analyses were conducted. The first analysis focused on the preview window before target word onset (0-1000 ms) and included three object types (target, related distractor, unrelated distractor). The aim of the analysis was to verify whether the overall fixation proportion on the different object pictures was equivalent before participants knew which one was the target. The second analysis was restricted to competition effects driven by verbal input. A large competition window from 1000 ms (word onset) to 3000 ms (end of target identification) was selected and the target was not included in the analysis. Indeed, activation of the properties shared by the target and the related distractor during word-to-picture matching is reflected by the timing of the fixations on the related compared to the unrelated object, which serves as baseline. By-item and by-subject analyses were conducted to take into account several possible confounding factors that co-varied with either items or participants. In the by-subject analysis, individual differences between conditions in the overall proportion of fixations on the different objects during the preview period (estimated with the random slopes for the adjustment of the object x condition interaction by participant) were added to the models, if significant differences were presented in the analysis of the data from the preview window. In the by-item analysis, differences between the related distractors from the different conditions and the target in terms of a) visual similarity and b) degree of semantic relatedness[1] were added to the models in Experiments 1 and 2.

In Experiment 1, semantic competition effects were expected in the competition window. Specifically, we predicted a main effect of object relatedness with more fixations on the related than unrelated distractor overall (intercept term) or on more restricted portions of the time window (other time terms), reflecting the presence of a semantic competition effect regardless of the condition. We further anticipated an interaction between object relatedness and semantic condition, particularly on the time terms, reflecting differences in the time course of the semantic competition between conditions. We will thus report only the effects of interest concerning the main effects of object relatedness and the interactions between object relatedness and semantic condition, on the intercept other time terms.

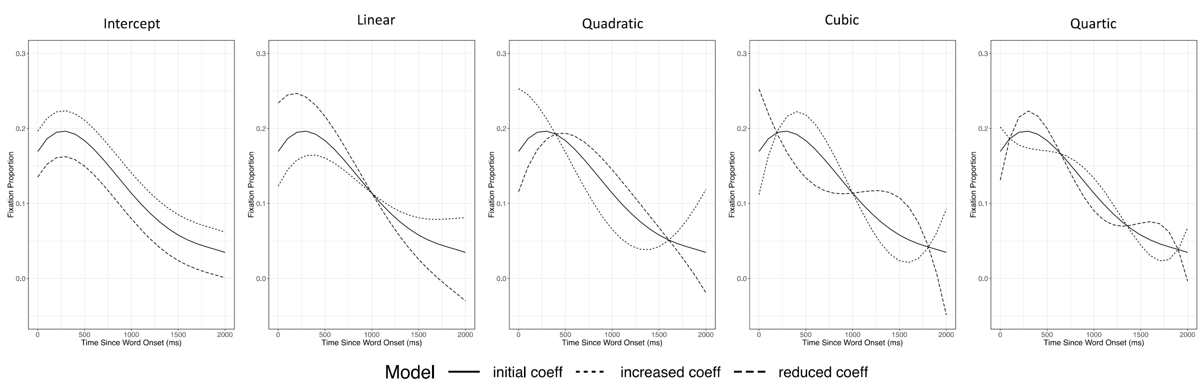

Figure 3. Illustration of positive or negative changes (increased or reduced estimates) for each coefficient of the 4th order orthogonal polynomial model of a putative fixation curve. Note that the direction of the effect changes depending on the coefficient: greater fixation proportion earlier in the time window tends to be reflected by smaller (more negative) linear and cubic estimates and greater (more positive) quadratic and quartic estimates.

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[1] R syntax of the model by-subject: fixation~(poly4*preview differences) + (poly4*object*condition)+(poly4|subject)+(poly4|subject:object:condition)

R syntax of the model by-item: fixation~(poly4*visual differences) + (poly4* relatedness differences) +(poly4*object*condition)+(poly4| item)+(poly4|item:object:condition)

Results

Participants were overall highly accurate in identifying the target object among distractors in all three conditions, performing at 97 %, 99 % and 100 % in the Function, Manipulation, and Context conditions, respectively. A non-parametric Friedman test of differences among repeated measures was conducted and rendered a Chi-square value of 14.92 (df= 2) which was significant (p=.001; Kendall's W= .02). The post-hoc test (Wilcoxon signed rank test) showed that participants' performance in the function condition was less accurate than in context condition (z= 2.93; p =.003; effect size: r =.15). No other significant differences were found. Mean computer mouse click reaction times (RTs) from display onset were 2791 msec, 2763 msec, 2685 msec in the Function, Manipulation, and Context conditions, respectively. The Friedman test rendered a Chi-square value of 7.60 (df= 2) which was significant (p= .02; Kendall's W= .01). The post-hoc test (Wilcoxon signed rank test) showed that participants in the function and the manipulation condition were slower than in the context one (z= 2.41; p = .01; effect size: r = .13 for function; z= 2.96; p = .002; effect size: r = .16 for manipulation). Although performance was very high in all conditions, mouse click results suggest that object identification was most difficult when a functionally similar and a manipulation similar distractor were present in the display.

Fixation data were collected from the onset of the picture display to the mouse click. Each trial received between 2 and 45 fixations (mean= 8.9, SD = 2.9). Trials where participants clicked on the incorrect picture or with mouse response times above three standard deviations from the participant's mean in that condition were excluded from fixation analyses (1.7% of data). Figure 4 shows the averaged time course of fixations to the target, competitor, and unrelated objects from display onset as a function of condition.

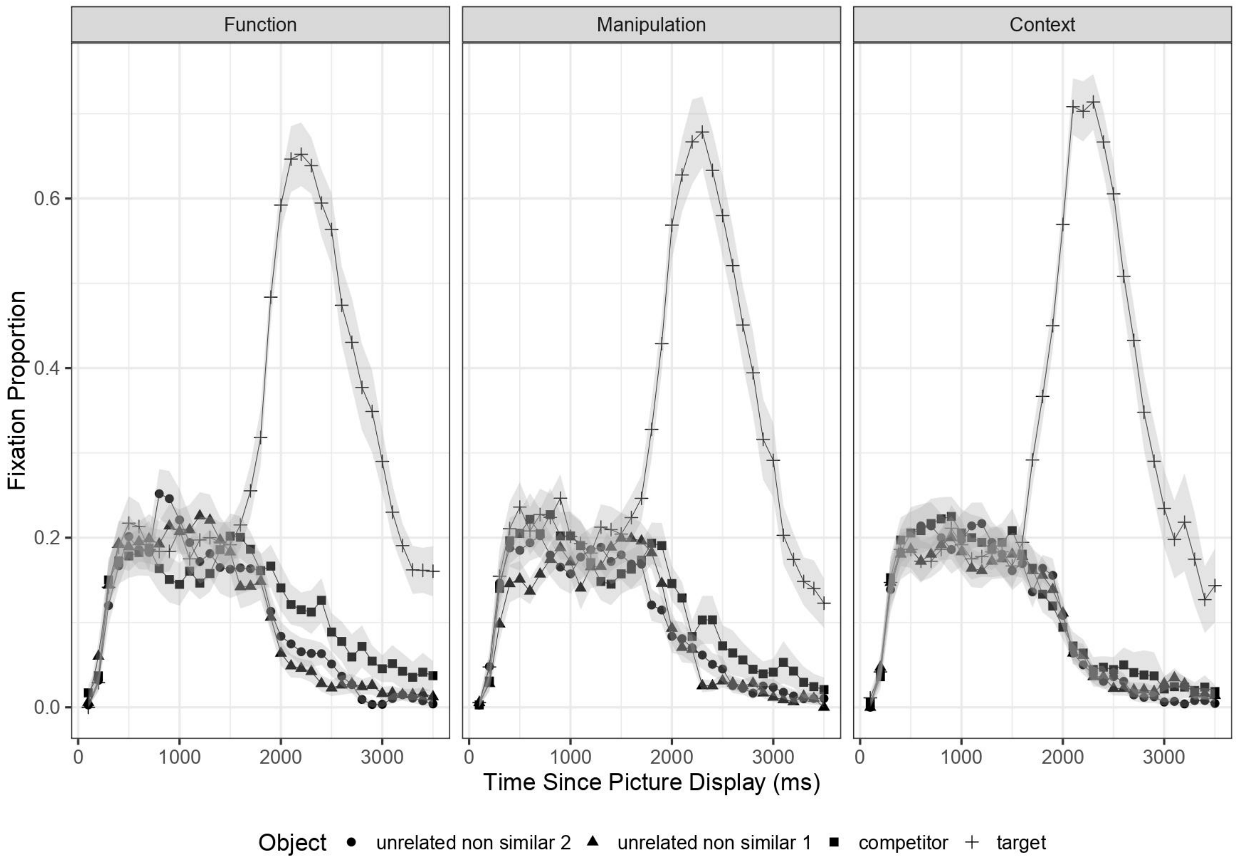


Figure 4. Mean fixation proportion (points) to the target, competitor, and unrelated objects as a function of time since the presentation of the picture display and semantic condition in Experiment 1. The statistical analyses was computed on the data from the preview window (0-1000) and from the competition window (from word onset, i.e. 1000-3000 ms).

Results from the preview window.

The model fits of the data of the preview window explained 87% (R^2= .87) and 83% (R^2 = .83) of total variance in the by-subject (1) and by-item (2) analyses, respectively. Test of the fixed effects of this model showed significant interactions between object types and conditions.

- There was greater anticipatory looks on the related distractor (ObjR) compared to the unrelated (ObjU) distractor in the manipulation (Manip) condition in comparison to the function (Function) condition [(intercept) ObjR:Manip (1)= + 0.059, SE = 0.024, df = 153.5, t = 2.419, p =.016, R^2 = .008; (intercept) ObjR:Manip (2) = + 0.061, SE = 0.026, df = 153.1, t = 2.327, p =.021, R^2 = .013].

- Similarly, there was greater anticipatory looks to the target (ObjT) compared to the unrelated (ObjU) distractor in the manipulation compared to the function condition [intercept estimate (1) for ObjT:Manip = +0.055, SE = 0.024, df = 153.5, t = 2.259, p =.025, R^2 = .007; intercept estimate (2) for ObjT:Manip = +0.061, SE = 0.026, df = 153.5, t = 2.327, p = .021, R^2 = .012].
- Finally, there was also greater anticipatory looks to the target compared to the unrelated distractor in the manipulation compared to the context (Context) condition [intercept estimate (1) for ObjT:Manip = +0.048, SE = 0.024, df = 96.67, t = 2.067, p =.041, R^2 = .009; intercept estimate (2) for ObjT:Manip = +0.049, SE =0.027, df = 102.05, t = 1.82, p =.071, R^2 = .013).

In brief, results from the preview window showed that unexpectedly, before word onset, participants fixated the target and the related distractor more than the unrelated distractor in the manipulation condition, in comparison to the function condition, and to a certain extent, to the context condition. Therefore, random effect estimates reflecting anticipatory looks to the different related distractors compared to the unrelated distractor were entered as covariate in the subsequent analysis of the competition effects after word onset.

Results from the competition window.

The model fit of the data of the competition time window is presented on Figure 5A. The model explained 76% (r^2 =0.76) and 71% (r^2 =0.71) of variance in the by-subject (1) and by-item analyses (2), respectively. The full results concerning the effects of interest are reported in Table 1 of Appendix C. On the intercept term, there was a main effect of object relatedness [(intercept) ObjR (1) = +0.026, SE = 0.012, df = 91.67, t = 2.29, p =.024, R^2 =.007; (intercept) ObjR (2) = +0.027, SE = 0.008, df = 91.797, t = 3.260, p = .002, R^2 = .015) that was not modulated by condition (all t-values for object relatedness x condition interactions <1.36). The main effect of object relatedness on the intercept reflected overall more fixations on the competitor than on the unrelated distractor, regardless of the type of competitor.

Interactions between semantic condition and object relatedness were however visible on the time terms, indicating differences in the time course of the competition effect between conditions (see Figure 5B).

- The curves of the manipulation and function competition effects differed on the quadratic term [t2:ObjR:Manip (1) = +0.143, SE = 0.056, df = 103.34, t = 2.573, p =.012, R^2 = .005; t2:ObjR:Manip (2) = +0.141, SE = 0.051, df = 98.47, t = 2.791, p =.006, R^2 = .010)]. This interaction reflected the fact that the function competition curve was more centrally distributed than the manipulation competition curve; in comparison the manipulation competition curve was flatter and thus more present at the extremities of the time window.

