Research Article

The Role of Shape in Semantic Memory Organization of Objects

An Experimental Study Using PI-Release

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Abstract. Visual information contributes fundamentally to the process of object categorization. The present study investigated whether the degree of activation of visual information in this process is dependent on the contextual relevance of this information. We used the Proactive Interference (PI-release) paradigm. In four experiments, we manipulated the information by which objects could be categorized and subsequently be retrieved from memory. The pattern of PI-release showed that if objects could be stored and retrieved both by (non-perceptual) semantic and (perceptual) shape information, then shape information was overruled by semantic information. If, however, semantic information could not be (satisfactorily) used to store and retrieve objects, then objects were stored in memory in terms of their shape. The latter effect was found to be strongest for objects from identical semantic categories.

Keywords: object shape, proactive interference, memory, categorization

If we observe a cat-like creature in the zoo, even if it is a type that we have never seen before, we are likely to classify that animal as belonging to the same category as lions, tigers, and pumas. Presumably, the reason for doing this is that the observed animal shares some observable properties with those of the other cat-like animals that we remember having seen before. Object categorization is hence a fundamental process in constructing and using our memory, as it helps to organize our knowledge and relate novel objects to other objects in order to assign meaning to them.

This process of object categorization is driven by mental representation. When we encounter an object, we create a mental representation based on sensory and semantic information. Sensory information refers to information that can be seen, felt, smelt, heard, or tasted, whereas semantic information involves (non-perceptual) features about the use of the object or association with other objects. In order to categorize the object, the mental representation is compared to a mental prototype that represents category members (Rosch & Mervis, 1975) or to other category exemplars in memory (Nosofsky, 1986). The representations are compared on both sensory and semantic information, however the relative weighting of these two types of information varies across concepts and semantic categories (Humphreys & Forde, 2001; Warrington & McCarthy, 1987). For example, the shape of an animal or the color of a fruit might be more important to assign the object to a specific category than the shape or color of a kettle. In the present study, we investigate how sensory features compare to semantic features in the categorization of visual objects. We focus on the visual sensory feature *shape* and investigate how the relative weighting of shape and semantic information affects the organization of semantic memory.

Barsalou (1999) proposed that sensory information plays a critical role in cognition. According to his Perceptual Symbols Theory, perception, action, and cognition share processing mechanisms. He views mental representation as a process of sensory-motor simulation. Central in his theory are perceptual symbols by which a mental representation is defined. A mental representation is constructed on the basis of a combination of several perceptual symbols for different components of the concept. This perceptual symbol formation process does not only concern the concept's visual features (e.g., its color, shape, and orientation), but operates as well on other sensory modalities such as audition, haptics, olfaction, and gustation. As such, perceptual symbols are learned through actual experiences with concepts. Modality-specific sensory-motor systems capture such experiences and hierarchical association areas integrate experiences from different modalities. Hence, these association networks represent knowledge of the concept that can be recruited for cognitive processing via the process of simulation (i.e., mental representation).

Evidence supporting Perceptual Symbols Theory is provided by work that shows that visual sensory information is indeed activated during language comprehension (e.g., Borghi, Glenberg, & Kaschak, 2004; Huettig & Hartsuiker, 2008; Huettig & McQueen, 2007; Kaschak et al., 2005;

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Pecher, Van Dantzig, Zwaan, & Zeelenberg, 2009; Pecher, Zeelenberg, & Barsalou, 2003; Pecher, Zeelenberg, & Raaijmakers, 1998; Solomon & Barsalou, 2001; Stanfield & Zwaan, 2001; Van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008; Van Weelden, Schilperoord, & Maes, 2013; Zwaan, Stanfield, & Yaxley, 2002). For example, Huettig and Hartsuiker (2008) showed that naming a category exemplar (e.g., musical instrument – saxophone) elicited eye movements to a picture of a semantically unrelated object that was similar in shape (e.g., ladle). This activation of visual sensory information is context related, such as determined by the content of utterances that have been produced in a preceding discourse. Zwaan et al. (2002) showed, for example, that such a context can affect the particular shape of the object that is represented. In their experiment, participants were presented with sentences like "The ranger saw the eagle in the sky" or "The ranger saw the eagle in its nest," which were followed by a line drawing of the object described in the sentence, in this case an eagle with outstretched wings or an eagle with folded wings. Participants recognized the picture faster if the implied shape of the object in the sentence matched the shape of the object in the picture. In the same vein, Van Weelden, Schilperoord, and Maes (2013) showed that sentence structure (which can define the relation between multiple objects) influences the shape of the represented object(s) as well. In their experiment, participants were presented with sentences that invited to compare two objects like "*A spinning top is like a ballerina*," which were followed by two line drawings of the objects described in the sentence. The two drawings either had a similar or dissimilar shape. Participants recognized the pictures faster if they were similarly shaped. Hence, a sentence structure that invites to (conceptually) compare two objects affects the shape of their mental representation.

While language has been shown to elicit perceptual representations, there is work that shows that the opposite occurs as well, which is that semantic information is activated during visual object perception. Boucart and Humphreys (1997) suggest that as a result of the strong interplay between sensory and semantic information, people cannot even attend selectively to the global shape of an object without automatically processing its semantic properties. Caramazza, Hillis, Rapp, and Romani (1990) explain this interaction with their Organized Unitary Content Hypothesis (OUCH). Their theory is based on the idea that, contrary to a word for a particular concept, the object itself tends not to have an arbitrary relationship to its meaning. Some visual sensory features are directly related to the semantic properties of the object that specify its function (cf. Gibson's Theory of Affordances, 1977, 1979). These features are therefore perceptually salient. For example, visual features of a "fork" are the handle, the tines, the silver color, and the smooth texture. While a spoon and a knife share properties (i.e., the handle and the silver color), it is the tines of the fork that define the fork's function "used for spearing food." So, the closer the perceptual feature is related to the object's function, the more salient that feature becomes. As such, shape is very frequently a salient perceptual feature. Note that, along the same line as Barsalou's (1999) PS theory, these perceptually salient features only become salient through actual experiences with the object.

Accordingly, visual sensory information contributes fundamentally to the process of object identification and categorization. In the present study, we propose that the *degree* of activation of visual information in the process of object categorization depends on the *contextual relevance* of this information. We define this contextual relevance as determined by the visual and semantic relations between the objects. For example, we might predict that when we have to look for an overarching category for a number of presented objects, visual features, such as shape, might play a different role when objects belong to different semantic categories as compared to when they stem from the same semantic category. Therefore, in the present study, we investigate whether shape information is encoded differently in our semantic memory for objects from similar and dissimilar semantic categories.

One way to investigate how visual information is encoded, and hence whether the objects are organized in semantic memory by means of their shape, is by looking at the process of retrieval of this particular information. The encoding and retrieval of the encoded information are interdependent; a retrieval cue will be effective most if the information in the cue was generated during encoding (Blaxton, 1989; Morris, Bransford, & Franks, 1977; Tulving & Thomson, 1973). Hence, by examining when the shape of objects is used as a retrieval cue when trying to retrieve objects from memory, we can shed light on the conditions in which shape information is encoded in semantic memory.

To do so, we use the Proactive Interference (PI) paradigm (Wickens, 1970). Proactive interference occurs when previously encountered information interferes with the memorial access of more recently encountered information. The standard procedure to test this interference is to present a triad of items from the same semantic category and, subsequently, have the participant perform a 25-s rehearsal-preventing task, such as a backward counting task. Then, participants recall the triad. This procedure is repeated for four trials. The idea is that because the items are members of the same semantic category, the meaning of the items is being encoded and so is the meaning of the non-presented category under which they subsume. The PI paradigm results in decreasing performance on the recall task as more triads from the same semantic category are presented. Because participants use the same category cue to recall the items, increasing interference arises. If, however, the semantic category shifts on the fourth (i.e., the critical) trial, the category cue will change as well. Therefore, the discriminability and accessibility of the items will increase, resulting in an increased performance on the recall task. This mechanism is called *release from interference*.

In previous studies, the PI paradigm has been used to investigate a variety of category memberships. For example, Dempster (1985) used the paradigm to investigate whether we encode the overarching topic of sentences during sentence processing. Gunter, Clifford, and Berry (1980) studied the memory for television news items, which they found to become worse if there was no change in the visual format of the news items. Katz and Law (2010) used the PI paradigm to study whether conceptual metaphors are automatically activated during the processing of instantiations of conceptual metaphors (e.g., whether "*LIFE IS A JOURNEY*" is activated when we read "*Her future depends on what path she chooses to take*").

