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Acquiring experiential traces in word-referent learning

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Abstract

Two experiments investigated the activation of perceptual representations of referent objects during word processing. In both experiments, participants learned to associate pictures of novel three-dimensional objects with pseudowords. They subsequently performed a recognition task (Experiment 1) or a naming task (Experiment 2) on the object names while being primed with different types of visual stimuli. Only stimuli that participants had encountered as referent objects during the training phase facilitated recognition or naming responses. New stimuli did not facilitate processing of object names, even if they matched a schematic or prototypical representation of the referent object that participants might have abstracted during word-referent learning. These results suggest that words learned by way of examples of referent objects are associated with experiential traces of encounters with these objects.

Key words: Embodied cognition – experiential traces – language comprehension – schemata – word-referent learning.

Acquiring experiential traces in word-referent learning

Experiential theories of language comprehension claim that the representations involved in language comprehension are of the same kind as the representations involved in sensory experiences, perceptions, and actions (e.g., Barsalou, 1999; Glenberg & Kaschak, 2002; MacWhinney, 1999; Zwaan, 2004). In support of this assumption, a large number of studies have demonstrated that different types of modal representations are indeed activated while comprehenders process words, sentences, or larger segments of text (for an overview, see Zwaan, 2004). Various researchers have proposed that both linguistic constructions such as words and mental representations of objects, people, and events are multimodal mental representations (e.g., Barsalou, 1999; Zwaan, 2004). For example, the word "cat" is associated with auditory and visual representations (of the spoken and written versions of the word, respectively), but also with various motor representations (e.g., of how to say, write, or type the word) and in some individuals with tactile representations (braille). Likewise, we have visual, auditory, olfactory, tactile (e.g., what a cat's fur feels like), and motor (how to pet or pick up a cat) representations of interacting with cats. The basic tenet of experiential theories is that these latter representations resonate with the activation of the word.

Important questions involve the nature of these word-referent associations and how they are acquired. Pulvermüller (1999) suggests that these associations are formed as a function of Hebbian learning. In the case of concrete content words, frequent co-activation of neurons representing word forms and neurons representing perceptions and actions related to its meaning leads to the formation of cell assemblies which represent words. Recently, Smith and Yu (2008; Yu & Smith, 2007) have suggested that in addition, word-referent associations may be formed as a function of cross-situational learning. Even though a child may not know to which element in a visual scene a word refers, it may be able to acquire the correct mappings across situations in which the word is uttered: the word refers to the common element across these situations.

The goal of the present research was to examine a related question about the role of perceptual features of referent objects in the formation of word-referent associations. We will pursue this question exclusively in the visual domain, but there is no reason to suspect that the effects we find will not generalize across modalities. Visually presented objects differ from each other in a variety of perceptual dimensions such as shape, color, and orientation. Basically, there are three theoretical possibilities of how the information provided by these perceptual dimensions might be used in the formation of word-referent associations. One possibility is that representations of the word form become associated with experiential traces of the particular objects that an individual has encountered in the course of word-referent learning. A second possibility is that individuals spontaneously form schematic perceptual representations of the word's referent. Both of these options are compatible with the experiential view on language comprehension. Accordingly, there is the third possibility that experiential traces as well as schematic perceptual representations are associated with representations of the word form. We will discuss each of these possibilities in turn.

The view that word-referent associations involve *traces of particular experiences* with the word's referents is related to exemplar models that have been developed in categorization research (e.g., Medin & Schaffer, 1978; Nosofsky, 1986). According to exemplar models, conceptual representations are based on memory traces of the specific instances of a category that a person has encountered in the past. Studies on the instantiation principle (Heit & Barsalou, 1996) provide evidence that exemplar representations may indeed play a role in the representation of natural language categories (see Storms, 2004, for an overview). These experiments have demonstrated for a variety of conceptual domains that people tend to generalize estimates of how typical particular exemplars (e.g., *cow*) are with respect to a superordinate category (e.g., *animals*) to estimates about how typical subordinate categories (e.g., *mammals*) are with respect to the same superordinate category. Linked to exemplar models is the research on the role of non-analytic cognition in concept formation initiated by Brooks (1978). According to this approach, cognitive activities such as classification are influenced by specific instances rather than abstract rules or generic schemata (Allen & Brooks, 1991). In some cases, categorization based on similar instances is even more adequate than an explicitly learned rule because it can be flexibly adapted to new circumstances (for an example from medical diagnosis, see Brooks, Norman, & Allen, 1991). These and other ideas stressing the importance of instance representations for higher-order cognition are compatible with the view that words become associated with experiential traces that represent encounters with their referents.