- The curves of the context and function competition effects differed on both the linear term [t1:ObjR:Context (1) = -0.163, SE = 0.074, df = 81.09, t = -2.199, p =.031, R^2 = .006; t1:ObjR:Context (2) = -0.166, SE = 0.060, df = 94.85, t = -2.767, p =.007, R^2= .014] and the quadratic term [t2:ObjR:Context (1) = +0.187, SE = 0.056, df = 103.93, t = 3.356, p =.001, R^2 = .008; t2:ObjR:Context (2) = +0.186, SE = 0.051, df = 98.47, t = 3.683, p =.000, R^2 = .018]. These interactions reflected the fact that the context competition curve was also flatter and with a smaller positive slope than the function competition curve.

- The manipulation and context competition curves only differed at their very extremities, as indicated by quartic differences [t4:ObjR:Context (1) = -0.105, SE = 0.047, df = 76.13, t = -2.254, p =.027, R^2 = .004; t4:ObjR:Context (2) = -0.103, SE = 0.046, df = 66.44, t = -2.242, p =.028, R^2 = .008].

The effects of the covariates, i.e. differences in anticipatory fixations in the by-subject analyses (1) and differences in visual similarity and degree of semantic relatedness in the by-item analyses (2) on the fixation curve were never significant.

Note that when the effect of object relatedness was tested separately in each condition, differences between related and unrelated distractor curves were visible in the function and the manipulation condition, but not in the context condition.

In the Function condition, the effect of object relatedness was visible:

- on the intercept, at least in the by-item analysis [(intercept) ObjR (1) = +0.026, SE = 0.018, df = 35.83, t = 1.439, p =.159 R^2 = .0018; (intercept) ObjR (2) = +0.027, SE = 0.008, df = 25.94, t = 3.159, p =.004, R^2 = .049], with overall more fixations on the distractor related by function than the unrelated distractor.
- on the linear term [t1:ObjR (1) = +0.149, SE = 0.052, df = 17.301, t = 2.874, p =.010, R^2 = .027; t1:ObjR (1) = +0.152, SE = 0.044, df = 29.211, t = 3.428, p = .002, R^2 = .073].
- on the quadratic term [t2:ObjR (1) = -0.150, SE = 0.033, df = 18.362, t = -4.550, p =.000, R^2 = .027; t2:ObjR (1) = -0.149, SE = 0.040, df = 30.73, t = -3.743, p =.001, R^2 = .071].

Both the positive slope and the central inflexion of the function competition curve indicated the presence of a competition effect in the later part of the time window in this condition.

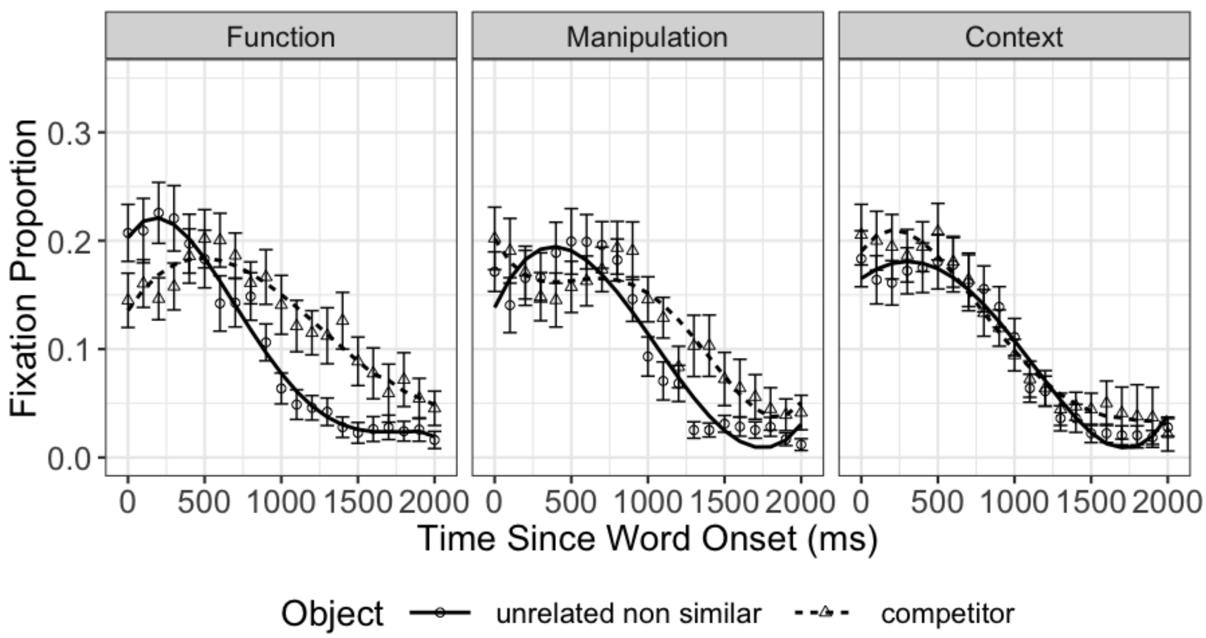
In the Manipulation condition, the effect of object relatedness was obvious:

- on the intercept, at least in the by-item analysis [(intercept) ObjR (1) = +0.021, SE = 0.011, df = 19.97, t = 1.841, p =.081, R^2 = .013; (intercept) ObjR (2) = +0.021, SE = 0.008, df = 21.48, t = 2.697, p =.013, R^2 = .025], with overall more fixations on the distractor related by manipulation than the unrelated distractor.
- on the cubic term [t3:ObjR (1) = -0.104, SE = 0.045, df = 32.27, t = -2.310, p =.027, R^2= .015; t3:ObjR (2) = -0.105, SE = 0.030, df = 27.28, t = -3.500, p =.002, R^2= .030].
- on the quartic term, at least in the by-item analysis [t4:ObjR (1) = +0.060, SE = 0.033, df = 38.02, t = 1.818, p =.077, R^2 = .005; t4:ObjR (2) = +0.059, SE = 0.020, df = 636.87, t = 3.007, p =.003 R^2 = .010].

The negative cubic estimate and the positive quartic estimate also reflect the fact that the manipulation competition effect was not equally distributed over time and appeared early in the time window.

In brief, results from the competition window highlighted differences of timing, more than differences in amplitude, in the competition effect elicited by function, manipulation and context competitors. Function competition effects were more centrally distributed and particularly present in the second part of the time window whereas manipulation competition effects emerged earlier and were less present in the central part of the time window. Competition effects with context competitors were not reliable and time-dependent.

A)



B)

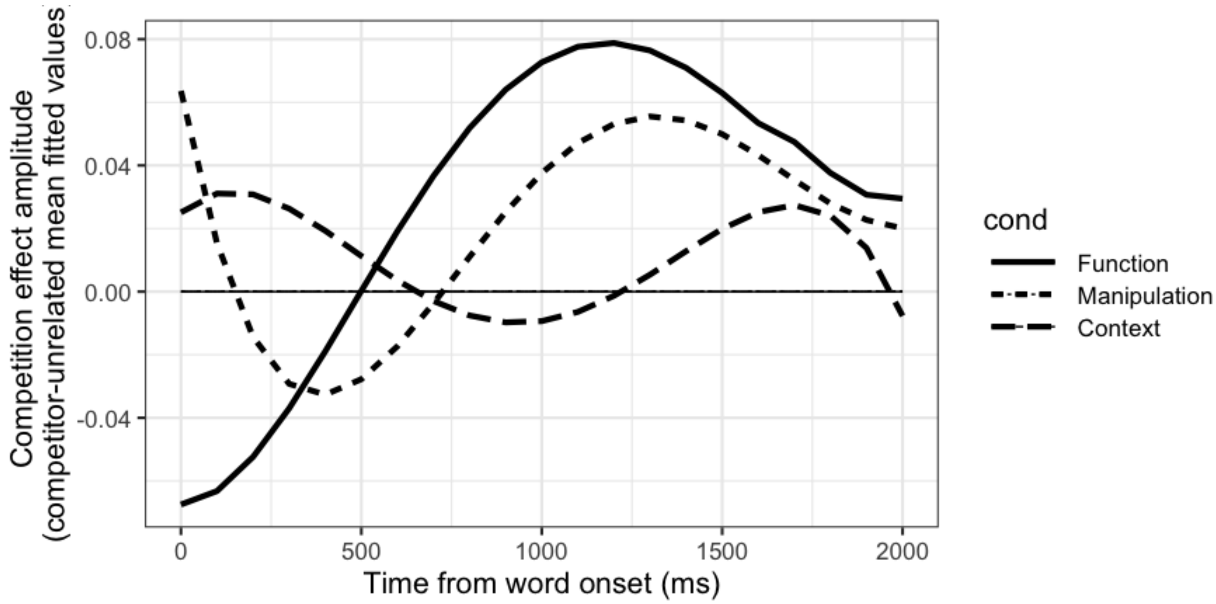


Figure 5. A) Model fit (lines) of the fixation data (points = means; error bars = standard errors) from the competition time window for the function (left), manipulation (middle), and context (right) conditions in Experiment 1. B) Time course of the competition effect amplitude corresponding to the difference in the fitted proportion of fixations between the competitor and unrelated objects as a function of time and condition.

Discussion

Results from Experiment 1 showed that, in line with our hypotheses, competitor objects for function and manipulation received more fixations than unrelated distractors. Importantly, these results cannot be explained by a) the amount of anticipatory fixations on the different objects during the preview of the pictures; b) differences in visual similarity between target and related distractor across function, manipulation and context conditions; and c) variations in the degree of semantic relatedness between target and competitor across conditions. Although the amplitude of the competition effect in the context condition did not significantly differ from the amplitude of the competition effect in the function and manipulation conditions, the difference in fixation proportions between the unrelated and related distractor objects did not reach significance in the context condition. Consistently, mouse clicks were the fastest in this condition, indicating that contextual distractors did not compete as much for attention. This suggests that context knowledge may not be primarily activated when individuals have to identify an object. One possibility is that activation of context information requires more time than the 1000 milliseconds of object preview that we allowed in the current task. Another possibility is that context knowledge is more relevant for other kinds of categorization tasks, such as those demanding an explicit analysis of the object properties (e.g., hand-made vs natural elements, etc). These speculations would need further studies.

In addition, both function and manipulation competition effects were significant on the intercept and the amplitude of the competition effects in the function and manipulation conditions did not significantly differ, indicating that they were equally good competitors. This result is consistent with the idea that both function and manipulation knowledge are central sources of information for manipulable manufactured object concepts. However, growth curve analysis results highlighted timing differences between function and manipulation conditions. The competition effect in the function condition was more centrally distributed compared to the manipulation condition that was more distributed over the whole time window, suggesting an earlier emergence of manipulation competition effects. This would contrast with some past studies (Garcea & Mahon, 2012; Collette et al., 2016) that have suggested a primary role of function with respect to the manipulation knowledge in accessing to object identity. Importantly, this effect could not be entirely explained by differences in visual similarity or in degree of semantic relatedness between the two types of semantic relations, as the results resisted these controls in the by-item analyses. Besides, earlier competition effects with manipulation distractors were not totally accounted for by the relatively greater number of anticipatory fixations on the manipulation distractor before word onset. Therefore, it seems that the type of object conceptual processing at play in word-to-picture matching recruits manipulation knowledge before function knowledge. This is consistent with the idea that the object features that are more closely bound to our sensorimotor experience with objects are more quickly activated from object concepts.

Although the earlier manipulation competition effects were not due to the greater visual similarity between targets and the competitor objects for manipulation, we cannot rule out the possibility that manipulation compared to the function knowledge may be more tied to visual features in the representation of objects. The extent to which visually similar objects, in terms of similar contour/shape, competes with semantically related objects during object identification will be explored in Experiment 2. Therefore, in Experiment 2 we contrasted the competition effects elicited by two types of distractors presented in the same display: a semantically related distractor (by manipulation, function or context) and a semantically unrelated but visually similar distractor. The visually similar distractor was considered the baseline for the computation of the competition effect and competition effect curves were compared among conditions.

EXPERIMENT 2

Experiment 2 differed from Experiment 1 in that one of the two unrelated objects was replaced by a visually related distractor. Therefore, the critical displays contained a target object, a semantically related object (for function, manipulation or context), a semantically unrelated and visually dissimilar object and a semantically unrelated but visually similar object.