Classic PI studies focused on the magnitude of the semantic distance between exemplars from different semantic categories (i.e., shift from fruits to vegetables as compared to shift from fruits to professions), phonemic categories (i.e., shift from words with "air" sound to "eye" sound), and sensory features (i.e., shift from "round" words to "white" words) (Wickens, Dalezman, & Eggemeier, 1976; Zinober, Cermak, Cermak, & Dickerson, 1975). The main conclusion drawn from these studies is that the degree of release from interference is inversely related to the number of common characteristics. That is, a shift between categories with a high overlap in characteristics (i.e., from fruits to vegetables) obtains a lower release from interference as compared to a shift between categories with no overlapping characteristics (i.e., from fruits to professions).

Moreover, Marques' (2000) study showed release from interference as a result of a shift from nonliving to living things. Interestingly, Marques tested this living/nonliving distinction for both words and pictures of the objects. The visual stimuli yielded the same types of interference effects as verbal stimuli. Accordingly, this study shows that the PI paradigm can also be used to investigate which retrieval cues people use to recall *visual* objects from their memory and, hence, which information was encoded when the visual objects were processed.

Besides the living/nonliving distinction, Marques' study also focused on the release from interference as a result of a shift in *visual features* within the category of living things, such as number of legs (from two-legged to four-legged animals) and size (from small to big animals). Prior to the experiments, participants were informed about the different stimuli that they could encounter (e.g., that the triads would be composed of objects that had four legs or fewer than four legs, or were bigger or smaller than a human being). For both words and pictures, Marques did not find release from interference as a result of the shift in number of legs. For the verbal condition, the shift might have been too subtle, because the number of legs is not a prominent feature in the mental representation of the concepts. For the visual condition, however, the manipulation of the number of legs was actually visible. Yet as a lot of other visual features changed along with the number of legs, the latter change might have been confounded. For the shift in size, Marques' results only showed release from interference in the verbal condition. The reason why this effect was limited to this condition might be that the manipulation was conceptual rather than perceptual. The manipulation concerned a shift from small to big animals, yet, in relation to the size of a human being. The size of the animals was not manipulated visually in terms of increased size with respect to the screen they were presented on. This way, the manipulation might have been more conceptual than visual, and as such too subtle to evoke the establishment of new category and thereby release from interference. Moreover, another possible explanation could be that the explicit cue about the visual feature change might have inhibited the effects. On a more general level, Marques' study shows that in investigating how visual features are stored in memory, the PI paradigm is highly sensitive to the precise manipulation of visual features and the instructions provided at the beginning of the task.

Taking this into account, the present study employs the PI paradigm (1) with the visual manipulation of a very prominent sensory feature of objects, their shape and (2) without explicit cues regarding the type of shifts. We refer to shape as the outline of the picture of a particular object, rather than its inherent shape. We predict that if depictions of objects are encoded in such a way as to include information about the shape of the objects, then objects sharing particular shape features should form a different category than objects that do not share shape features. Therefore, interference should build up as objects with similar shapes are presented on successive trials, and release from interference should occur as a result of a shift of shape. Yet the relative weighting of shape information might differ as a result of the relevance of this information. In four experiments, we manipulate the semantic and shape similarity between the objects and, thereby, the relevance of shape. In Experiment 1, we combine a shift of shape with a semantic shift (i.e., from fruits to flowers). For this type of shift, we expect that a semantic category cue will be sufficient to recall the objects from the critical trial. So, in this context, the role of shape might be inferior. We expect that shape plays a more prominent role when there is no distinguishing semantic category cue available. In Experiment 2, we will only manipulate a shift of shape, keeping the semantic category (i.e., fruits) similar throughout the experiment. As the preceding objects belong to the same semantic category, a semantic category cue might not be sufficient to retrieve the objects of the critical trial. In this context, we expect shape to be a distinguishing factor and to be used as retrieval cue. Yet we expect shape to play an even more important role when there is no shared semantic category present. In Experiments 3 and 4, we will manipulate the shift of shape as well, but this time each object will stem from a distinct semantic category (i.e., fruits, flowers, animals, plants, and vegetables). As such, object shape will be the only possible retrieval cue, rather than a preestablished semantic cue. The difference between Experiments 3 and 4 will be the type of shape shift; a shift of shape between and within triads (i.e., from irregularly shaped to a particular shape), or a shift of shape between triads (i.e., from a particular shape to another shape), respectively. By gradually changing the relation between object shape and semantic knowledge over the four experiments, we hope to gain more insight into the interplay of these two factors in semantic memory organization of visual objects.

Experiment 1

This first experiment evaluated the role of shape in the PI-release situation with both a shape and semantic categorical shift. The semantic shift comprised a shift between two natural categories, fruits and flowers. We used this type of shift because living things are primarily differentiated on the basis of perceptual features (Humphreys & Forde, 2001; Warrington & McCarthy, 1987). That is, most types of natural objects have a high perceptual overlap, and therefore small perceptual differences are highly informative. Hence, it can be expected that visual information will have a relatively high weighting as compared to other types of information in the representation of living things.

Both the participants in the Shift and No-Shift condition of the present experiment received three fruits triads followed by a flower triad, as shown in Appendix A. In the No-Shift condition, the shape of the fruits and flowers did not change throughout the experiment. The objects either were round in shape (Appendix A1) or were shaped irregularly (Appendix A3). In the Shift condition, however, the shape of the objects changed on the critical trial. The critical trial established a shift from irregularly shaped objects to round shaped objects (Appendix A2) or vice versa (Appendix A4).

For both the Shift and No-Shift condition, we predicted release from interference to occur as the change from fruits to flowers reduces or eliminates interference. However, there may be gradual differences in the amount of release, both as a result of the shape shift itself and the type of shape shift. We expected the release to be most prominent for the Shift condition as there is an additional shift of shape. Considering the type of shape shift, we predicted the release to be stronger when triads changed from round shaped objects to irregularly shaped objects than the other way around. That is, if pictures of objects are encoded in such a way as to include information about the shape of the objects, then a similar round shape might be a stronger organizing feature than irregular shapes. As such, the buildup of interference is stronger for round objects, which might result in a stronger release effect.

For the No-Shift condition, we predicted the release from interference to be hampered when the triads of the four trials consist of round objects. Although there was a semantic change from fruits to flowers, the objects remained perceptually similar. As a result, the previously seen objects may continue to interfere with the objects presented on the critical trail. When the triads of the four trials consist of irregularly shaped objects, however, this interference effect may be more moderate as the objects are not perceptually similar. The semantic shift would then be sufficient to eliminate such interference effects.

Method

Participants

Eighty Tilburg University undergraduates (57 women and 23 men) participated for course credit. The mean age was 21 years, ranging from 18 to 34. All participants were naïve with respect to the purpose of the experiment and had normal or corrected-to-normal vision.

Materials

The stimulus pictures consisted of 18 pictures of fruits (nine round shapes and nine irregular shapes) and six pictures of flowers (three round shape and three irregular shapes). With these pictures, we created six triads of fruits and two triads of flowers, shown in Appendix A. Note that for each round shaped object, there was a differently shaped version of that object in the set of irregularly shaped objects. For example, the first triads presented in Appendices A1 and A2 both consist of an apple, a raspberry, and a lemon, but in Appendix A1 the objects are round and in Appendix A2 the object are irregularly shaped.

In arranging the triads, we controlled for various factors. For the fruit triads, we controlled for typicality. In a typicality pretest, 10 participants (who did not participate in our future PI experiments) were asked to sort the pictures of the objects from most typical member of the category "fruits" to the least typical member of this category. Based on this taxonomy, every fruits triad was assigned a low, medium, and high typical member of the category. In addition, every fruits and flowers triad consisted of three differently colored objects. We kept the mean visual complexity similar across the triads in terms of mean JPEG file sizes (Chikhman, Bondarko, Danilova, Goluzina, & Shelepin, 2012; Donderi, 2006).

With these triads, four different sets were created. For two sets, the first three triads consisted of nine pictures showing round objects (fruits). For one of these, the triad for the fourth trial also consisted of round objects (flowers), and for the other set it consisted of irregularly shaped objects (flowers). For the two other sets, the first three triads consisted of nine pictures showing irregularly shaped objects (fruits). For one of these, the triad for the fourth trial also consisted of irregularly shaped objects (flowers), and for the other set it consisted of round objects (flowers). Thus, in two of the sets the shape of the objects changed between Trials 3 and 4 and in the other two sets the shape remained the same (i.e., all round or all irregularly shaped). In all conditions, the category changed from fruits to flowers between Trials 3 and 4. An additional practice set was created that consisted of 12 pictures of animals. For this set, there was no semantic or shape shift between Trials 3 and 4.