The alternative view that word-referent associations are formed by abstracting a schematic representation of a word's referent is related to several classical theories of semantic memory and categorization. According to these theories, conceptual representations are *abstract summary representations* that consist of a set of defining features (e.g., Collins & Quillian, 1969) or of a prototype (Reed, 1972). Schema theory and rule-based representations illustrate the idea of defining feature representations particularly well. Schemata are assumed to combine feature slots with fixed, defining values and feature slots with variables that may vary between instances of the schema (Rumelhart, 1980). Rule-based representations consist of dimensional boundaries that govern the classification of instances (e.g., "Large items are in Category A, small items are in Category B", Erickson & Kruschke, 1998). In contrast to models that rely on defining features, prototype models can account for the fact that some instances are perceived as more typical members of a category than others (Rosch & Mervis, 1975). Prototypes represent a combination of typical (rather than defining) features abstracted from members of category that a person has encountered in the past. Thus, just as schemata, prototypes are abstract and generic summary representations that need not be identical to any particular object that a word may refer to. In his theory of perceptual symbol systems, Barsalou (1999) has shown that abstract summary representations can be conceptualized as multimodal representations (Barsalou, 1999). Thus, it is a distinct theoretical possibility that individuals construct multimodal schemata that are based on those perceptual features of the objects that remain constant across contexts, omitting perceptual features that vary from context to context. When new words are acquired, these multimodal schemata could become associated with a representation of the word form.

The experiential traces view and the multimodal schemata view have different implications for the kind of perceptual representations that are associated with words denoting concrete referent objects (e.g., concrete count nouns) and, as a result, may be activated by comprehenders upon hearing or reading these words. According to the experiential traces view, comprehenders associate words with particular experiences with referent objects (or a salient subset thereof) that are activated when they encounter a word referring to these objects. As a consequence, the perceptual representations associated with words are likely to include configurations of perceptual features of particular referent objects, including those features that vary across contexts. In contrast, the multimodal schemata view assumes that a perceptual but nonetheless abstract summary representation is associated with a word. As a consequence, the perceptual representations associated with a word should include those perceptual features that are invariant across contexts or, at least, those perceptual features that appear in a greater part of contexts.

From the more general perspective of experiential theories of language comprehension, it must be noted that the experiential traces view and the multimodal schemata view need not necessarily be regarded as mutually exclusive accounts. Rather, word-referent learning might involve the abstraction of a multimodal schema that is stored along with experiential traces of encounters with the referent objects. Comprehenders would gain a great deal of flexibility by having two types of representations available. Whereas experiential traces might provide good-enough representations for most comprehension situations, multimodal schemata might be required for more analytic kinds of language processing (such as conceptual combination or language-based reasoning, Barsalou, 1999). The idea that there are two representational systems, one exemplar-based and one schema- or prototype-based, serving different types of cognitive activities is also adopted by researchers in the area of categorization (e.g., multiple systems theory, Ashby & Waldron, 1999; Ashby, Alfonso-Reese, Turken, & Waldron, 1998; or hybrid models of categorization, Anderson & Betz, 2001). In addition, task-dependent switching between the use of generic schemata and representations of individual instances is stressed in research on analytic vs. non-analytic cognition (e.g., Whittlesea, Brooks, & Westcott, 1994). In the light of these approaches, it makes sense to acknowledge that both the experiential traces view and the multimodal schemata might contribute to understanding the nature of perceptual representations involved in language comprehension.

We combined a word-referent learning paradigm with a priming method to investigate the nature of representations that become associated with words denoting concrete objects. In two experiments, participants first learned to apply six (pseudo)words (such as *floint*) to pictures of novel three-dimensional objects. The new words were extensionally defined by fixed values on two perceptual dimensions that could be shape, color, or orientation whereas values on the third perceptual dimension varied between referent objects of the same words. For example, all referents of one new word were blue and oriented upright, while the referents of another word had a single characteristic shape and were oriented to the left (Figure 1). All three perceptual dimensions are potentially relevant in the recognition of real objects. While shape is the universal cue in object recognition, color plays a role in the recognition of color-diagnostic objects such as many fruits and vegetables (Tanaka, Weiskopf, & Williams, 2001). Orientation is an important cue for recognizing objects with a canonical orientation such as trees, houses, and cars (e.g., Jolicoeur, 1985; Tarr & Bülthoff, 1998). Importantly, the object names taught in our experiments had a clear extensional definition in the sense of linearly separable categories. Thus, it was possible to grasp their conceptual structure by abstract summary representations such as prototypes, schemata, or simple rules. The use of three different perceptual dimensions should make it easier for participants to keep the defining and non-defining features of the new words' referents.