Participants. 20 participants took part into the experiment (8 males; age range: 22-31; mean age: 25.65). They were recruited among students of the University of Lille (France).

Procedure, Experimental design and Data Analysis.

Procedure, experimental design and data analysis were the same as Experiment 1 except for a semantically unrelated but visually similar object that was included along with the target, the semantic competitor and the completely unrelated object. Specifically, we selected 18 objects that were rated by 12 participants (see Appendix B/3 for all the details) as being as least as visually similar to the target (contour shape, internal details) to the target object with respect to all the other competitors and unrelated objects. Importantly, the visually similar objects were completely unrelated to the targets on all other semantic dimensions (i.e. function, manipulation and context).

This unrelated object was considered the baseline for the computation of the competition effect. Thus, the fixed effect of Object relatedness still involved two levels, related or unrelated, but the unrelated was visually similar.

In Experiment 2, we tested whether the semantically related distractor would still compete more for attention than the unrelated but visually similar distractor (main effect of object relatedness) and whether the effect of object relatedness would interact with semantic conditions. This will inform about the priority of the different semantic features over visual features during object conceptual processing. It will further evaluate to what extent semantic features, and especially manipulation features, are related to visual features in object representations: if the manipulation and visual features are closely tied, then fixation curves on manipulation and visual distractors should largely overlap and the competition effect contrasting semantically related and unrelated distractors should not be visible anymore (*cf*. Colette et al., 2016).

Results

Participants were overall highly accurate in identifying the target object among distractors in all three conditions, performing at 98 %, 99 % and 100 % in the Function, Manipulation, and Context conditions, respectively. A non-parametric Friedman test of differences among repeated measures was conducted and rendered a Chi-square value of 8.16 (df =2) which was significant (p= .017; Kendall's W= .012). The post-hoc test (Wilcoxon signed ranks test) showed that participants' performance in the function condition was less accurate than in context condition (z= 2.52; p = .011; effect size r= .13). No other significant differences were found. Mean computer mouse click reaction times (RTs) from display onset were 2638 msec, 2644 msec, 2581 msec in the Function, Manipulation, and Context conditions, respectively. The Friedman test rendered a Chi-square value of 8.54 (df= 2) which was significant (p= .014; Kendall's W= .012). The post-hoc test (Wilcoxon signed ranks test) showed that participants in context condition were faster than in manipulation (z= 3.41; p = .0006; effect size r= .18) and function condition (z= 2.02; p = .04; effect size r= .11). Although performance was very high in all conditions, mouse click results suggest that object identification was more difficult when a manipulable similar and a function+visually similar distractors were present in the display.

Fixation data were collected from the onset of the picture display to the mouse click. Each trial received between 1 and 43 fixations (mean= 8.84, SD = 3.5). Trials where participants clicked on the incorrect picture or with mouse response times above 3 standard deviations from the participant's mean in that condition were excluded from fixation analyses (1.1% of data). Figure 6 shows the averaged time course of fixations to the target, competitor, unrelated similar and unrelated non similar objects from display onset as a function of condition.

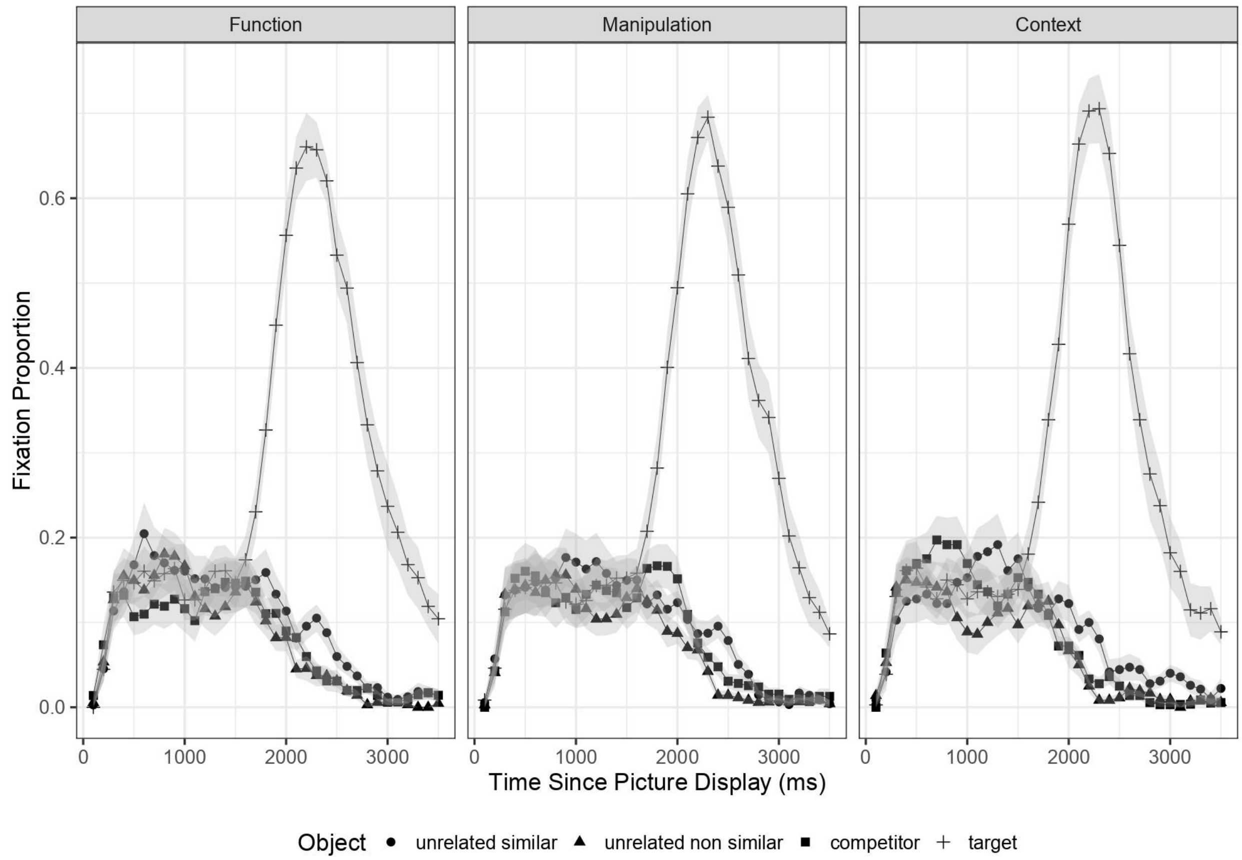


Figure 6. Mean fixation proportion (points) to the target, competitor, unrelated similar and unrelated non similar as a function of time since the presentation of the picture display and semantic condition in Experiment 2. The statistical analyses was computed on the data from the preview window (0-1000) and from the competition window (from word onset, i.e. 1000-3000 ms).

Results from the preview window.

The model fits of the data of the preview window explained 90% (R^2 = .90) and 80% (R^2 = .80) of total variance in the by-subject (1) and by-item (2) analyses, respectively. Test of the fixed effects of this model showed significant differences between semantically related and unrelated objects that were modulated by the semantic condition.

- There was greater anticipatory looks on the unrelated but visually similar distractor (ObjU) compared to the related (ObjR) distractor overall [(intercept) ObjR (1) = -0.029, SE = 0.013, df = 156.09, t = -2.106, p =.036, R^2 = .003; (intercept) ObjR (2) = -0.027, SE = 0.012, df = 146.07, t = -2.290, p =.023, R^2 = .009].

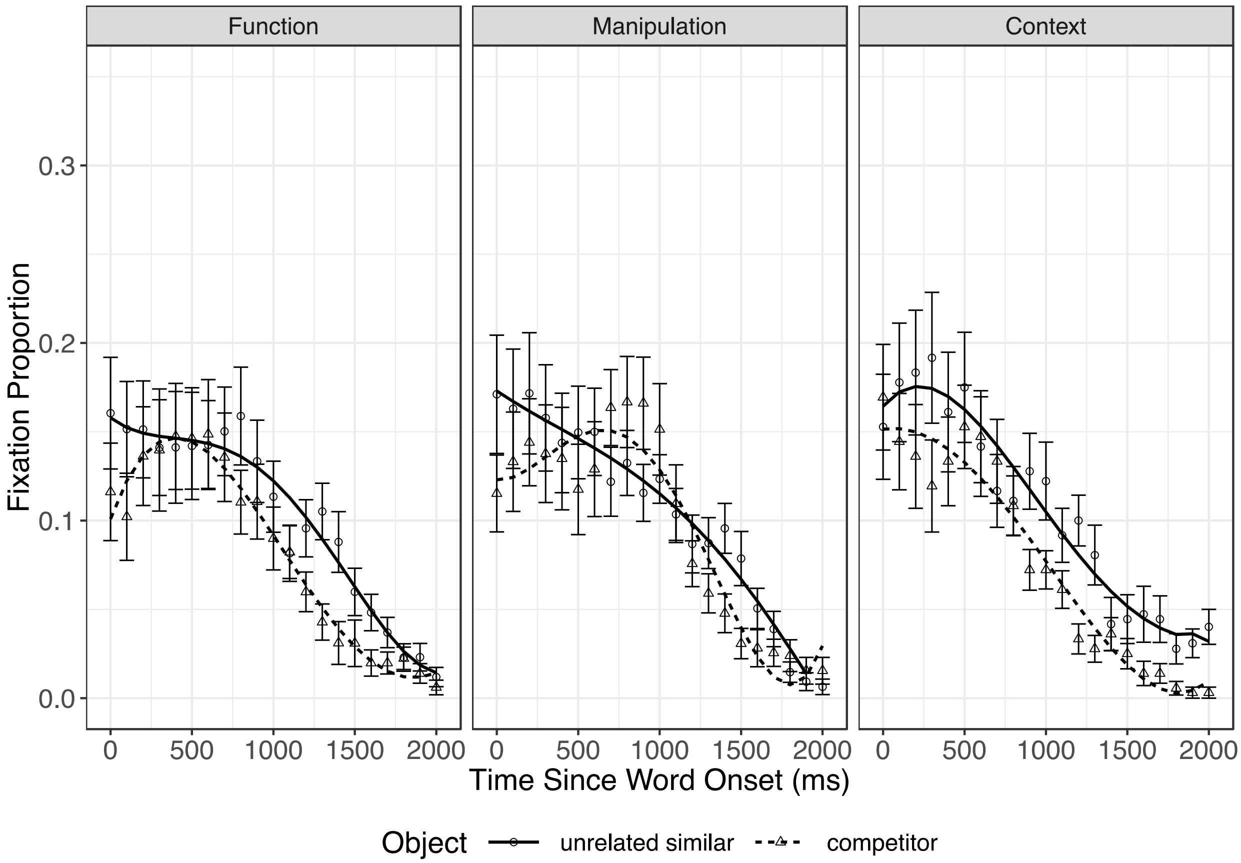
- The advantage of the unrelated but visually similar distractor was more pronounced in the function (Function) than in the context (Context) condition [(intercept) ObjR:Context (1) = + 0.066, SE= 0.019, df= 156, t= 3.392, p=.001, R^2=.009; (intercept) ObjR:Context (2) = + 0.062, SE = 0.017, df = 146.07, t = 3.811, p =.001, R^2 = .026] and in the manipulation (Manip) than in the Context condition [(intercept) ObjR:Manip (1) = + 0.051, SE = 0.019, df = 102.6, t = 2.537, p =.013, R^2 = .007; [(intercept) ObjR:Manip (2) = +0.051, SE = 0.016, df = 95.53, t = 3.113, p =.002, R^2 = .024].

In brief, results from the preview window indicated that before word onset, participants fixated the unrelated but visually similar distractor more than the related distractor, in particular in the manipulation and function conditions. Therefore, random effect estimates reflecting anticipatory looks to unrelated versus related distractors were entered as covariate in the subsequent analysis of the competition effects after word onset.