Design

The experiment had a $2 \times 2 \times 4$ design, with Shift (levels: Shift and No-Shift) and Triad Shape (levels: Round shape and Irregular shape – of the build-up triads) as between-subjects factors and Trial (levels: 1–4) as within-subjects factor.

Procedure

The participants were informed that the purpose of the experiment was to test their ability on both backward counting and their memory of triads of objects. During each trial, participants first saw a fixation cross in the center of the screen for 2 s. Subsequently, the objects of one triad were presented one-by-one for 2 s each (with no interstimulus interval). Participants were instructed to identify the objects silently, to remember them, and to remember the order of the objects. They were told that they had to recall the objects in the right order afterwards. A three-digit number was then presented in the middle of the screen for 25 s during which the participant had to count backwards by threes out loud. Participants were instructed to count backwards as fast as possible while still being accurate. After 25 s the question "Which three objects did you see?" appeared, signaling the beginning of the 12 s recall period. Participants typed the names of the three objects. After 12 s the question was replaced with "Time's up" to indicate the end of the recall period. Participants pressed a button to continue to the next trial. The next trial started again with the fixation cross.

Participants trained on both the counting backward and memory task with a four trial training block. E-Prime software was used to control the presentation durations of the fixation crosses and pictures, to randomize the first three triads, and to collect the responses. The entire procedure took approximately 15 min.

Results and Discussion

For each participant, the mean recall score was computed for each trial. Following the procedure of Wickens et al. (1976), one point was given for each object recalled correctly and one extra point was assigned when the three objects were recalled in the correct order. So, for each trial, there was a maximum of four points. The raw data can be found online (see Electronic Supplementary Material 1, ESM 1). The mean scores per Shift and Trial are presented in Figure 1.

PI-buildup and PI-release effects were analyzed independently. The PI-buildup analysis was performed on the first three trials. The PI-release analyses were performed on (1) the third and fourth trial and (2) on the fourth trial separately. For all three analyses an ANOVA was conducted with Shift (levels: Shift and No-Shift) and Triad Shape (levels: Round shape and Irregular shape) as between-subjects factors. For the PI-buildup analysis the latter factor concerned the Shape of the first three triads, whereas for the PI-release analyses this regarded the Shape of the fourth triad. The PI-buildup analysis also involved the within-subjects factor Trial (levels: 1, 2, and 3).

For PI-release, the analysis on the third and fourth trial revealed a main effect of Trial, $F(1, 152) = 31.19$, $MSE = 1.35$, $p < .001$, $\eta_p^2 = .17$. The mean recall score was higher on the fourth trial ($M = 3.55$, $SD = 0.95$) than on the third trial ($M = 2.53$, $SD = 1.31$). Participants recalled more items after the semantic shift. There was no effect of Shift, $F < 1$, or Triad Shape, $F < 1$, and there were

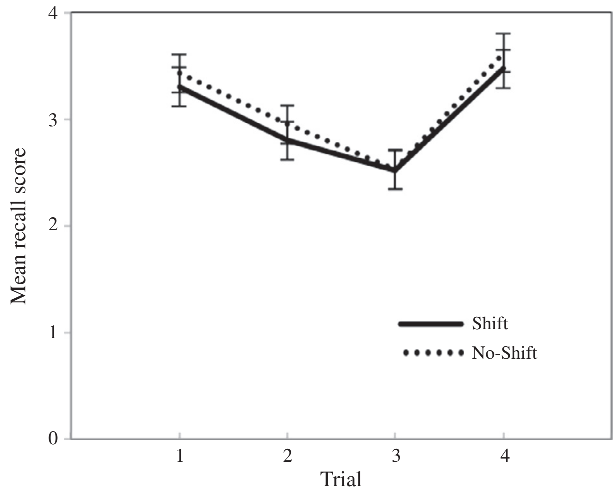

Figure 1. Mean recall scores on each trial for the Shift and No-Shift condition in Experiment 1. Note that both the Shift and the No-Shift condition had a semantic category shift between Trials 3 and 4. Bars represent standard errors.

no two- or three-way interactions between the factors, $F < 1$.

The analysis on the fourth trial alone revealed neither a main effect of Shift, $F < 1$, and Triad Shape, $F < 1$, nor an interaction between the two, $F(1, 76) = 1.98$, $MSE = .91$, $p = .16$, $\eta_p^2 = .03$. As can be seen in Figure 1, the semantic shift did result in release from interference, but there were no (gradual) differences in release as a result of the shift in shape on the fourth trial.

For PI-buildup, the analysis showed a main effect of Trial, $F(2, 228) = 9.31$, $MSE = 1.52$, $p < .001$, $\eta_p^2 = .08$. Participants recalled fewer items as the number of trials increased. Post hoc analyses showed that the decrease from Trial 1 to Trial 2 was significant, $p < .05$. The decrease from Trial 2 to Trial 3 did not reach significance, $p = .22$. There was no effect of Shift, $F < 1$, nor an effect of Triad Shape, $F < 1$. The analysis did not reveal any two- or three-way interactions between the factors.

These results show that in the categorization of objects, in this particular context, semantic information played a more important role than shape information. Only semantic information was used as retrieval cue, as indicated by the buildup of interference during the first three trials and the release from interference when the semantic category changed. The change in shape did not affect performance.

We expected that the role of shape becomes more prominent if a semantic retrieval cue is not sufficient to recall the objects of the critical trial. This possibility was explored in Experiment 2.

Experiment 2

This second experiment evaluated the role of shape in the PI-release situation where no semantic categorical shift took place. Participants in both the Shift and No-Shift condition received only fruits triads, as shown in Appendix B. Identical to Experiment 1, the shape of the fruits was similar throughout the four trials in the No-Shift condition, in the sense that the objects either had a round shape (Appendix B1) or were shaped irregularly (Appendix B3). In the Shift condition, the shape of the objects changed on the critical trial. The change concerned a shift from irregularly shaped objects to round shaped objects (Appendix B2) or vice versa (Appendix B4).

For the Shift condition, we predicted release from interference to occur as a result of the shape shift. Again, we expected the release to be more prominent when triads changed from round shaped objects to irregularly shaped objects than when they shifted in the opposite direction. For the No-Shift condition, we predicted that the buildup of interference would continue throughout the four trials. The decrease in performance was expected to be the strongest for the round shaped objects as compared to the irregularly shaped objects.

Method

Participants

Eighty Tilburg University undergraduates (57 women and 23 men) participated for course credit. The mean age was 22 years, ranging from 18 to 33. All participants were naïve with respect to the purpose of the experiment and had normal or corrected-to-normal vision. None of the participants had participated in Experiment 1.

Materials

The triads of the first three trials were the same as in Experiment 1. The experimental materials for these triads consisted of 18 pictures of fruits (nine round shapes and nine irregular shapes). For the present experiment, the triads of the fourth trial consisted of six pictures of fruits (three round shapes and three irregular shapes), shown in Appendix B. In arranging these triads, we controlled again for typicality, color, and visual complexity. With these triads, four different sets were created in the same way as in Experiment 1. The practice set was identical to the one of Experiment 1.

Design

The experiment had a 2 × 2 × 4 design, with Shift (levels: Shift and No-Shift) and Triad Shape (levels: Round shape and Irregular shape – of the build-up triads) as between-subjects factors and Trial (levels: 1, 2, 3, and 4) as within-subjects factor.

Procedure

The procedure was the same as in Experiment 1 with respect to the instructions, the triad presentation, and the training session.

Results and Discussion

For each participant, the mean recall score was computed for each trial. As in Experiment 1, there was a maximum of four points per trial. The raw data can be found online (see ESM 2). The mean scores per Shift and Trial are presented in Figure 2.

PI-buildup and PI-release effects were analyzed independently in the same way as in Experiment 1. For PI-release, the analysis on the third and fourth trial revealed a trend of an effect of Shift, $F(1, 152) = 2.76$, $MSE = 1.38$, $p = .09$, $\eta_p^2 = .02$. The analysis also showed a trend of an interaction between Shift and Trial, $F(1, 152) = 2.89$, $MSE = 1.38$, $p = .09$, $\eta_p^2 = .02$. There was no main effect of Triad Shape, $F < 1$, or Trial, $F < 1$, nor any other two- or three-way interactions.