Subsequent to the learning phase, participants performed either a recognition task on the newly learned words (Experiment 1) or they simply named these words (Experiment 2). These tasks were chosen because they share some properties of lexical decision and word naming, two tasks that are commonly used in language experiments to investigate routine and basic aspects of word access. Neither lexical decision nor word naming require access to word meanings as they can be accomplished on the basis of orthographic information and phonological information alone. Nevertheless, large scale regression analyses with lexical decision and naming latencies have shown that the ease of lexical decision and, to a smaller extent, the ease of word naming is usually affected by the semantic features of words, suggesting that representations of word meanings are involved when people decide whether a word is a word or even when they simply name the word (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; see also Chumbley & Balota, 1984; Strain, Patterson, & Seidenberg, 1995). However, unlike semantic tasks such as classification or property verification, tasks resembling lexical decision and word naming focus participants' attention on the words themselves, rather than requiring a response that is based on the learned objects. As indirect tasks, they seem to be well suited for investigating the kind of mental representation of referent objects that are associated with newly learned words.

Recognition judgments and naming of the newly learned words were primed by picture stimuli. Accordingly, the test phase followed a paradigm similar to the one that has been used extensively in picture-word priming studies to investigate the structure of semantic memory (for an overview, see Glaser, 1992). In priming experiments in which a word and a picture are presented in close succession, facilitating and interference effects have been observed in both directions, i.e. when picture processing is primed with semantically related words or the processing of words is primed by semantically related pictures (e.g., Rahman & Melinger, 2007; Richter & Zwaan, in press; Sperber, McCauley, Ragain, & Weil, 1979). In the present experiments, the picture stimuli were either referent objects that participants had already seen during the first phase of the experiment (old stimuli), or they were new stimuli that differed from old ones either in a defining perceptual dimension (e.g., a green and upright object if the word was defined by the color blue and an upright orientation) or in a dimension that was irrelevant for the definition of the word and also varied across referent objects that participants had seen in the learning phase (e.g., a blue and upright object with a different shape if the category was defined by the color blue and an upright orientation). Given the assumption of the experiential view that perceptual representations are activated when words referring to concrete objects are processed, priming by old stimuli was expected to facilitate recognition as well as naming of the new words. New stimuli that differed from old stimuli in a defining perceptual dimension, in contrast, should not facilitate these tasks because they neither corresponded to experiential traces of particular referent objects nor to an abstract summary representation associated with the newly learned word.

The second type of new stimuli, which differed from the old ones in a non-defining dimension that varied across contexts, was included to disentangle the experiential traces view from the multimodal schemata view. Being congruent with the extensional definition of the newly learned words, these stimuli matched a modal schema or prototype that participants may have abstracted during the learning phase of the experiment. However, they did not correspond to any particular referent object that participants had already encountered. For this reason, the multimodal schemata view but not the experiential traces view predicts facilitation for these stimuli.

The old stimuli that were used as priming stimuli were either ordinary referent objects with values on the third, non-defining perceptual dimension that appeared frequently in other objects from the same category, or they were outstanding referent objects with a unique value on this dimension that appeared infrequently, i.e. only in this particular object but not in other objects in the category. The distinction between ordinary and outstanding referent objects relates to the different roles that the experiential traces view on the one hand and the multimodal schemata view on the other hand ascribe to the distributions of perceptual features of referent objects across contexts. If abstract summary representations in the form of prototypes are activated when the newly learned words are processed, referent objects with perceptual features more frequent within a category might exert greater facilitation effects as they match the prototype better than referent objects with infrequent values on this dimension. In contrast, the experiential traces view does not imply an advantage of priming stimuli with more frequent perceptual features. If anything, referent objects with infrequent values might even cause greater facilitation effects. This is because a priming stimulus that is highly similar to one particular referent of one newly learned word (but dissimilar to referents of other words) should selectively prime only this one word.

Experiment 1

In Experiment 1, participants provided speeded recognition judgments for the newly learned (pseudo)words that they had seen during the training phase of the experiment. This task resembles lexical decisions that are commonly used in language experiments to detect the activation of lexical representations. Similar to lexical decisions, the speeded recognition judgments did not require participants to retrieve meaning representations, but it is likely to involve some degree of semantic processing (e.g., Balota et al., 2004).