The model fit of the data of the competition time window is presented in Figure 7A. The model explained 76% (R^2 =0.76) and 67% (R^2 =0.67) of variance in the by-subject (1) and by-item analysis (2), respectively. The full results concerning the effects of interest are reported in Table 2 of Appendix C. On the intercept term, there was a main effect of object relatedness [(intercept) ObjR (1) = -0.021, SE = 0.007, df = 94.75, t = -2.94, p =.004, R^2 =.004; [(intercept) ObjR (2) = -0.022, SE = 0.007, df = 89.37, t = -3.099, p =.003, R^2 =.012]. The main effect of object relatedness on the intercept reflected a general advantage of the unrelated but visually similar distractor that received more fixations than the related distractor. Yet the effect of object relatedness was modulated by condition. The advantage of the unrelated but visually similar distractor (ObjU) over the related distractor (ObjR) was more important in the Context than in the Manip condition [(intercept) ObjR:Context (1)= -0.020, SE = 0.010, df = 56.66, t = -2.020, p =.048, R^2 = 0.003; [(intercept) ObjR:Context (2) = -0.020, SE =.009, df = 55.29, t = -2.143, p =.037, R^2 =.007]. There were no significant differences between the Function condition and the other conditions.

In Experiment 2, interactions between semantic condition and object relatedness did not reach significance, neither on the intercept term nor on the time terms (all t-values < 1.75), indicating that the competition curves did not differ significantly between the three conditions (see Figure 7B).

A)


Function
Manipulation
Context
Fixation Proportion
0.0
0.1
0.2
0.3
0
500
1000
1500
2000
Time Since Word Onset (ms)
Object
unrelated similar
competitor

B)

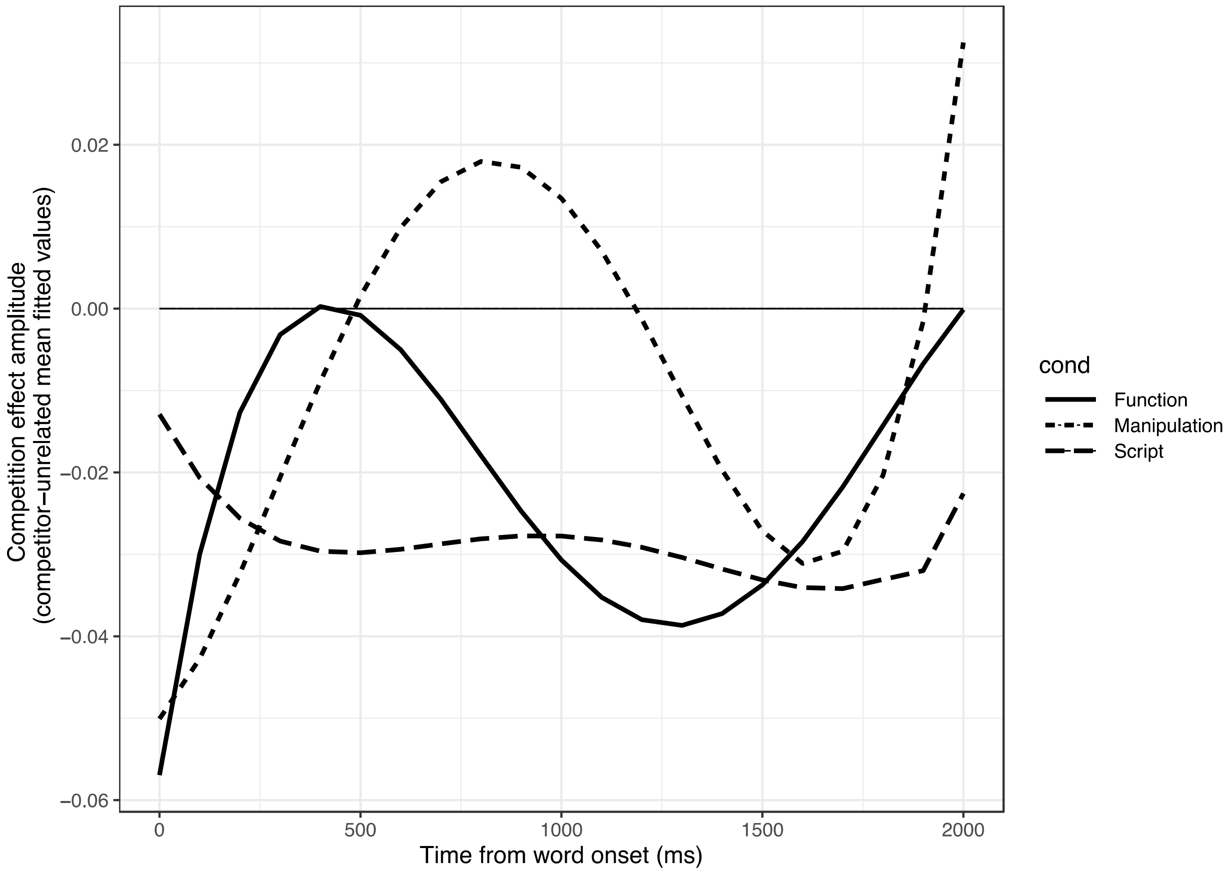


Figure 7. A) Model fit (lines) of the fixation data (points = means; error bars = standard errors) from the competition time window for the function (left), manipulation (middle), and context (right) conditions in Experiment 2. B) Time course of the competition effect amplitude corresponding to the difference in the fitted proportion of fixations between the competitor and unrelated objects as a function of time and condition.

The effects of the covariates, i.e. differences in anticipatory fixations in the by-subject analyses (1) and differences in visual similarity and degree of semantic relatedness in the by-item analyses (2) on the fixation curve were never significant.

Note that when the effect of object relatedness was tested separately in each condition, the general advantage of the unrelated but visually similar distractor over the related distractor was significant in the Function and Context condition, but not in the Manipulation condition.

In the Function condition, the effect of object relatedness was visible:

- on the intercept [(intercept) ObjR (1) = -0.021, SE = 0.009, df = 22.25, t = -2.351, p =.028, R^2 =.013; (intercept) ObjR (2) = -0.022, SE = 0.009, df = 24.91, t = -2.564, p =.017, R^2 =.025], with overall more fixations on the unrelated visually similar than the related distractor.
- on the cubic term [t3:ObjR (1) = +0.064, SE = 0.035, df = 26.31, t = 1.85, p =.076, R^2 = .006; t3:ObjR (2) = +0.065, SE = 0.030, df = 29.24, t = 2.177, p =.038, R^2 =.011]. The positive cubic estimate reflects the fact that the advantage of the unrelated visually similar distractor was more salient in the second part of the time window.

In the Manipulation condition, the effect of object relatedness was only present on the cubic term [t3:ObjR (1) = +0.073, SE = 0.030, df = 32.84, t = 2.453, p = 0.020, R^2=.007; t3:ObjR (2) = +0.074, SE = 0.030, df = 32.55, t = 2.465, p =.019, R^2=.020]. In the absence of intercept difference, the positive cubic estimate reflects the fact that the advantage of the unrelated visually similar distractor was only present in the second part of the time window.

In the Context condition, the effect of object relatedness was only present on the intercept term [(intercept) ObjR (1) = -0.028, SE = 0.008, df = 19.41, t = -3.420, p =.003, R^2 =.023; (intercept) ObjR (2) = -0.028, SE = 0.007, df = 21.49, t = -4.150, p =.000, R^2 =.046], with overall more fixations on the unrelated visually similar than the related distractor.

In brief, results from the competition window showed that the unrelated but visually similar distractor was overall a better competitor than the semantic competitor. The advantage of visual similarity was even stronger when a context competitor was present in the display, but was similar between displays involving function and manipulation competitors. Nonetheless it should be noted that the superiority of the visually similar distractor reached significance in the Function and Context conditions, but not in the Manipulation condition.

Discussion

Results from Experiment 2 revealed that the presence of objects visually similar to the target affected the competition effects with function, manipulation, and context distractors, even if some differences were visible. As in Experiment 1, results could not be attributed to the amount of anticipatory fixations on the different objects during their preview or to variations in visual similarity or degree of semantic relatedness between target and competitor across conditions.

Overall, the visually similar distractor was favored over semantic competitors, regardless of the condition. This indicates that surface visual features are prioritized over semantic attributes in a word-to-picture matching task and suggest that, although visual similarity scores did not covariate with the amount of fixation proportions (see Experiment 1), part of perceived similarity between objects related by function, manipulation or context may be caused by visual similarity. Interestingly, the difference in the amount of fixations to the visually similar and manipulation distractor did not reach significance, in contrast to the other conditions. This second result should be considered with caution since competition effect amplitude did not significantly interact with condition. Yet this might nuance the role of visual similarity in manipulation competition effects. One possibility is that it reflects the greater resemblance in contour/shape of objects that are usually manipulated in the same way. This was indeed reflected in our similarity ratings (see Appendix B/3), but taken into account in the by-item analyses. Another non-exclusive possibility is that activation of visual features may have somehow spread to related sensorimotor features, which would have benefited to the manipulation competitor, as if priority was given to sensorimotor features overall. These effects could have been enhanced by the fact that manipulation and visual distractors were previewed together before word onset: the presence of both visual and manipulation similarities between pictures may have increased their commonalities.

We speculate that the pattern of results observed in Experiment 2 reflects the priority of sensorimotor features in object recognition. The shape represents the base-structure of an object and allows its recognition (Bülthoff & Edelman, 1992; Tarr & Bülthoff, 1995; but see Biederman & Gerhardstein, 1995). Furthermore, according to the ecological approach to the visual perception (Gibson, 1979) and the evidence about the effect of object recognition on motor planning, the shape of an object affords information useful for reaching and grasping that object (Gentilucci, 2002). Finally, neurons in the anterior intraparietal area were found to respond selectively to the observation of objects of a particular size, shape and orientation (Murata et al., 2000), suggesting the involvement of a parieto-frontal network in performing visuo-motor transformations that allow object interaction. In other words, the shape of an object would automatically activate the motor program useful for acting with it (van Elke et al., 2009). If we assume that "shape" is a critical feature for recognizing an object and interacting with it, then we should expect that it has a primary role in guiding the visual search, quickly followed by manipulation features. Other attributes, such as what it is used for (i.e. function information), would become more relevant later during the recognition process. This is consistent with the idea that the access to object concepts during word-to-picture matching occurs first through sensorimotor simulation of past perceptual and motor experience with objects (Barsalou, 1999).

In summary, results from Experiment 2 would suggest that the object identification process, at least in the context of a visual search, is primarily driven by the visual features of the object, and possibly extending to sensorimotor features. However, the absence of a strong advantage of visually similar object in the manipulation condition does not mean that manipulation knowledge is more important than function knowledge for object recognition. As a matter of fact, we found that function distractors on one hand, and manipulation distractors on the other hand compete for attention during target visual search when no visual objects were present in the display (Experiment 1) and did not compete for attention anymore when visually similar objects were presented in the display. So the question arises whether manipulation and function distractors induce similar competition when presented in the same visual array, which will be explored in the last experiment. In turn, this will reveal whether the two competitors are equally important or not in guiding the visual search of the target object.

EXPERIMENT 3

The crucial condition of the Experiment 3 was the one in which the distractor object sharing the same manipulation and the distractor object sharing the same function of the target object were presented in the same visual display (Function vs. Manipulation). Furthermore, since objects with a similar function can usually share the same context, we created another condition in which the possible confound of context similarity was assessed. Therefore, in the second condition the object sharing the same function and the one sharing the same context have been included in the same visual display (Function vs. Context). Finally, by following the same logic, a last condition was added in which the object sharing the same manipulation and the one sharing the same context have been presented in the same visual display (Manipulation vs. Context). Therefore, the trials of the three conditions contained a reference object (the target), two competitors (i.e. manipulation vs. function; function vs. context; manipulation vs. context) and a semantically unrelated and visually dissimilar object.

Participants. Twenty participants entered the experiment (10 males; age range: 19-26; mean age: 22.10). They all were students of the University of Lille (France).

Procedure, Experimental design and Data Analysis.

Procedure, experimental design, and data analyses were the same as Experiment 1 except for the visually similar but semantically unrelated object that was replaced by an alternative semantic distractor. Accordingly, the fixed effect of Object relatedness involved two levels, related 1 and related 2, each semantic competitor being put against the other in 3 conditions (Function vs. Manipulation, Manipulation vs. Context vs. Function). In contrast to the previous experiments, the effect of Object relatedness was directly tested in the 3 conditions separately since there was no reason to compare this effect among conditions.