The analysis of the fourth trial alone revealed a main effect of Shift, $F(1, 76) = 5.70$, $MSE = 1.37$, $p < .05$, $\eta_p^2 = .07$. The mean recall score was higher for the Shift condition ($M = 2.58$, $SD = 1.30$) than for the No-Shift condition ($M = 1.92$, $SD = 1.05$). Participants recalled more items after the shape shift. There was no main effect of Triad Shape, $F < 1$, nor an interaction between Shift and Triad Shape, $F(1, 76) = 2.21$, $MSE = 1.37$, $p = .14$, $\eta_p^2 = .03$. These findings show that the shape shift resulted in release from interference, causing an increase of the recall scores on the fourth trial.

For PI-buildup, the analysis showed a main effect of Trial, $F(2, 228) = 18.40$, $MSE = 1.29$, $p < .001$, $\eta_p^2 = .14$. Post hoc analyses showed that both the decrease from Trial 1 to Trial 2, $p < .01$, and from Trial 2 to Trial 3, $p < .001$, was significant. There was no effect of Shift, $F < 1$, nor an effect of Triad Shape, $F < 1$. The analysis did not reveal any two- or three-way interactions between the factors.

These results show that if semantic information is insufficient to recall the objects of the critical trial, shape comes

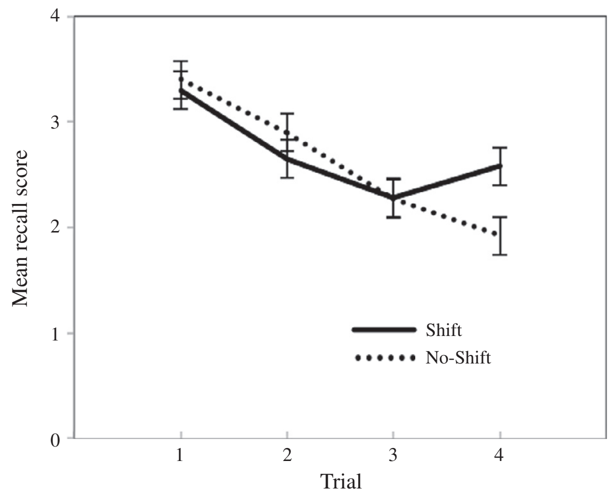

Figure 2. Mean recall scores on each Trial for the Shift and No-Shift condition in Experiment 2. Note that in both the Shift and the No-Shift condition there was no semantic category shift between Trials 3 and 4. Bars represent standard errors.

into play. The fact that shape is used as a retrieval cue to recall objects from memory suggests that the objects are assigned to a subordinate shape category within the semantic category of "fruits," or that a category for fruits and for "round objects" was established, and that the latter category was additionally used as cue to recall the objects.

We expected the role of shape to become even more prominent if there is no common semantic category available, both for the objects of the first three trials and the critical trial. This possibility was explored in Experiment 3.

Experiment 3

This third experiment evaluated the role of shape in the PI-release situation without the presence of a common semantic category, both for the PI-buildup and PI-release trials. Participants in both the Shift and the No-Shift condition received four triads of semantically dissimilar objects, see Appendix C. The shape of the objects was similar throughout the four trials in the No-Shift condition. The objects either had a round shape (Appendix C1) or were shaped irregularly (Appendix C3). In the Shift condition, the shape of the objects changed on the critical trial. The change concerned a shift from irregularly shaped objects to round shaped objects (Appendix C2) or vice versa (Appendix C4).

Similar to the expectations in Experiment 2, we predicted release from interference to occur as a result of the shape shift in the Shift condition. The release was expected to be more prominent when triads changed from round shaped objects to irregularly shaped objects than when they shifted in the opposite direction. Although the results of Experiment 2 did not confirm this expectation, we decided to retain this hypothesis for the present experiment. We expected the shape manipulation to be more effective when there is no preestablished semantic category available. For the No-Shift condition, we predicted that the buildup of interference would continue throughout the four trials. Especially since there is no common semantic category present to which the objects can be assigned, we expect the decrease in performance to be the strongest for the round shaped objects as compared to the irregularly shaped objects.

Method

Participants

Eighty Tilburg University undergraduates (61 women and 19 men) participated for course credit. The mean age was 22 years, ranging from 18 to 55. All participants were naïve with respect to the purpose of the experiment and had normal or corrected-to-normal vision. None of the participants had participated in Experiment 1 or 2.

Materials

The stimulus pictures consisted of 24 pictures of (12 round and 12 irregular shaped) objects from different natural categories, such as fruits, vegetables, animals, flowers, nuts, plants, etc. The stimuli are presented in Appendix C. The pictures were arranged in triads (i.e., four triads with round objects and four triads with irregular shaped objects). In arranging these triads, we controlled again for color, visual complexity, and category distance. To create the highest category distance among the objects within a triad, we ran a materials pretest in which participants rated the category membership of every possible object pair. Seven participants were instructed to move a slider along a track from 0 (from entirely different categories) to 10 (from the same category) to indicate their judgment about the category membership of the object pairs. Based on these scores, we created the triads of objects with the highest possible category distance.

Design

The experiment had a $2 \times 2 \times 4$ design, with Shift (levels: Shift and No-Shift) and Triad Shape (levels: Round shape and Irregular shape – of the build-up triads) as between-subjects factors and Trial (levels: 1, 2, 3, and 4) as within-subjects factor.

Procedure

The procedure was the same as in Experiments 1 and 2 with respect to the instructions, the triad presentation, and the training session.

Results and Discussion

For each participant, the mean recall score was computed for each trial. As in the previous experiments, there was a maximum of four points per trial. The raw data can be found online (ESM 3). The mean scores per Shift and Trial are presented in Figure 3.

PI-buildup and PI-release effects were analyzed independently in the same manner as in the previous experiments. For PI-release, the analysis on the third and fourth trial showed no effect of Shift, $F < 1$. There was a main effect of Trial, $F(1, 152) = 17.06$, $MSE = 1.55$, $p < .001$, $\eta_p^2 = .10$. The mean recall was lower on the fourth trial ($M = 1.84$, $SD = 1.25$) than on the third trial ($M = 2.65$, $SD = 1.32$). The analysis also revealed a main effect of Triad Shape, $F(1, 152) = 8.92$, $MSE = 1.55$, $p < .01$, $\eta_p^2 = .05$. The mean recall for Round objects ($M = 2.54$, $SD = 1.30$) was higher than the recall of the Irregularly shaped objects ($M = 1.95$, $SD = 1.33$). There was an interaction between Shift and Triad Shape, $F(1, 152) = 4.95$, $MSE = 1.55$, $p < .05$, $\eta_p^2 = .03$. For the Round objects, the mean recall on the third and fourth trial was higher for the Shift condition ($M = 2.83$, $SD = 1.22$) as compared to No-Shift condition ($M = 2.25$, $SD = 1.33$). For the Irregular objects, the mean recall on the third and fourth trial was higher for the No-Shift condition ($M = 2.10$, $SD = 1.43$) than for the Shift condition ($M = 1.80$, $SD = 1.22$). There was no two-way interaction between

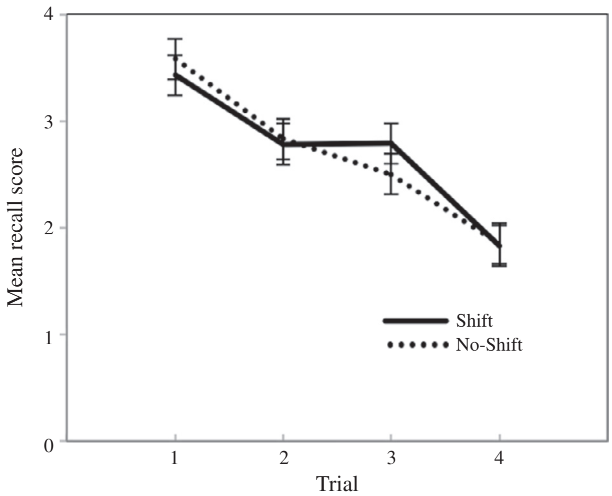

Figure 3. Mean recall scores on each trial for the Shift and No-Shift condition in Experiment 3. Note that in both the Shift and the No-Shift condition, the objects had no overlapping semantic category. Bars represent standard errors.

Shift and Trial ($F < 1$), nor a three-way interaction between the three factors ($F < 1$).