The experiential approach to language comprehension holds that perceptual representations of referent objects are associated with concrete count nouns that can become activated when these nouns are processed. This assumption implies that the processing of these words should be facilitated when representations of their referents are activated concurrently. Accordingly, pictures of referent objects presented together with the newly learned words should facilitate recognition of these words. In contrast, pictures of new objects lacking the defining perceptual features of the referent object should not facilitate recognition. In addition to this core hypothesis of the experiential view, we explored two further questions that might elucidate the characteristics of the perceptual representations formed during word-referent learning. First, we tested whether new stimuli that shared the two defining features of the old stimuli but differed on a third, irrelevant dimension would also cause a facilitation effect. Such an effect would be expected if participants had abstracted a schematic summary representation during word-referent learning (multimodal schemata view) but not if word-referent associations were based on memory traces of experiences with particular referent objects (experiential traces view). Second, we investigated whether the magnitude of the facilitatory effects depended on the distribution of non-defining perceptual features across referent objects. Here, the idea that words become associated with abstract summary representations during word acquisition suggests that referent objects with perceptual features that are frequent within one category (ordinary referent objects) exert stronger priming effects because these objects are closer to the prototype than objects with features that are infrequent (outstanding referent objects). In contrast, the experiential traces view does not make such a prediction.

Method

Participants. Twenty-seven psychology undergraduates at the University of Cologne (Germany) participated in Experiment 1. Twenty-two of them (81%) were female and 5 (19%) were male. Their mean age was 25.1 years (SD = 6.4).

Stimulus materials. Stimulus materials were twelve monosyllabic pseudowords that were consistent with the orthography and phonology of German (e.g., *Flont, Kralt, Schoft*) and pictures of novel three-dimensional objects. The twelve pseudowords consisted of six pairs that were matched with respect to number of letters and starting letter. These six pairs were used to construct two parallel lists of object names and distracters. The depicted objects varied in shape, color, and orientation that were used to create six different categories of objects. Each of the perceptual dimensions could take five different values. Shape varied between conical shapes with a sphere, a cuboid or a pyramid attached to their bases, and two different complex polyeders. Color varied between blue, red, green, purple, and orange. Orientation varied between horizontally left, horizontally right, upright, diagonally left, and diagonally right. For the referent objects of each of the six pseudowords, two of the perceptual dimensions (e.g., color and orientation) were used to derive defining features of objects that were associated with the same name. The third dimension (e.g., shape) differed between objects with the same name and was used to create ordinary and outstanding referent objects (see Figure 1 and Appendix for examples; one full experimental list of object pictures is available on the internet, http://www.allg-psych.uni-koeln.de/richter/Exemplars.pdf). If objects associated with a particular pseudoword were defined by a conical shape with a cuboid attached to its base and an upright orientation, for instance, their color would vary between blue and red (two colors that occurred in objects associated with other pseudowords as well). However, one single referent object would stand out because of its orange color (a color that occurred in none of the other objects presented during the learning phase). Thus, outstanding referents were created by assigning unique values to the perceptual dimension that was irrelevant for the definition of the pseudowords. Two values on each of the three perceptual dimensions were reserved for creating outstanding referent objects (shape: the two complex polyeders; color: purple and orange; orientation: diagonally right and diagonally left). Three stimulus lists with six categories of referent objects were created by permutations of ordinary values on the perceptual dimensions.

Procedure. The experiment consisted of a training phase and a test phase. The instructions for training and test phases were embedded in a fictional scenario. Participants were asked to imagine that a geologist called Professor Cosmo was selecting research assistants for an expedition to Alpha Centauri. For this purpose, Professor Cosmo had designed several diagnostic tasks to test participants' ability to remember the appearances and names of novel crystals. In the training phase, participants learned to apply six object names to picture stimuli that were presented to them on a computer screen. In the first part of the training phase, the six object names were introduced one after the other by presenting the pseudoword and pictures of nine referent objects (eight ordinary referent object and one outstanding referent object). The picture stimuli were presented one-by-one below the pseudoword for 4000 ms each, with a blank screen (1000 ms) followed by a fixation cross (250ms) between stimulus presentations. The order of pseudowords and the order of referent objects associated with each pseudoword were randomized across participants. In the second part of the training phase, participants assigned objects to pseudowords and received feedback on the accuracy of their responses. The training trials were grouped in cycles with eleven pictures of referent objects for each pseudoword (ten ordinary referent objects and one outstanding referent object). The participants' task was to indicate via key presses for each stimulus picture the pseudoword with which it was associated. There were six response keys, each one corresponding to one object name. The order of picture stimuli within each cycle and the assignment of pseudowords to response keys were randomized across participants. Participants were trained until they were able to assign referent objects to object names with high accuracy (85% correct assignments). Participants who did not reach the performance criterion were trained for an extended period of time (35 minutes) before they could move on to the test phase.