In the Experiment 3, the semantically related objects benefited from their semantic and visual similarity with the prime, as in Experiment 1. Thus, we expected Manipulation and Function competitors to receive more and/or earlier fixations than Context competitors. When contrasting Manipulation and Function competitors directly, results from Experiment 1 suggested no differences in the overall number of fixations received (i.e. they should be equally good competitors overall), but possible differences in timing, with an early advantage of the manipulation competitor in the time window.

Results

Participants were overall highly accurate in identifying the target object among distractors in all three conditions, performing at 99 %, 100 % and 99 % in the Function, Manipulation and Context conditions, respectively (no significant differences among conditions with Friedman test: $\chi^2 = 5$; $p = .08$; Kendall's W= .006).

Mean mouse click reaction times from display onset were 2754 msec, 2764 msec, 2717 msec in the Function vs Manipulation, Manipulation vs Context, and Function vs Context conditions, respectively. Results from Friedman test revealed no significant difference among the three conditions (χ^2 = 2.15, df= 2; p= .34; Kendall's W= .004).

Fixation data were collected from the onset of the picture display to the mouse click. Each trial received between one and 28 fixations (mean= 9.1, SD = 2.5). Trials where participants clicked on the incorrect picture or with mouse response times above 3 standard deviations from the participant's mean in that condition were excluded from fixation analyses (1.8% of data). Figure 8 shows the averaged time course of fixations to the target, the two competitors and unrelated distractor from display onset as a function of condition.

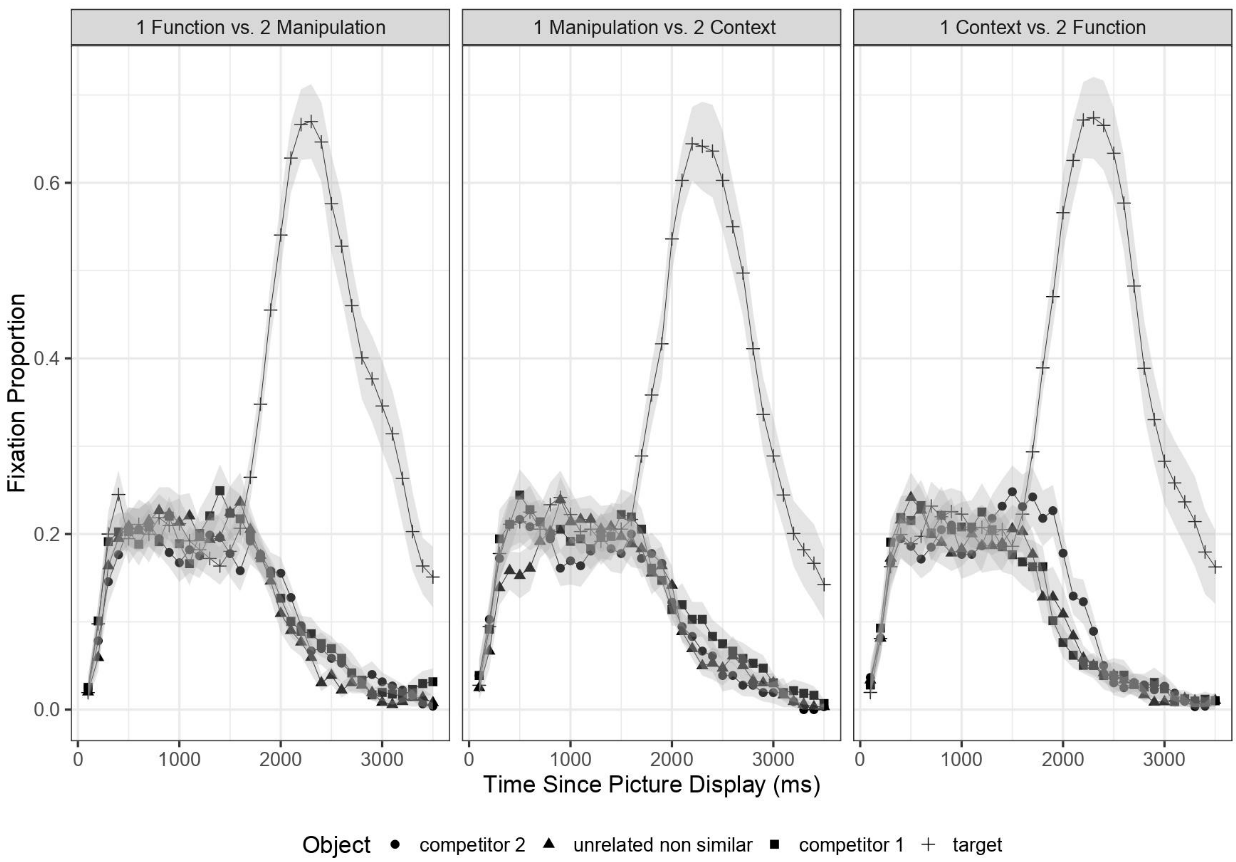


Figure 8. Mean fixation proportion (points) to the target, competitor 1, competitor 2 and unrelated non similar as a function of time since the presentation of the picture display and condition in Experiment 3. On the left, competitor 1 is function and competitor 2 is manipulation; in the middle competitor 1 is manipulation and competitor 2 is context; on the right competitor 1 is context and competitor 2 is function. The statistical analyses was computed on the data from the preview window (0-1000) and from the competition window (from word onset, i.e. 1000-3000 ms).

Function vs. Manipulation

The model fits of the data of the preview window explained 82% of total variance (R^2 = .82) in both the by-subject (1) and by-item (2) analyses. Test of the fixed effects of this model did not show any significant differences in the anticipatory fixations towards the target or the function competitor and the alternative manipulation competitor (all t-values < 1.187). Preview data were thus not included as covariate in the analysis of fixation data from the competition window.

The model fit of the data of the competition window explained 76% (R^2 = .76) and 77% (R^2 = .77) of total variance in the by-subject (1) and by-item (2) analyses, respectively. As visible on Figure 8 (left), there were no significant differences in the global proportion of fixations towards the function and manipulation competitors [(intercept) ObjR (1) = +0.007, SE = 0.014, df = 28.87, t = 0.550, p =.586, R^2 = .002; (intercept) ObjR (2) = +0.007, SE = 0.010, df = 23.81, t = 0.719, p =.479, R^2 =.002]. Moreover, there was no statistical evidence of differences in the shape of the function and manipulation fixation curves (all t-values < 1.508 see Table 3 of Appendix C).

Manipulation vs. Context

The model fit of the data of the preview window explained 90% (R^2 = .90) and 85% (R^2 = .85) of total variance in the by-subject (1) and by-item (2) analyses, respectively. Test of the fixed effects of this model did not show any significant differences in the anticipatory fixations towards the target or the manipulation competitor and the alternative context competitor (all t-values < 0.892). Preview data were thus not included as covariate in the analysis of fixation data from the competition window.

The model fit of the data of the competition window explained 76% (R^2 = .76) and 72 % (R^2 = .72) of total variance in the by-subject (1) and by-item (2) analyses, respectively. Again, the overall difference in the proportion of fixations towards the manipulation and context competitors did not reach significance [(intercept) ObjR (1) = +0.018, SE = 0.011, df = 17.86, t = 1.720, p =.10, R^2 = .009; (intercept) ObjR (2) = +0.018, SE = 0.010, df = 17.93, t = 1.884, p =.076, R^2=.017], as visible on Figure 9 (middle). In addition, there was no statistical evidence of differences in the shape of the manipulation and context fixation curves (all t-values < .973, see Table 3 of Appendix C).

Context vs. Function

The model fit of the data of the preview window explained 87% (R^2 = .87) and 82% (R^2 = .82) of total variance in the by-subject (1) and by-item (2) analyses, respectively. Test of the fixed effects of this model did not show any significant difference in the anticipatory fixations towards the target or the context competitor and the alternative function competitor (all t-values < 1.388 see Table 3 of Appendix C). Preview data were thus not included as covariate in the analysis of fixation data from the competition window.

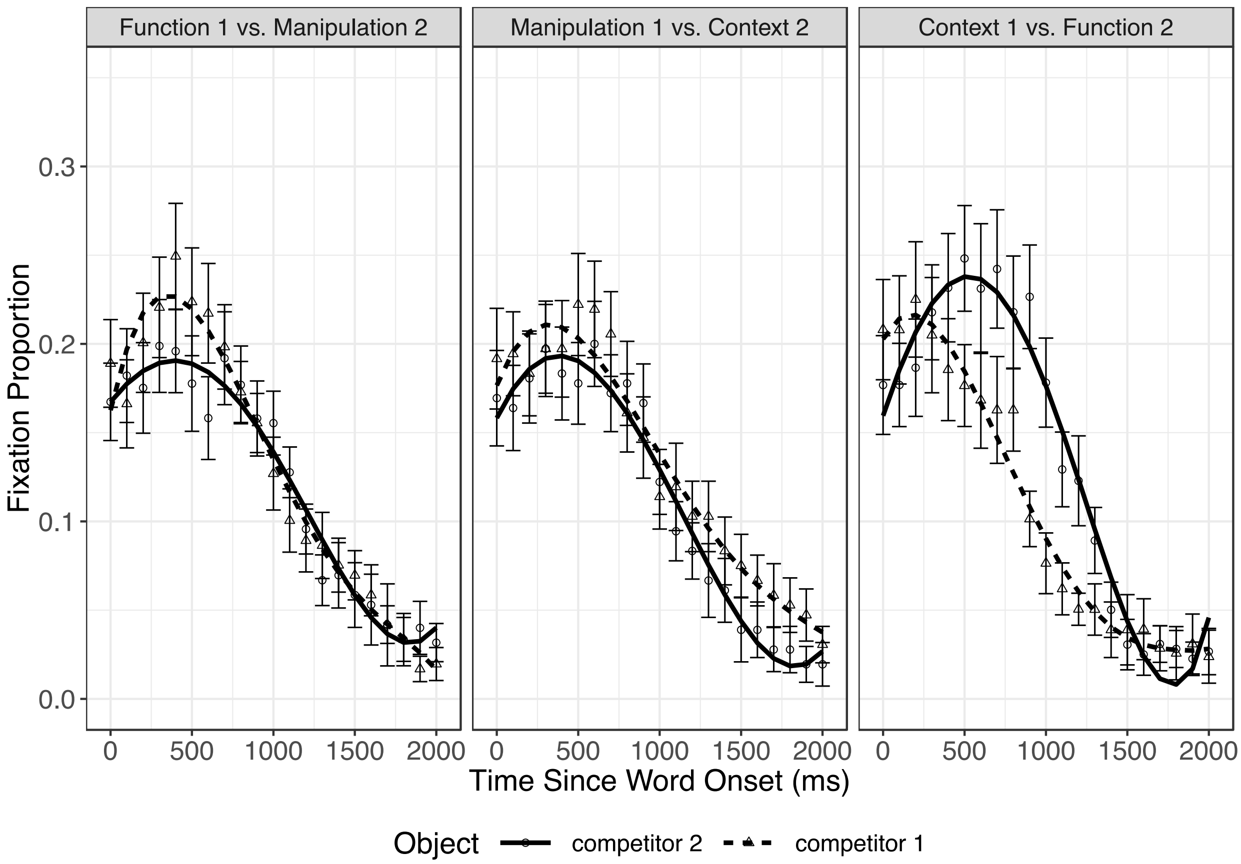


Figure 9. Model fit (lines) of the fixation data (points = means; error bars = standard errors) from the competition time window in the three conditions of Experiment 3. Left: competitor 1 = function and competitor 2 = manipulation. Middle: competitor 1 = manipulation and competitor 2 = function. Right: competitor 1 = context and competitor 2 = function.

The model fit of the data of the competition window explained 75% of total variance (R^2 = .75) in both the by-subject (1) and by-item (2) analyses. In contrast to the other conditions, results showed overall greater fixations on the function competitor compared to the context competitor when context and function competitors were directly contrasted [(intercept) ObjR (1) = -0.029, SE = 0.008, df = 22.55, t = -3.717, p =.001, R^2 = .020; (intercept) ObjR (2) = -0.029, SE = 0.006, df = 19.59, t = -4.706, p =.000, R^2= .040], as visible on Figure 9 (right). The context and function fixation curves also differ on several time terms. In particular, in both the by-subject and by-item analyses the two curves significantly differed on the quadratic term [t2:ObjR (1) = +0.166, SE = 0.052, df = 38.30, t = 3.191, p =.003, R^2 = .030; t2:ObjR (2) = +0.165, SE = 0.031, df = 23.00, t = 5.324, p =.000, R^2 = .059]. The positive quadratic estimate further indicates that the advantage of the function competitor was well centered over the competition time window.