The analysis on the fourth trial alone revealed no main effect of Shift, $F < 1$, and Triad Shape, $F(1, 76) = 1.88$, $MSE = 1.49$, $p = .17$, $\eta_p^2 = .03$. As in the previous analysis, we did find an interaction between Shift and Triad Shape, $F(1, 76) = 4.43$, $MSE = 1.49$, $p < .05$, $\eta_p^2 = .06$. For the Round shaped objects, the objects were recalled better for the Shift condition ($M = 2.30$, $SD = 1.13$) as compared to No-Shift condition ($M = 1.75$, $SD = 1.29$). For the Irregularly shaped objects, the objects were better recalled for the No-Shift condition ($M = 1.95$, $SD = 1.40$) than for the Shift condition ($M = 1.35$, $SD = 1.04$). To get more insight into the effect of Shift for the different object shapes, we performed a separate analysis on the two types of Triad Shapes. The analyses show that for both the Round shaped objects, $F(1, 38) = 2.06$, $MSE = 1.47$, $p = .16$, $\eta_p^2 = .05$, and for the Irregularly shaped objects, $F(1, 38) = 2.38$, $MSE = 1.51$, $p = .13$, $\eta_p^2 = .06$, the effect of Shift did not reach significance. The interactions found in the analyses on the third and fourth trial, and on the fourth trial only do however indicate that, contrary to our expectation, recall was better when the triads changed from irregularly shaped objects to round shaped objects than when they shifted in the opposite direction.

For PI-buildup, the analysis showed a main effect of Trial, $F(2, 228) = 12.64$, $MSE = 1.31$, $p < .001$, $\eta_p^2 = .10$. Post hoc analyses showed that only the decrease from Trial 1 to Trial 2 was significant, $p < .001$. There was no decrease from Trial 2 to Trial 3, $p = 1$. There was no effect of Shift, $F < 1$, nor an effect of Triad Shape, $F < 1$. The analysis did not reveal any two-way interactions. There was an interaction between the three factors, $F(2, 228) = 5.99$, $MSE = 1.31$, $p < .01$, $\eta_p^2 = .05$.

As there was no effect of Shift, object shape seems not to be used as retrieval cue when recalling objects from different semantic categories. However, the findings of this experiment do indicate that the recall is better for similarly shaped objects after having seen differently shaped objects (see Appendix C2) than for differently shaped objects after having seen similarly shaped objects (see Appendix C4). This finding might be explained in terms of the correspondences *within* a triad. The switch from objects without semantic and shape correspondences to objects with shape correspondences might result in the establishment of a retrieval cue of same shaped objects, whereas a switch from objects without semantic but with shape correspondences to objects without shape correspondences does not result in a useful retrieval cue.

For semantically dissimilar objects, it might hence be that object shape is used as retrieval cue when the objects *within* a triad have the same shape. This possibility was explored in Experiment 4.

Experiment 4

This fourth experiment evaluates the role of shape in the PI-release situation with objects from different semantic categories as well. As in Experiment 3, the triads of objects consist of members from different semantic categories, such that the objects can only be categorized based on their shape. Different from the previous experiment is that the shift in shape concerns a shift from one shape to another shape, rather than from irregularly shaped objects to objects with a particular shape, or the other way around. The shape of the objects *within* a triad is therefore always the similar.

Participants in both the Shift and the No-Shift condition received four triads of semantically dissimilar objects, see Appendix D. The shape of the objects was similar throughout the four trials in the No-Shift condition. The objects either had a round shape (Appendix D1) or an oblong shape (Appendix D3). In the Shift condition, the shape of the objects changed on the critical trial. The change concerned a shift from oblong shaped objects to round shaped objects (Appendix D2) or vice versa (Appendix D4).

Similar to the expectations in Experiments 2 and 3, we predicted release from interference to occur as a result of the shape shift in the Shift condition. For the No-Shift condition, we predicted that the buildup of interference would continue throughout the four trials, with no differences between the round and oblong shaped objects.

Method

Participants

Eighty-two Tilburg University undergraduates (67 women and 15 men) participated for course credit. The mean age was 21 years, ranging from 17 to 27. All participants were naïve with respect to the purpose of the experiment and had normal or corrected-to-normal vision. None of the participants had participated in Experiments 1, 2, or 3.

Materials

The stimulus pictures consisted of 24 pictures of (12 round and 12 oblong) objects from different natural categories, such as fruits, vegetables, animals, flowers, nuts, plants, etc. Eleven of the round shaped objects and four of the irregular shaped objects were also used in Experiment 3. The stimuli are presented in Appendix D. The pictures were arranged in triads (four triads of round objects and four triads of oblong objects). In arranging these triads, we controlled for color, visual complexity, and category distance. Due to added objects, the combination of objects within a triad needed to be changed as compared to Experiment 3.

Design

The experiment had a 2 × 2 × 4 design, with Shift (levels: Shift and No-Shift) and Triad Shape (levels: Round shape and Oblong shape – of the build-up triads) as between-subjects factors and Trial (levels: 1, 2, 3, and 4) as within-subjects factor.

Procedure

The procedure was the same as in Experiments 1, 2, and 3 with respect to the instructions, the triad presentation, and the training session.

Results and Discussion

For each participant, the mean recall score was computed for each trial. As in the previous experiments, there was a maximum of four points per trial. The raw data can be found online (ESM 4). The mean scores per Shift and Trial are presented in Figure 4.

PI-buildup and PI-release effects were analyzed independently in the same manner as in the previous experiments. For PI-release, the analysis on the third and fourth trial showed neither an effect of Shift, $F < 1$, nor an effect of Trial, $F < 1$. The analysis did reveal a main effect of Triad Shape, $F(1, 156) = 6.44$, $MSE = 1.36$, $p < .05$, $\eta_p^2 = .04$. The mean recall for Oblong shaped objects ($M = 2.54$, $SD = 1.30$) was higher than the recall of Round shaped objects ($M = 1.95$, $SD = 1.33$). The analysis showed no two-way interaction between Shift and Triad Shape, $F < 1$, nor between Shift and Trial, $F(1, 156) = 1.63$, $MSE = 1.36$, $p = .20$, $\eta_p^2 = .01$, and between Triad Shape and Trial, $F(1, 156) = 1.76$, $MSE = 1.36$, $p = .19$, $\eta_p^2 = .01$. There was a trend of an interaction between the three factors, $F(1, 156) = 3.86$, $MSE = 1.36$, $p = .05$, $\eta_p^2 = .02$.

The analysis on the fourth trial alone revealed no main effect of Shift, $F < 1$, and Triad Shape, $F < 1$. The analysis

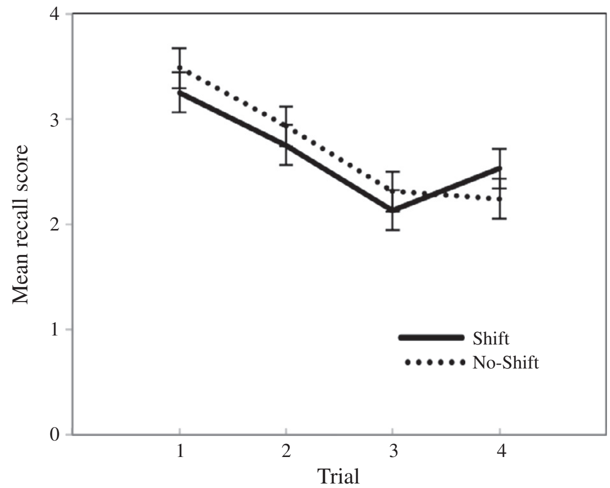

Figure 4. Mean recall scores on each trial for the Shift and No-Shift condition in Experiment 4. Note that in both the Shift and the No-Shift condition, the objects had no overlapping semantic category. Bars represent standard errors.

did show a trend of an interaction between Shift and Triad Shape, $F(1, 78) = 2.85$, $MSE = 1.59$, $p = .09$, $\eta_p^2 = .04$. For the Round shaped objects, the objects were recalled better for the Shift condition ($M = 2.65$, $SD = 1.50$) as compared to No-Shift condition ($M = 1.91$, $SD = 1.19$). For the Oblong shaped objects, the objects were (only slightly) better recalled for the No-Shift condition ($M = 2.60$, $SD = 1.10$) than for the Shift condition ($M = 2.40$, $SD = 1.23$). To get more insight into this difference, we performed a separate analysis on the two types of Triad Shapes. The analysis shows that there is a trend of an effect of Shift for the Round shaped objects, $F(1, 40) = 3.18$, $MSE = 1.81$, $p = .08$, $\eta_p^2 = .07$, see Figure 5. Such an effect is absent for the Oblong shaped objects, $F < 1$.