In brief, results from Experiment 3 indicate that when directly contrasted, manipulation and function distractors on the one hand and manipulation and context distractors on the other hand were equally good competitors during object identification. Interestingly however, function largely overcomes context knowledge when directly compared.

Discussion

Results from Experiment 3 showed that when objects sharing the same manipulation as the targets were presented along with objects sharing the same function or context with the target, overall, they received a similar number of fixations. In Experiment 1 we observed that manipulation knowledge was activated slightly earlier than function knowledge during object conceptual processing. Therefore, results from Experiment 3 cast some shadows about the primary role of sensorimotor representations over more “abstract” knowledge in guiding the visual search of an object. Instead, these results support the idea that both function and manipulation represent key features of object concepts that can have an equal role in word-to-picture matching. As in Experiment 2, the co-occurrence of two related distractors in the same display might have changed the early processing of the pictures as well as their competitor roles during target identification. Contrary to previous experiments, there was no significant difference in the amount of anticipatory fixations towards the different competitors during the preview period. The reasons underlying this discrepancy remain to clarify but it suggests a different visual processing of the pictures during the preview period when two semantic distractors are simultaneously displayed. The presence of the more “abstract” semantic relations in the display might have driven visual attention away from object sensorimotor features that were prioritized when no such relations were present.

As regards the function vs context condition, the results of experiment 3 showed that objects sharing the same function received more fixations than objects sharing the same context, in accordance with the pattern of results in Experiment 1. This confirms that function knowledge cannot be reduced to mere contextual information and that the former is a more central component of manipulable object concepts.

Finally, as regards the "manipulation *vs*. context" condition, results from Experiment 1 suggested an advantage of manipulation over context competitors. However, we found them equally good competitors in Experiment 3. This suggests that manipulation and context knowledge may share some representational units. Contextual information may convey action related information about how manipulable objects are used in the same context (Kalenine et al., 2009; Iacoboni et al., 2005). For example, Kalénine and colleagues (2009) suggested that the context in which objects are experienced would work "*as a glue*" to link action events encountered with exemplars together. Indeed, there is evidence that contextual knowledge provides visual information (e.g., visual categories of object) but also motor information (Iacoboni et al., 2005). Future studies would be necessary to understand in what way and to what extent manipulation and context knowledge can be dissociated.

General Discussion

In three experiments using eye tracking in the VWP, for the first time we directly compared the activation of object manipulation and function knowledge. Furthermore, we also took into account the potential confounds of visual and context similarities. In the first Experiment, we presented participants with visual settings comprising four objects pictures: a target object, an object related to the target according to function, or manipulation, or context, and other two completely unrelated objects. Afterwards, participants heard a word indicating one of the objects and they had to identify the target object by clicking on the corresponding image. Overall, results showed that the proportion of fixations for objects sharing some semantic features (i.e. manipulation, function and context) was higher than for objects completely unrelated. Nevertheless, a closer inspection of the pattern of fixations in each condition showed that this semantic competition effect was reliable for manipulation and function, but not for context.

These results are in line with those reported in previous studies (Myung et al., 2006; Lee et al. 2013; Kalénine et al., 2012; Yee et al., 2011) confirming that object function and manipulation features are activated during object identification. Crucially, we also showed that the temporal dynamics of these activations were different, with the activation of manipulation knowledge appearing at an early stage with respect to that of function knowledge.

In order to further investigate the role of visual versus semantic similarity in the identification process, in a second Experiment we introduced an object visually similar to the target one in replacement of one of the two unrelated objects. Results showed that the semantic competition effects observed in Experiment 1 disappeared. Indeed, participants tended to fixate more the visually similar object than the ones similar in terms of function and context, whereas no differences appeared with the objects similar in manipulation. This would suggest that a) the processing of visual similarities is prioritized with respect to "functional" and "contextual" semantic features; b) the early activation observed in the manipulation condition of Experiment 1 could be due to the fact that manipulation competitors share some visual features (i.e. similar contour/shape) with the target object. Indeed, when function and manipulation competitors were directly compared (Experiment 3) no significant differences appeared between them.

Together, the findings from experiments 1 and 2 support the idea that visuo-perceptual and sensorimotor features are critical for object processing and are accessed quickly without explicit instructions, as shown also from the analysis of the preview window (i.e. participants tended to fixate more the objects visually similar, *cf.* Experiment 2, and the objects similar in manipulation, *cf.* Experiment 1, than other distractors before the target word was presented). As competition from visual similarity partially overcame competition from manipulation similarity (*cf*. Experiment 2), we assume that contour/shape similarity is a key feature of the representation of objects similar in term of manipulation. The fact that shape and manipulation properties are intrinsically linked in object concepts has been shown by Smith (2005). In this study, 2-year-old children were asked to move horizontally or vertically a novel round object associated with a novel label. Afterwards, they were shown with two elongated versions of this object, one horizontally elongated object and one vertically elongated object. Children generalized the novel label to the elongated version of the object that was congruent with their manipulation experience: they choose the vertically extended object if they had moved the exemplar along a vertical path, and vice versa. These results suggest that early object shape categories are strongly influenced by the way we usually manipulate those specific objects.

Since the contour/shape intrinsically contributes to the semantic representation of an object in terms of “manipulation” (i.e. two objects to be manipulated in the same way should have a similar shape), this may prioritize the use of sensorimotor over abstract features during object identification. This priority might come from a greater pre-activation of sensorimotor representations during picture processing, which would enhance the speed of their language-driven activation from the onset of the target word. As a matter of fact, the relevant role of action in building up conceptual representations of the external world is not novel. The importance of object manipulation has been largely maintained by Piaget (1955), who suggested that the active sensorimotor experience that children have with the external world facilitates the conceptualization of the environment. Indeed, during cognitive development an initial identity would exist between action and object, and action patterns are used to make deductions about the environment (see also Smith, 2005). Children and even adults often gain knowledge of object function by exploring the object. This is the reason why the shape of a manipulable object affords motor information on how to grasp that object (Gentilucci, 2002). In line with this, the current study shows that the relationship between object sensorimotor properties and their conceptual representation remains visible in adult conceptual processing (e.g., Goldstone & Barsalou, 1998), and it suggests that shape and related manipulation features are prioritized over function during word-to-picture matching (see also Yee et al., 2011 for a similar proposal).

Overall, this evidence would support a theoretical model of object conceptual representations in which sensorimotor features would be considered the front door for accessing object concepts. This model would belong to the modality specific theories claiming that conceptual representations are grounded in perceptual and motor representations (e.g., Barsalou, 1999; Gallese & Lakoff, 2005).

Concerning function knowledge, in line with Kalénine and colleagues (2012b), we found that it is also activated (*cf*. Experiment 1) and, as found in Experiment 3, it seems to strongly compete with manipulation knowledge when both sources of information are present in the same visual array. However, we also found that the shape of an object guides visual search more than function knowledge (*cf*. Experiment 2). In fact, when the role of visual similarity is directly assessed (*cf*. Experiment 2), its influence fades that of object function similarity. Two possible interpretations can be proposed for this evidence. The first is that visual similarity is simply an experimental confound. In other words, objects similar in term of function would receive more fixations than unrelated objects just because they are more visually similar to the target objects than the others. However, this interpretation is contradicted by the results of Experiment 3 where objects similar in term of manipulation, despite being more visually similar to the target objects, received a similar number of fixations as objects similar in term of function. The second explanation is that competition from function distractors depends on the degree of pre-activation of object functional features from the visual processing of the pictures during the one second preview. The presence of many semantically related pictures in the display might have favored the pre-activation of object functional features in Experiment 3 where similar function and manipulation competition effects were observed, in comparison to Experiment 1 where earlier manipulation than function competition effects were evidenced. In contrast, the presence of visually related pictures might have driven away visual attention from object functional features during the preview period (Experiment 1). The reasons for such effects remain to clarify but could be related to evidence showing that semantic commonalities (taxonomic relations) are more easily perceived when there are several exemplars to be observed to solve the task (e.g., see Liu, Golinkoff, & Sak, 2001). The relations between the objects present in the display probably modify object processing before the emergence of competition effects during word-to-picture matching. The recruitment of function knowledge during object identification might be particularly sensitive to the conditions of prior visual inspection.

Finally, the fact that we did not find any advantage of function over manipulation knowledge is at odds with some previous studies using explicit tasks. In fact, it has been found that the processing of object function is faster (*cf*. Garcea & Mahon, 2012) or facilitates object identification (Collette et al., 2016) in healthy adults than object manipulation. We thought that the advantage of object function over manipulation found in these two studies could be due to the fact that participants were submitted to explicit tasks. One may argue that explicit retrieval of manipulation and function knowledge may rely on slightly different processes and for certain conceptual judgements the sensorimotor information can be relevant but not strictly necessary (see Garcea & Mahon, 2012; Mahon & Caramazza, 2008; Binder & Desai, 2011; Chatterjee, 2010; Hickok, 2009). Another explanation could be in relation to the verbal responses. For example, in Collette and colleagues' study (2016) participants had to name the objects, whereas in Garcea and Mahon' study (2012) function judgments were particularly fast in comparison to manipulation judgments when words were used as stimuli along with a verbal-naming response. This speculation is supported by a study conducted by Chua and colleagues (2018) using a priming paradigm. Participants were primed with a visually presented object or an object-word, and had to perform a reach-to-grasp movement towards a target object having the same shape of the prime. Results indicated that movement time to reach-to-grasp was slower when the prime was an object-word as compared to when it was a visually presented object, thus suggesting that the movements prompted by the object-word relied on semantic knowledge. Moreover, in an fMRI study, Egorova and colleagues (2016) found activations in the left angular gyrus when participants explicitly named objects visually presented (i.e. "What are these objects called?"). The left angular gyrus is supposed to link information about word forms and the corresponding object, but the activation of brain areas involved in action-oriented tasks were not found. The third and last explanation for the absence of an advantage of function over manipulation could be due to the fact that, as suggested by Yee and colleagues (2011), object function with respect to sensorimotor information is not immediately available in the visual array participants are presented with, and its full activation would require more time as compared to the sensorimotor features. The same logic could be applied to the context knowledge for which we did not observe any clear or strong effect. It is possible that contextual information would require more time to be activated or simply it is a kind of knowledge that is more useful for other kinds of task, such as categorization or taxonomic tasks (Kalénine et al., 2009), rather than for guiding the visual search of objects. All in all, future studies need to further explore this issue, especially in the light of the absence of a difference in the number of fixations towards manipulation and context competitors when the two were presented in the same scenario.

Conclusions

For the first time we directly compared the activation of function and manipulation knowledge with a VWP and found out that both sources of knowledge are incidentally used to identify an object among distractors (*cf.* Experiment 1 and 3). Importantly, the use of the VWP allowed us to identify temporal differences between the two: activation of manipulation seems to appear earlier than function knowledge (*cf.* Experiment 1). Furthermore, results from this study highlight the importance of controlling for visual similarity. Indeed, the presence of an object with a similar contour/shape as the target reduces the appearance of semantic competition effects, although the priority of visual over semantic features may be less pronounced for manipulation knowledge (*cf.* Experiment 2). Thus, results suggest that sensorimotor features might be considered as the primary source of information individuals activate during a visual search task. Finally, another novel finding refers to the fact that contextual and manipulation information might share some relevant information (*cf.* Experiment 3) whose nature needs further explorations to be identified. From an empirical point of view, these results, along with the evidence from previous studies, suggest that the kind of knowledge that appears to be activated may depend on the characteristics of the task at hand (e.g., implicit vs explicit requirements), and on the semantic and visuo-perceptual features of the elements present in the visual scenario.

At the theoretical level, results from this study would support a model in which both sensorimotor and abstract sources of knowledge contribute to object identification but with different temporal dynamics. The modulation of the priority given to sensorimotor versus abstract features across experiments support a flexible view of object conceptual processing. The weight and timing of activation of sensorimotor features depend on the situational context and task demands, as also highlighted by situated and grounded views of conceptual representations (e.g., Barsalou 1999; Gallese & Lakoff, 2005).