For PI-buildup, the analysis showed a main effect of Trial, $F(2, 234) = 23.55$, $MSE = 1.14$, $p < .001$, $\eta_p^2 = .17$. Post hoc analyses showed that the decrease from Trial 1 to Trial 2, $p < .01$ and from Trial 2 to Trial 3, $p < .001$, was significant. There was no effect of Shift, $F(2, 234) = 2.08$, $MSE = 1.14$, $p = .15$, $\eta_p^2 = .01$, nor an effect of Triad Shape, $F < 1$. The analysis showed no two-way interaction between Shift and Triad Shape, $F < 1$, and between Shift and Trial, $F < 1$. There was a trend of an interaction between Triad Shape and Trial, $F(2, 234) = 3.41$, $MSE = 1.14$, $p = .05$, $\eta_p^2 = .03$. The analysis showed an interaction between the three factors, $F(2, 234) = 5.77$, $MSE = 1.14$, $p < .01$, $\eta_p^2 = .05$.

Similar to Experiment 3, there was no main effect of Shift. Hence, object shape seems not to be used as retrieval cue when recalling objects from different semantic categories. However, the present study does suggest an effect of the *type* of object shape. The difference found between the two types of shape shifts (i.e., from oblong to round and from round to oblong) might be explained in terms of the *inclusiveness* of the (shape) categories. That is, every

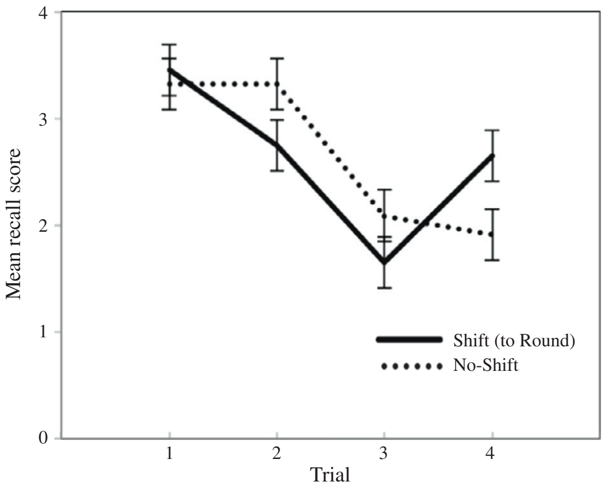

Figure 5. Mean recall scores on each trial for the Shift (from Oblong to Round) and No-Shift (only Round) condition with Round objects on the fourth trial in Experiment 4. Bars represent standard errors.

category is related to other categories by means of inclusion (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). In the taxonomy of categories, basic categories are at the most inclusive level and any category below this basic level will be a subordinate category. For example, the category of vertebrates includes the categories of mammals, birds, fish, reptiles, and amphibians. As such, this vertebrates' category has a higher level of abstraction and, thereby, a higher level of inclusiveness than the category of mammals. So, the higher the level of abstraction, the greater the inclusiveness of a category. If it comes to shape categories, some shapes might be more basic than others, consider, for example, circles, squares, and triangles as opposed to ellipses, kites, and hexagons (see "the graphic lexicon" by Cohn, 2012). A circle might be more of a basic level shape than an oblong and, as category, be classified on a higher level of "the taxonomy of shapes." The category of round objects that was established during the buildup of interference might therefore have had a higher level of inclusiveness as compared to the established category of oblong objects. As a result, when the shape of the objects shifted from round to oblong, the oblong objects of the critical trial might have been included into the established category of round objects, thereby continuing the buildup of interference. The other way around, round shaped objects were not included into the category of oblong objects, resulting in the establishment of a new category and release of interference.

General Discussion

The purpose of the present study was to investigate the role of sensory information (i.e., object shape) and semantic knowledge in semantic memory organization of visual objects. We predicted that if depictions of objects are encoded in such a way as to include information about the shape of the objects, then objects with a particular shape should form a different category than objects with another shape. We also predicted that the degree of activation of shape information might depend on the contextual relevance of this information. Therefore, in four experiments, we investigated semantic memory organization in four different contexts, using the PI paradigm. We created these different contexts by manipulating the objects' semantic information. The latter has been defined in terms of varying the availability of semantic categories. In Experiment 1, two semantic categories were at play, in Experiment 2 only one category, and in Experiments 3 and 4 there were many categories involved. The results of the present study suggest that semantic memory organization of objects is indeed dependent on the relevance of semantic information.

Experiment 1 showed that if objects can be categorized both on semantic and shape information, then shape information is overruled by semantic information. Namely, as indicated by the release from interference as a result of the semantic category change, semantic information was used as retrieval cue, which was not affected by the shift in shape.

Experiment 2 showed however that shape does play an important role in object categorization, if semantic information is not a distinguishing factor. In this experiment the semantic information remained unchanged (i.e., the objects stemmed from the same category), whereas the shape of the objects did change. The release from interference as a result of the shift in shape showed that object shape was indeed used as retrieval cue.

Where we combined a shift in shape with a semantic shift in Experiment 1 and studied a shift in shape while keeping the semantic category constant in Experiment 2, we investigated a shift in shape for objects from disparate semantic categories in Experiment 3. Hence, there was no straightforward semantic category available to which the objects could be assigned. The experiment generally showed that object shape was not used to create an ad hoc category when the fourth triad was presented (Barsalou, 1983, 1991). Interestingly however, the findings did suggest that shape information does receive activation when the objects are suddenly similarly shaped *within* a triad. The recall of similarly shaped objects after having seen differently shaped objects was better than for differently shaped objects after having seen similarly shaped objects. This indicates that object shape receives higher activation when the objects are presented in a manner in which shared perceptual features are easier to perceive and the creation of a perceptual group is stimulated (cf. Wertheimer's Gestalt theory, 1923).

In Experiment 4, we investigated a shift in shape for objects from disparate semantic categories as well. However, the shift in shape concerned a shift from one shape to another shape, keeping the object shapes similar within a triad. The release from interference as a result of the shift in shape from oblong to round shaped objects showed that the round object shape was used as retrieval cue. On the other hand, the absence of the release from interference as a result of the shift in shape from round to oblong shaped objects showed that the oblong object shape was *not* used as a retrieval cue. In the Discussion section of Experiment 4, we already tried to interpret this finding in terms of inclusiveness (Rosch et al., 1976). A circle might be at the top of the taxonomy of shapes. As such, the category of round shapes is a higher-level category which is more inclusive than the category of oblong shapes.

The findings of our four experiments suggest that if people are given the task to retrieve objects from long-term memory, a general and opportunistic "semantic category-first" rule is at play. If semantic information allows for PI-release (i.e., can be employed as retrieval cue), it overrules the need to use sensory-based retrieval cues (i.e., Experiment 1). When the number of semantic categories available is either one or many, sensory information enters the retrieval process, albeit in ways that are complex and far from being fully understood. In case of one category, shape information is used to recall the objects (i.e., Experiment 2). However, in the case where there are many semantic categories available, sensory information is employed only if the shift goes from "many shapes to one shape" (i.e., Experiment 3, see Appendix C2) or goes from "less basic to basic shapes" (i.e., Experiment 4, see Appendix D2).

A theoretical account for these results may be derived from Humphreys and Forde's (2001) Hierarchical Interactive Theory (HIT). The theory originally describes how perceptual and semantic (i.e., conceptual) information influence object *identification*, but the theory's architecture provides an explanation to our findings as well. The theory posits a top-down relation between the two types of object knowledge investigated in our experiments: structural descriptions (i.e., sensory information) and semantic knowledge. According to HIT, identifying objects is initially guided by the activation of (multiple) structural descriptions, which, among others, involves object shape. Structural descriptions spread activation to stored semantic knowledge of the object. Interestingly, the theory posits that the activated semantic knowledge feeds back to structural descriptions. Due to higher activation of semantic knowledge, the activation of the correct structural description is reinforced, and the activation level of competing structural descriptions is suppressed. So, first, visual information provides access to nonvisual semantic information, and second, this semantic information reinforces visual information in object identification. This explains how people recognize, for example, an orange, but also how they are capable of distinguishing such an object from, for example, a tennis ball. The crucial tenet of the theory is that it allows the two types of information to interact freely. A similar albeit reversed interaction between structural and semantic information can be proposed for retrieval processes investigated in our study, see Figure 6.