Authors Note: Experiments data sets can be recovered at this link https://osf.io/e2wp9/?view_only=61db17ed1c924237af224c52a5223856 (see Ruotolo et al., 2019, in the references section).

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APPENDIX A

LIST OF ITEMS USED FOR THE CRITICAL TRIALS FOR THE THREE EXPERIMENTS

Reference object	Function	Manipulation	Context	Visually similar	Unrelated 1	Unrelated 2
Drill	Screwdriver	Sprayer	Painting	Crane*	Ball	Bench**
Umbrella	K-way	Torch	Thermometer	Switch*	Hot-air-balloon	Crane**
Shopping cart	Basket	Lawn mower	Cash register	Toaster*	Guitar	Camera**
Piano	Violin	Keyboard	Music stand	Suitcase*	Ladle	Shell**
Vacuum cleaner	Dustpan	Rake	Apron	Slide*	Notebook	Hot-air-balloon**
Bicycle bell	Bell	Joystick	Traffic light	Wristwatch*	Crown	Grater**
Lock	Padlock	Tap	House	Camera*	Peeler	Hat**
Digital lock	Key	Calculator	Mailbox	Grater*	Dart	Slide**
Magnifying glass	Binoculars	Mirror	Stamp	Medal*	Electric cable	Teddy bear**
Measuring tape	Ruler	Tape	Stepladder	Saucepan*	Mobile phone	Rocking horse**
Fan	Ventilator	Flag	Bottle	Shell*	Toilet	Chain-saw**
Stopwatch	Hourglass	Lighter	Sneaker	Satellite dish*	Knife	Helicopter**
Axe	Saw	Gavel	Woodworker jacket	Tobacco pipe*	Skirt	Book**
Scissors	Cutter	Salad tongs	Gift	Goggles*	Makeup Palette	Shoe**
Stove	Pan	Brush plates	Sink	Table clock*	Rearview	Bag**
Hinge	Button	Highlighter	Bobbin thread	Fork*	Glass	Aircraft**
Binder clip	Paper clip	Nail clipper	Typewriter	Purse*	Comb	Stool**
Toy car	Spinning top	Iron	Lollipop	Stapler*	Shovel	Circus Tent**

*Pictures only used in Experiment 2; **Picture not used in Experiment 2 and 3

APPENDIX B

1) Name agreement. Since the Experiment was carried out at the University of Lille (France), all the names of the objects presented in the trial list of Appendix A were translated in French. We asked 12 participants to freely name the objects and we included in the experiment all the objects that were named in the same way by at least 11 participants;

2) Manipulation, Function, and Context Similarity. The 18 reference pictures were paired with each of their five corresponding related and unrelated pictures (three critical competitors, two unrelated competitors). The 90 pairs were presented to 12 university students on separate sheets in random order. For each pair, they were asked to rate on a 8-point scale (0= not similar at all, to 7 = highly similar) to what extent (a) the two pictures could be manipulated in the same way; (b) the objects displayed had the same function; (c) the objects could be found in the same context. A Friedman ANOVA was carried out on the ratings for the manipulation, context, and function between the target object (i.e. the reference object) and its competitors to see if there was a difference in the strength of the semantic relationships among the three conditions. Results showed no significant difference: mean score for function = 5.71, for manipulation = 5.35; for context = 5.74; $\chi^2 = 3.63$ (N= 18, df= 2), p= .16; Kendall's W = .10. This meant that the degree of semantic relatedness was similar through the conditions. See the table below for all the other scores.

	FUNCTION Average *(SD)*	MANIPULATION Average *(SD)*	CONTEXT Average *(SD)*
Objects related for **FUNCTION**	**5.71** *(.14)*	0.89 *(0.43)*	4.86 *(1.09)*
Objects related for **MANIPULATION**	0.68 *(0.74)*	**5.35** *(.93)*	1.23 *(1.32)*
Objects related for **CONTEXT**	0.66 *(.82)*	1.15 *(.25)*	**5.74** *(.39)*
NON RELATED (mean of the two non related objects)	0.21 *(.12)*	0.26 *(.10)*	0.25 *(.16)*

Notes: as regards objects related for function, the average score for function significantly differed from manipulation and context (at least p < .005). As regards objects related for manipulation, the average score for manipulation significantly differed from function and context (at least $p < .00001$). As regards objects related for context, the average score for context significantly differed from function and manipulation (at least $p < .00001$). No differences were found for the non-related objects;

3) Visual Similarity Experiment 2. In order to see if the visually similar unrelated objects were judged as more visually similar than the function, manipulation, context related ones and the other unrelated object, we asked 12 participants to rate the visual similarity (0= not similar at all, to 7 = highly similar) of all the five competitors (i.e. visually similar, function, manipulation, context, unrelated) with respect to the target objects. An Anova for repeated measure was carried out on the visual similarity ratings. Results showed a significant difference between the ratings: $F(4, 68) = 57.12$, $p < .00001$, $\eta^2_p = .77$. The Bonferroni post-hoc test showed that participants rated as more visually similar the visually similar unrelated object (M= 4.65, SD= .96) than all the other related and unrelated competitors (at least p = .000001; see the table A for the average scores). Furthermore, participants rated the visually similar objects on their function, manipulation and context similarity with the target objects. Paired t-tests were carried out on these scores and those obtained on the objects related for function, manipulation and context respectively. Results showed that the visually similar objects were rated as less semantically related to the target ones in terms of function (t= 21.68, df= 17, p < .0000001, Cohen's d = 2.47), manipulation (t= 7.38, df= 17, p < .000001, Cohen's d = 1.43), and context (t= 3.58, df= 17, p < .005, Cohen’s d = 5.38) (see the table B for the average scores). Finally, Paired t-tests were carried out on the visual similarity scores obtained on the objects related for function, manipulation and context. Results showed that manipulation competitors were rated as more visually similar to the target than the function (t = -2.91, df= 17, p = .0098, Cohen’s d = 0.70) and context competitors (t = 4.72, df= 17, p = .0002, Cohen’s d = 1.61), and competitors for function were rated as more visually similar than the competitors for context (t = -2.38, df= 17, p = .02, Cohen’s d = 0.80).

Table A

	Objects related for **FUNCTION**	Objects related for **MANIPULATION**	Objects related for **CONTEXT**	**NON RELATED**	Objects **VISUALLY SIMILAR**
VISUAL SIMILARITY SCORES Average *(SD)*	**1.67** *(1.41)*	**2.74** *(1.63)*	**0.85** *(.27)*	**0.33** *(.44)*	**4.65** *(.96)*

Table B

	Objects **VISUALLY**

	SIMILAR Average *(SD)*
FUNCTION	**0.67** *(.69)*
MANIPULATION	**0.51** *(.70)*
CONTEXT	**1.03** *(.17)*

4) Degree of semantic relatedness (DSR). In order to control for the overall degree of semantic relatedness between the target and the objects presented in the same visual array, 26 participants were asked to assess the strength of the relationship between two objects (one of the object was always the target one) on the basis of their meaning without considering their possible visual similarity. A total of 108 dyads (18 dyads for Function, Manipulation, Context, Visually Similar, Non-related Exp1, Non-related Exp2 respectively) of objects were presented and judged on a Likert scale from 0 (non associated) to 7 (strongly associated). For each participant, all the dyads were randomly presented. For each dyad the average of judgments was calculated. Afterwards, data were separately averaged for the kind of relationship (i.e. function, manipulation, context, visual similarity, Non related Exp1, and Non related Exp2).

Table C

	Objects related for **FUNCTION**	Objects related for **MANIPULATION**	Objects related for **CONTEXT**	**NON RELATED Exp1**	**NON RELATED Exp2**	Objects **VISUALLY SIMILAR**
DSR SCORES Average *(SD)*	**6.17** *(0.82)*	**2.46** *(1.13)*	**4.55** *(1.46)*	**0.83** *(.40)*	**1.33** *(0.93)*	**1.53** *(0.90)*

An Anova for repeated measures was carried out on the scores for the 6 different relationships. Results showed a significant difference between the different kinds of relationships: $F(5, 70)=91.23$, $p=0.000001$, $\eta^2_p= 0.87$.

Bonferroni post-hoc test showed that the relation based on function similarity was rated as more meaningful than all the others, followed by Context and Manipulation. Moreover, the relationship based on context similarity was stronger than that based on manipulation similarity and the relationship based on manipulation similarity was stronger than those based on visual similarity and non related objects (at least $p< .05$). Finally, no difference was found among the relationships based on visual similarity and non related objects for both Exp1 and Exp2.

APPENDIX C

Table 1. Results of the by-subject and by-items models of the gaze data from the competition window in Experiment 1. Only results concerning the effects of interest – involving the effect of object type in isolation or in interaction with condition– are presented.

Model with Function. Manipulation, and Context conditions (Baseline: Function) and Competitor. Unrelated objects (Baseline: Unrelated)

	By-subject						By-item					
	Est.	SE	df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	0.026	0.012	91.670	2.290	0.024	0.007	0.027	0.008	91.797	3.260	0.002	0.015
ObjR:Manipulation	-0.006	0.016	91.477	-0.340	0.734	0.000	-0.005	0.012	91.797	-0.462	0.645	0.000
ObjR:Context	-0.016	0.016	91.670	-0.950	0.345	0.001	-0.016	0.012	91.797	-1.365	0.176	0.003
t1:ObjR	0.149	0.052	81.092	2.844	0.006	0.010	0.152	0.042	94.853	3.576	0.001	0.024
t2:ObjR	-0.150	0.039	103.928	-3.796	0.000	0.010	-0.149	0.036	98.475	-4.163	0.000	0.023
t3:ObjR	-0.017	0.041	112.917	-0.427	0.670	0.000	-0.020	0.036	98.634	-0.547	0.586	0.000
t4:ObjR	0.038	0.032	114.243	1.215	0.227	0.001	0.039	0.031	100.963	1.261	0.210	0.002
t1:ObjR:Manipulation	-0.082	0.074	80.750	-1.110	0.270	0.002	-0.086	0.060	94.853	-1.435	0.155	0.004
t1:ObjR:Context	-0.163	0.074	81.092	-2.199	0.031	0.006	-0.166	0.060	94.853	-2.767	0.007	0.014
t2:ObjR:Manipulation	0.143	0.056	103.342	2.573	0.012	0.005	0.141	0.051	98.475	2.791	0.006	0.010
t2:ObjR:Context	0.187	0.056	103.928	3.356	0.001	0.008	0.186	0.051	98.475	3.683	0.000	0.018
t3:ObjR:Manipulation	-0.086	0.058	112.584	-1.494	0.138	0.002	-0.086	0.050	98.634	-1.699	0.092	0.004
t3:ObjR:Context	-0.009	0.058	112.917	-0.153	0.879	0.000	-0.006	0.050	98.634	-0.126	0.900	0.000
t4:ObjR:Manipulation	0.022	0.045	113.684	0.501	0.617	0.000	0.020	0.044	100.963	0.453	0.651	0.000
t4:ObjR:Context	-0.083	0.045	114.243	-1.857	0.066	0.002	-0.083	0.044	100.963	-1.889	0.062	0.004

Model with only Manipulation and Context conditions (Baseline: Manipulation) and Competitor. Unrelated objects (Baseline: Unrelated)

	By-subject						By-item					
	Est.	SE	df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	0.021	0.010	54.841	2.085	0.042	0.007	0.021	0.008	59.871	2.727	0.008	0.014

ObjR:Context	-0.010	0.014	54.998	-0.702	0.486	0.001	-0.010	0.011	59.871	-0.944	0.349	0.002
t1:ObjR	0.067	0.057	48.452	1.164	0.250	0.003	0.066	0.043	63.448	1.542	0.128	0.006
t2:ObjR	-0.006	0.041	68.314	-0.157	0.875	0.000	-0.008	0.034	63.658	-0.231	0.818	0.000
t3:ObjR	-0.104	0.040	75.375	-2.595	0.011	0.008	-0.105	0.035	60.831	-3.039	0.003	0.017
t4:ObjR	0.061	0.033	75.776	1.842	0.069	0.003	0.059	0.032	66.437	1.821	0.073	0.005
t1:ObjR:Context	-0.081	0.081	48.629	-0.992	0.326	0.002	-0.080	0.060	63.448	-1.328	0.189	0.005
t2:ObjR:Context	0.044	0.058	68.686	0.758	0.451	0.001	0.045	0.047	63.658	0.953	0.344	0.002
t3:ObjR:Context	0.077	0.057	75.615	1.370	0.175	0.002	0.079	0.049	60.831	1.621	0.110	0.005
t4:ObjR:Context	-0.105	0.047	76.127	-2.254	0.027	0.004	-0.103	0.046	66.437	-2.242	0.028	0.008

Model with Competitor. Unrelated objects (Baseline: Unrelated) in the Function condition

	By-subject						By-item					
	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	0.026	0.018	35.832	1.439	0.159	0.018	0.027	0.008	25.942	3.159	0.004	0.049
t1:ObjR	0.149	0.052	17.301	2.874	0.010	0.027	0.152	0.044	29.211	3.428	0.002	0.073
t2:ObjR	-0.150	0.033	18.362	-4.550	0.000	0.027	-0.149	0.040	30.727	-3.743	0.001	0.071
t3:ObjR	-0.017	0.036	20.597	-0.492	0.628	0.000	-0.020	0.036	32.648	-0.547	0.588	0.001
t4:ObjR	0.038	0.027	30.535	1.401	0.171	0.002	0.039	0.030	32.759	1.315	0.198	0.005

Model with Competitor. Unrelated objects (Baseline: Unrelated) in the Manipulation condition

	By-subject						By-item					
	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	0.021	0.011	19.967	1.841	0.081	0.013	0.021	0.008	21.485	2.697	0.013	0.025
t1:ObjR	0.067	0.056	23.155	1.198	0.243	0.006	0.066	0.043	26.665	1.526	0.139	0.012
t2:ObjR	-0.007	0.044	29.756	-0.156	0.877	0.000	-0.008	0.037	28.290	-0.209	0.836	0.000
t3:ObjR	-0.104	0.045	32.273	-2.310	0.027	0.015	-0.105	0.030	27.276	-3.500	0.002	0.030
t4:ObjR	0.060	0.033	38.012	1.818	0.077	0.005	0.059	0.020	636.876	3.007	0.003	0.010

Model with Competitor. Unrelated objects (Baseline: Unrelated) in the Context condition

	By-subject						By-item					

	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	0.011	0.009	21.529	1.184	0.249	0.004	0.011	0.007	22.906	1.524	0.141	0.008
t1:ObjR	-0.014	0.052	26.289	-0.271	0.789	0.000	-0.014	0.042	24.067	-0.339	0.737	0.001
t2:ObjR	0.038	0.038	31.887	1.000	0.325	0.002	0.037	0.032	27.402	1.171	0.252	0.005
t3:ObjR	-0.026	0.027	31.786	-0.962	0.343	0.001	-0.026	0.038	25.906	-0.690	0.497	0.002
t4:ObjR	-0.044	0.032	32.320	-1.394	0.173	0.003	-0.044	0.034	29.673	-1.289	0.207	0.006

Table 2. Results of the by-subject and by-items models of the gaze data from the competition window in Experiment 2. Only results concerning the effects of interest – involving the effect of object type in isolation or in interaction with condition– are presented.

	Model with Function. Manipulation. and Context conditions (Baseline: Function) and Competitor. Unrelated objects (Baseline: Unrelated)											
	By-subject						By-item					
	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	-0.021	0.007	94.751	-2.943	0.004	0.004	-0.022	0.007	89.365	-3.098	0.003	0.012
ObjR:Manipulation	0.013	0.010	94.996	1.235	0.220	0.001	0.013	0.010	89.365	1.323	0.189	0.002
ObjR:Context	-0.007	0.010	94.933	-0.701	0.485	0.000	-0.006	0.010	89.492	-0.634	0.528	0.001
t1:ObjR	0.001	0.037	95.454	0.035	0.972	0.000	0.006	0.034	96.780	0.167	0.867	0.000
t2:ObjR	0.010	0.036	95.416	0.273	0.786	0.000	0.008	0.032	91.622	0.260	0.796	0.000
t3:ObjR	0.065	0.032	97.640	2.019	0.046	0.002	0.065	0.030	98.166	2.150	0.034	0.005
t4:ObjR	-0.028	0.033	95.332	-0.851	0.397	0.000	-0.026	0.033	100.586	-0.800	0.426	0.001
t1:ObjR:Manipulation	0.024	0.052	95.901	0.462	0.645	0.000	0.020	0.048	96.780	0.427	0.670	0.000
t1:ObjR:Context	-0.014	0.052	95.812	-0.278	0.782	0.000	-0.017	0.048	97.090	-0.359	0.720	0.000
t2:ObjR:Manipulation	-0.055	0.051	95.842	-1.062	0.291	0.001	-0.057	0.045	91.622	-1.273	0.206	0.002
t2:ObjR:Context	0.000	0.051	95.804	0.010	0.992	0.000	0.004	0.045	92.009	0.089	0.929	0.000
t3:ObjR:Manipulation	0.009	0.045	98.000	0.189	0.850	0.000	0.009	0.043	98.166	0.203	0.840	0.000
t3:ObjR:Context	-0.067	0.045	98.000	-1.487	0.140	0.001	-0.066	0.043	98.533	-1.535	0.128	0.003
t4:ObjR:Manipulation	0.073	0.047	95.605	1.564	0.121	0.001	0.072	0.046	100.586	1.553	0.124	0.003
t4:ObjR:Context	0.041	0.047	95.547	0.879	0.382	0.000	0.041	0.046	100.823	0.889	0.376	0.001
	Model with only Manipulation and Context conditions (Baseline: Manipulation) and Competitor. Unrelated objects (Baseline: Unrelated)											
	By-subject						By-item					
	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	-0.009	0.007	56.702	-1.247	0.218	0.001	-0.009	0.006	55.194	-1.345	0.184	0.003
ObjR:Context	-0.020	0.010	56.659	-2.019	0.048	0.003	-0.020	0.009	55.289	-2.143	0.037	0.007
t1:ObjR	0.025	0.038	57.799	0.657	0.514	0.000	0.026	0.033	62.726	0.787	0.434	0.001
t2:ObjR	-0.045	0.035	58.521	-1.282	0.205	0.001	-0.049	0.032	67.225	-1.539	0.129	0.004
t3:ObjR	0.073	0.031	60.770	2.379	0.021	0.004	0.074	0.030	63.528	2.452	0.017	0.010
t4:ObjR	0.045	0.033	59.514	1.374	0.175	0.001	0.046	0.032	66.541	1.432	0.157	0.004

t1:ObjR:Context	-0.038	0.054	57.747	-0.705	0.484	0.001	-0.038	0.047	62.939	-0.803	0.425	0.001
t2:ObjR:Context	0.055	0.049	58.494	1.119	0.268	0.001	0.061	0.045	67.513	1.358	0.179	0.003
t3:ObjR:Context	-0.076	0.044	60.770	-1.744	0.086	0.002	-0.075	0.043	63.769	-1.748	0.085	0.005
t4:ObjR:Context	-0.032	0.046	59.478	-0.691	0.492	0.000	-0.031	0.045	66.709	-0.679	0.499	0.001
	Model with Competitor. Unrelated objects (Baseline: Unrelated) in the Function condition											
	By-subject						By-item					
	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	-0.021	0.009	22.251	-2.351	0.028	0.013	-0.022	0.009	24.906	-2.564	0.017	0.025
t1:ObjR	0.001	0.036	22.078	0.033	0.974	0.000	0.006	0.033	28.839	0.174	0.863	0.000
t2:ObjR	0.010	0.041	34.714	0.236	0.815	0.000	0.008	0.029	20.613	0.289	0.776	0.000
t3:ObjR	0.064	0.035	26.306	1.849	0.076	0.006	0.065	0.030	29.239	2.176	0.038	0.011
t4:ObjR	-0.028	0.034	37.047	-0.827	0.414	0.001	-0.026	0.033	28.781	-0.796	0.432	0.002
	Model with Competitor. Unrelated objects (Baseline: Unrelated) in the Manipulation condition											
	By-subject						By-item					
	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	-0.009	0.007	19.561	-1.178	0.253	0.002	-0.009	0.007	25.467	-1.330	0.195	0.006
t1:ObjR	0.025	0.042	20.172	0.607	0.551	0.001	0.026	0.036	30.416	0.726	0.473	0.003
t2:ObjR	-0.045	0.038	28.672	-1.176	0.249	0.003	-0.049	0.035	32.405	-1.401	0.171	0.009
t3:ObjR	0.073	0.030	32.840	2.453	0.020	0.007	0.074	0.030	32.551	2.465	0.019	0.020
t4:ObjR	0.045	0.026	20.655	1.717	0.101	0.003	0.046	0.035	32.080	1.291	0.206	0.008
	Model with Competitor. Unrelated objects (Baseline: Unrelated) in the Context condition											
	By-subject						By-item					
	Est.	SE	Df	t	p	R2	Est.	SE	df	t	p	R2
ObjR	-0.028	0.008	19.411	-3.420	0.003	0.023	-0.028	0.007	21.494	-4.150	0.000	0.046
t1:ObjR	-0.013	0.039	20.313	-0.344	0.734	0.000	-0.011	0.030	32.750	-0.361	0.721	0.000
t2:ObjR	0.010	0.023	25.950	0.432	0.669	0.000	0.013	0.029	33.589	0.459	0.649	0.000
t3:ObjR	-0.003	0.029	32.241	-0.104	0.918	0.000	0.000	0.033	31.478	0.004	0.997	0.000
t4:ObjR	0.013	0.031	30.266	0.413	0.683	0.000	0.016	0.029	32.233	0.538	0.594	0.001

Table 3. Results of the by-subject and by-items models of the gaze data from the competition window in Experiment 3. Only results concerning the effects of interest – involving the effect of object type in each condition– are presented.

	Model with Function and Manipulation competitors (Baseline: Manipulation)											
	By-subject						By-item					
	Est.	SE	df	T	p	R2	Est.	SE	df	t	p	R2
ObjR	0.007	0.014	28.869	0.550	0.586	0.002	0.007	0.010	23.813	0.719	0.479	0.002
t1:ObjR	-0.051	0.047	16.894	-1.093	0.290	0.003	-0.050	0.046	33.304	-1.094	0.282	0.005
t2:ObjR	-0.003	0.036	35.927	-0.088	0.930	0.000	-0.001	0.041	31.022	-0.017	0.986	0.000
t3:ObjR	0.021	0.039	35.172	0.531	0.598	0.001	0.018	0.049	34.066	0.358	0.723	0.001
t4:ObjR	-0.050	0.037	37.705	-1.362	0.181	0.003	-0.049	0.032	34.642	-1.508	0.141	0.005
	Model with Manipulation and Context competitors (Baseline: Context)											
	By-subject						By-item					
	Est.	SE	df	T	p	R2	Est.	SE	df	t	p	R2
ObjR	0.018	0.011	17.858	1.720	0.103	0.009	0.018	0.010	17.929	1.884	0.076	0.017
t1:ObjR	0.016	0.038	16.446	0.408	0.689	0.000	0.016	0.033	29.141	0.477	0.637	0.001
t2:ObjR	0.014	0.043	35.706	0.323	0.749	0.000	0.014	0.032	19.220	0.439	0.665	0.000
t3:ObjR	-0.022	0.038	29.677	-0.572	0.572	0.001	-0.022	0.037	34.171	-0.589	0.560	0.001
t4:ObjR	-0.024	0.041	38.146	-0.583	0.563	0.001	-0.024	0.024	34.273	-0.973	0.337	0.001
	Model with Context and Function competitors (Baseline: Function)											
	By-subject						By-item					
	Est.	SE	df	T	p	R2	Est.	SE	df	t	p	R2
ObjR	-0.029	0.008	22.550	-3.717	0.001	0.020	-0.029	0.006	19.592	-4.706	0.000	0.040
t1:ObjR	0.012	0.054	18.636	0.227	0.823	0.000	0.007	0.041	31.370	0.176	0.861	0.000
t2:ObjR	0.166	0.052	38.297	3.191	0.003	0.030	0.165	0.031	23.008	5.324	0.000	0.059
t3:ObjR	-0.077	0.046	38.733	-1.668	0.103	0.006	-0.074	0.027	28.536	-2.751	0.010	0.012
t4:ObjR	-0.065	0.043	38.207	-1.502	0.141	0.005	-0.069	0.031	31.310	-2.244	0.032	0.011