Retrieval processes initially seem to operate on activated semantic information. If there is a shift in semantic category, then that category is used as retrieval cue (i.e., Experiment 1). If the semantic information renders no distinctive feature available (i.e., because all objects stem for one category), the system will check whether distinct structural descriptions can be activated. Our study has shown that different structural descriptions based on object shape

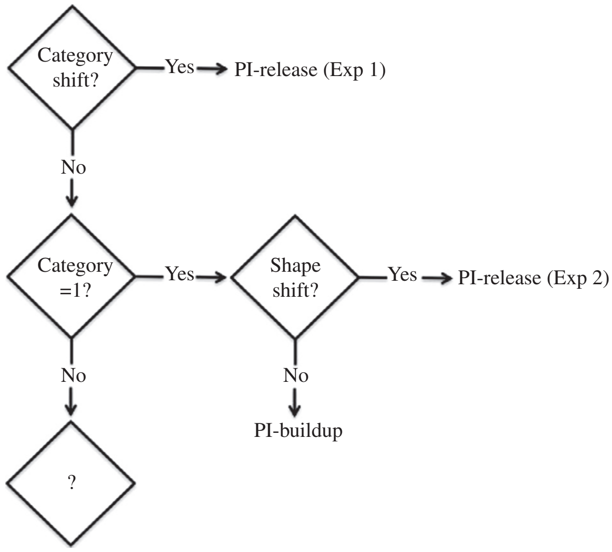

Figure 6. Process of retrieval based on Experiments 1 and 2.

can indeed affect retrieval processes (i.e., Experiment 2). This shape effect is intriguing given the fact that the PI paradigm basically consists of a semantic task, that is, people are instructed to name objects they have seen in preceding trials (and are not requested to describe their shape). Intuitively, this directs the participants' focus of attention more to meaning-related rather than perceptual properties of the shown objects. An issue that deserves further scrutiny is what role exactly is played by structural descriptions when the semantic information that is activated is divergent because more than one semantic category is activated (i.e., Experiments 3 and 4). Our experiments show that more subtle retrieval processes are at play as well, in cases where there is a shape shift from many shapes to one shape (i.e., Experiment 3) or when there is shift from a less basic shape to basic shape (i.e., Experiment 4).

With respect to the findings of Experiment 4, it would be interesting to further investigate the relation between spreading activation and a "taxonomy of shapes." If basic shapes have a higher level of inclusiveness and thereby a wider range of spreading activity than less basic shapes, then it might be interesting to set up an experiment in which semantically different objects change from one basic shape to another (such as, from circles to squares). As the level of inclusiveness would then be similar for both types of objects, release from PI might be produced in both directions of the shape shift.

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Electronic Supplementary Material

The electronic supplementary material is available with the online version of the article at http://dx.doi.org/10.1027/1618-3169/a000284

ESM 1. Sav file
Raw data Experiment 1
ESM 2. Sav file
Raw data Experiment 2
ESM 3. Sav file
Raw data Experiment 3
ESM 4. Sav file
Raw data Experiment 4

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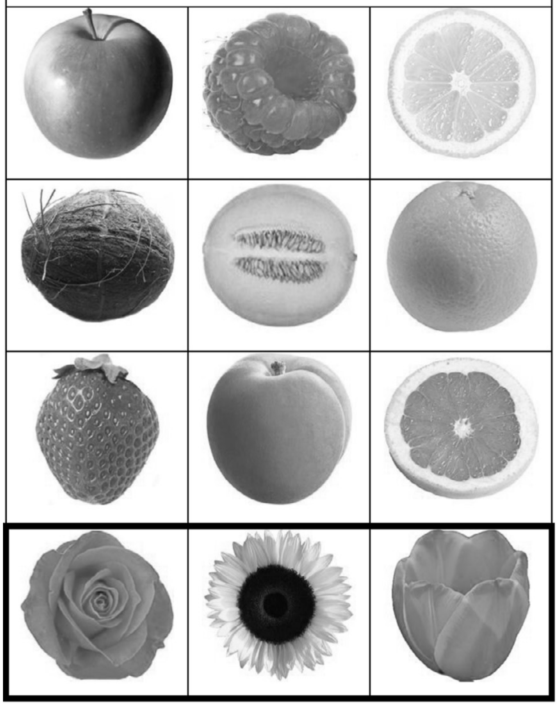
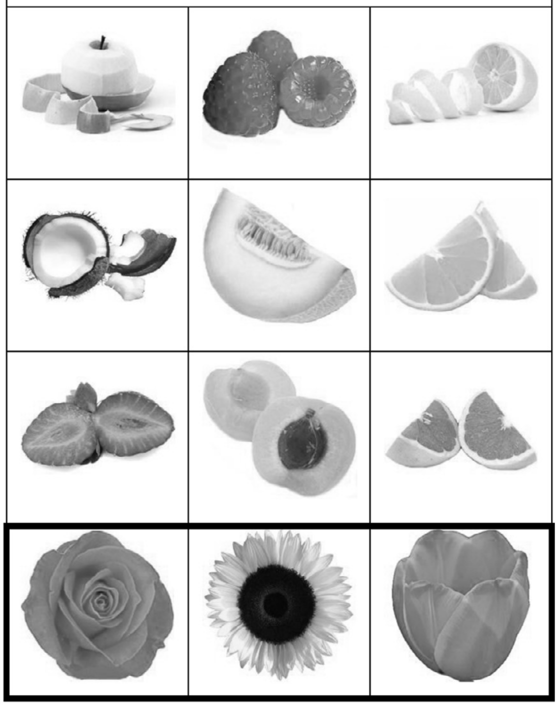
Appendix A

Stimuli Experiment 1

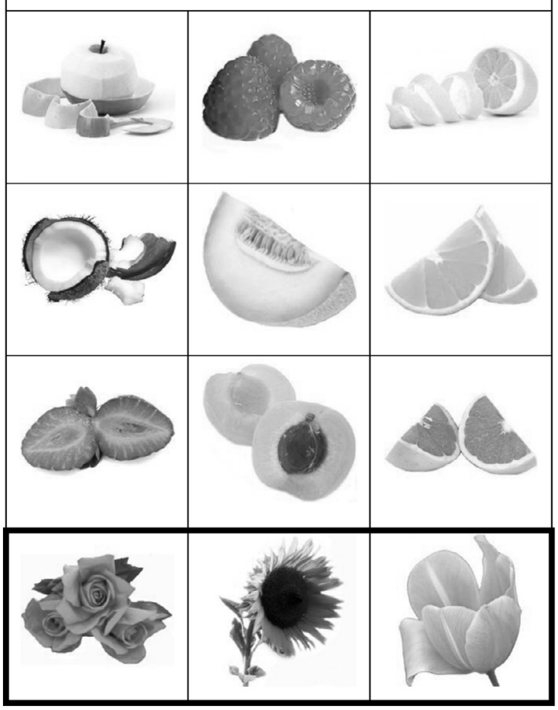
1: No-Shift condition (Round)



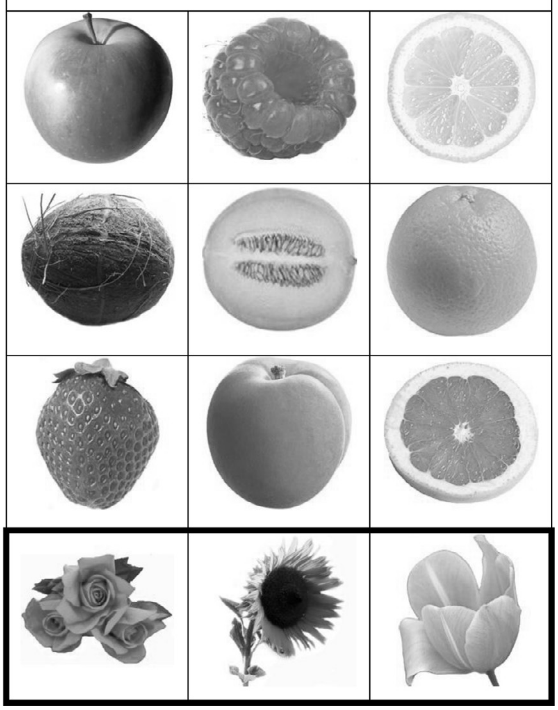
2: Shift condition (Irregular – Round)



3: No-Shift condition (Irregular)



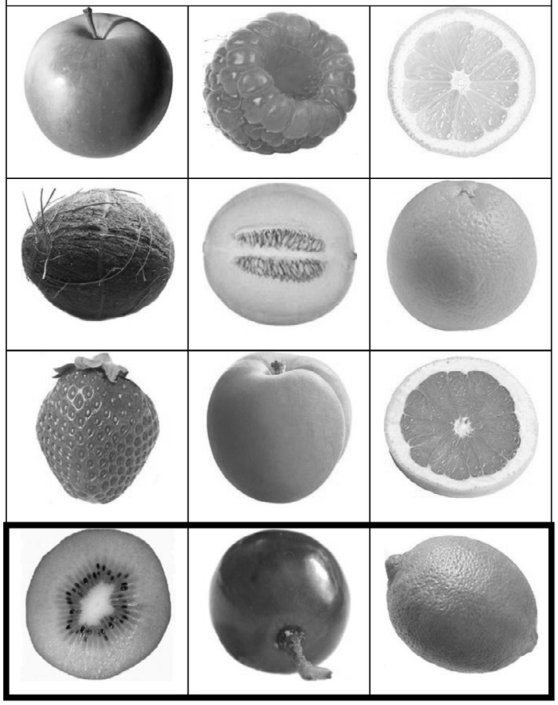
4: Shift condition (Round – Irregular)



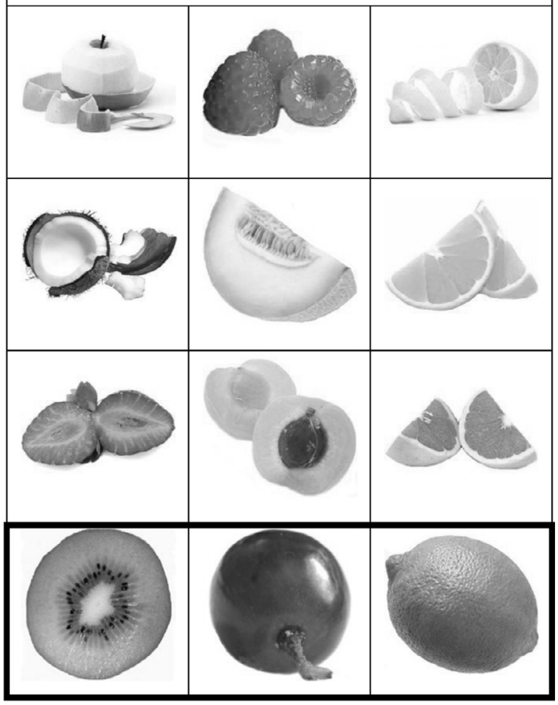
Appendix B

Stimuli Experiment 2

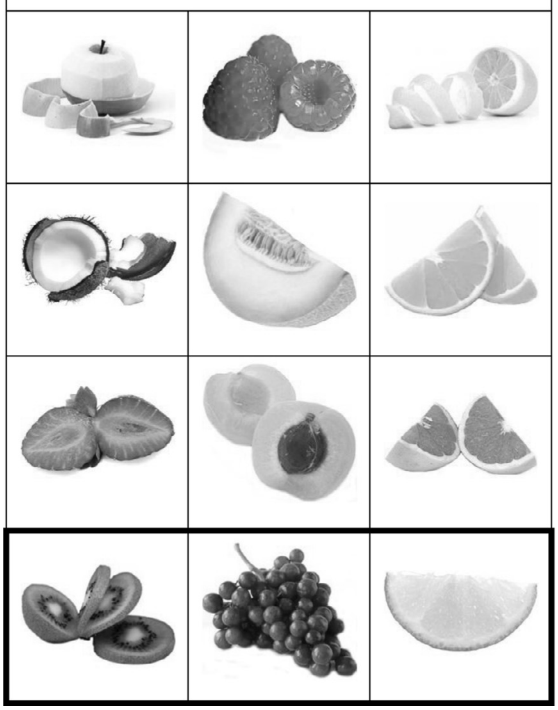
1: No-Shift condition (Round)



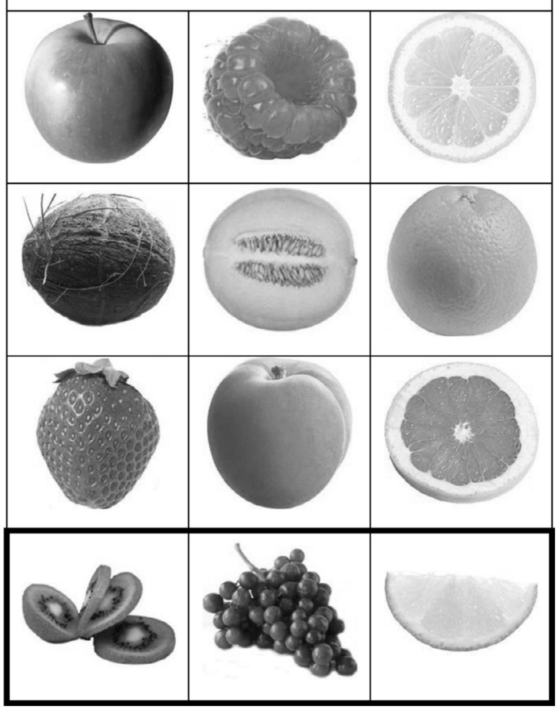
2: Shift condition (Irregular – Round)



3: No-Shift condition (Irregular)

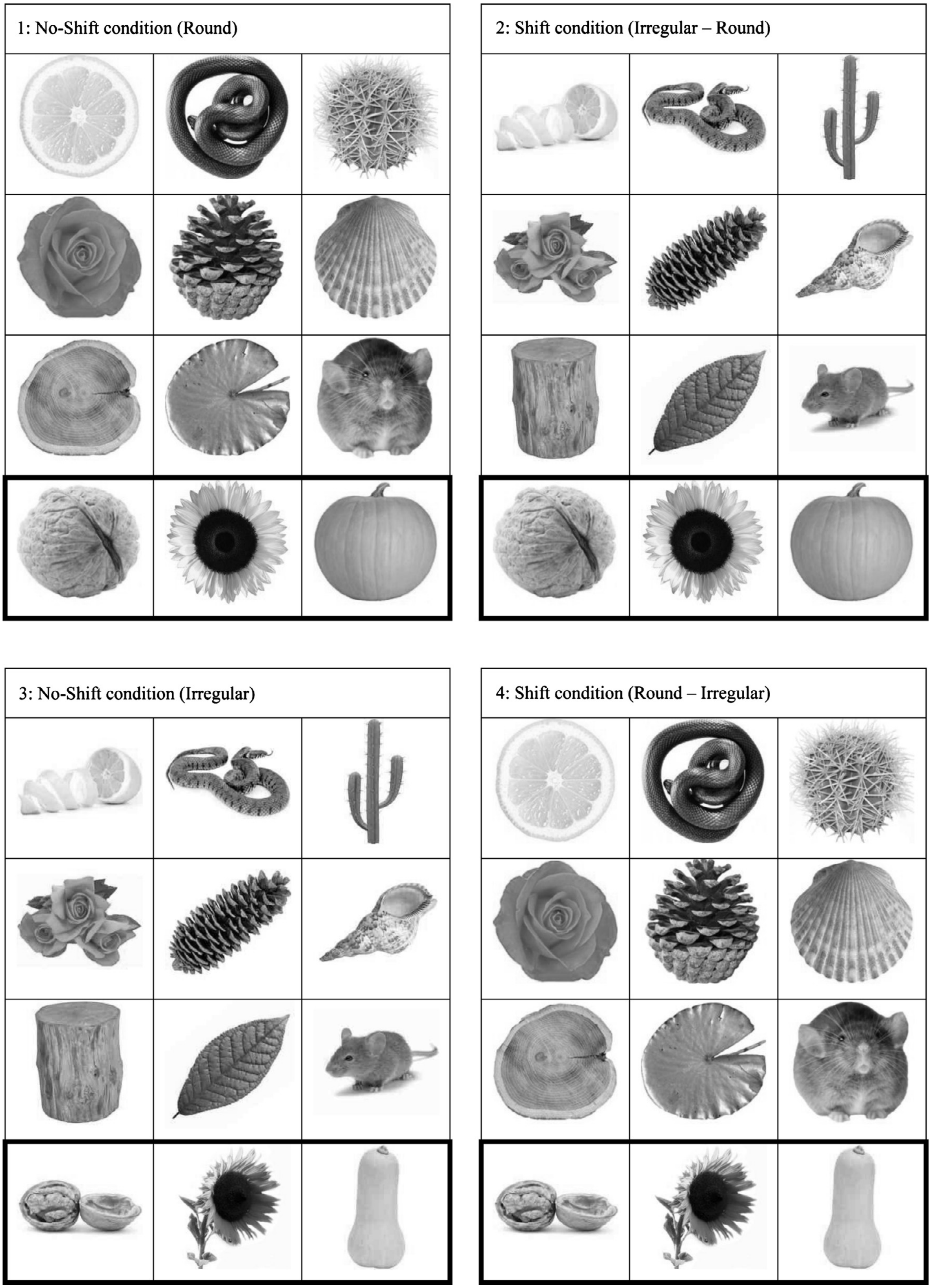


4: Shift condition (Round – Irregular)



Appendix C

Stimuli Experiment 3



Appendix D

Stimuli Experiment 4