In the test phase, participants performed a recognition task on the six pseudowords they had seen during training and six new nonwords (distracters) that they had not seen before. They were told that letter strings would appear one by one on the screen one by one. They were instructed to indicate by key presses whether the letter string was one of the object names they had seen before or whether it was a new stimulus. At a stimulus onset asynchrony of 250 ms before each verbal stimulus, a priming stimulus was presented that was (1) either an old ordinary referent object, (2) an old outstanding referent object, (3) a new object that differed from the old referent objects in a category-irrelevant, non-defining dimension and was therefore consistent with a schematic representation of the referent objects, (4) a new object that differed from the old referent objects in a defining perceptual feature and was therefore inconsistent with a schematic perceptual representation of the referent objects, or (5) a neutral picture stimulus (a grey rectangle). The picture stimulus remained on the screen while the verbal stimulus was presented. Each pseudoword appeared twice in each condition, and it was yoked to a matching distracter nonword that was presented with the same priming stimuli. Accordingly, there were 60 experimental trials with learned pseudowords and 60 filler trials with distracter nonwords. The order of experimental trials and filler trials in the test phase was randomized across participants.

Design. The design was a one-factor within-subjects design with type of priming stimulus (old ordinary referent objects, old outstanding referent objects, new objects with a change on a non-defining dimension, new objects with a change on a defining dimension, neutral stimulus) as independent variable. The assignment of ordinary perceptual features to pseudowords was counterbalanced across participants on the basis of the three stimulus lists. As a result of the way the visual stimuli were constructed, the assignment of perceptual dimensions to defining or non-defining dimensions was counterbalanced within participants. Thus, color, shape, and orientation served as defining perceptual dimensions for any four of the six pseudowords that each participant received during the training phase. Finally, the assignment of the two lists of verbal stimuli to either category names or distracter items was counterbalanced across participants.

Results and Discussion

Significance tests and power. All significance tests reported in this article were based on a type-I-error probability α of .05. For multiple comparisons, α was adjusted by the sequential Holm-Bonferroni procedure (Holm, 1979). Given the sample size of Experiment 1, the power for detecting a medium-sized difference (d = .60) between any of the experimental conditions and the neutral condition was .96 while the power for detecting a small difference (d = .40) was still .65 (at α = .05, one-tailed; power analyses were performed with the software GPower; Faul, Erdfelder, Lang, & Buchner, 2007).

Accuracy of object-name assignments and name recognition. The mean proportion of correctly assigned stimuli at the end of the training phase was .80 (SD = 0.15), indicating that in general, participants learned the word-referent associations well. Twelve participants (44%) exceeded the performance criterion of 85% correct classifications within the time limit of 35 minutes. The mean proportion of correctly recognized object names in the experimental phase was .93 (SD = 0.06). An ANOVA performed on the arcsine-transformed proportions of correctly recognized stimuli did not reveal any differences between experimental conditions, $F(3,78) = 2.0$, $p = .12$. The mean proportion of correctly rejected distracter pseudowords was .94 (SD = .07). Again, an ANOVA performed on the arcsine-transformed proportions of correctly rejected distracter stimuli did not reveal any significant differences between experimental conditions.

Recognition latencies. Recognition latencies deviating more than three standard deviations from the condition mean (less than 3.2% of all latencies) were treated as outliers and removed from the data set. There was a medium to large overall effect for type of priming stimulus (Figure 2a), $F(4,104) = 4.4$, $p < .01$, $\eta^2 = .14$. Recognition responses primed with old ordinary referent objects (M = 793 ms, SE_M = 43) were faster than responses in the neutral condition (M = 929 ms, SE_M = 54), $t(26) = -3.0$, $p < .0125$ (one-tailed, Holm-Bonferroni correction), d = 0.58. The same was true of recognition responses primed with old outstanding referent objects (*M* = 801 ms, SE_M = 38), *t*(26) = -3.2, *p* < .0167, *d* = 0.62 (one-tailed, Holm-Bonferroni correction). In contrast, there were no latency differences to the neutral condition for responses primed with new objects with a change on a non-defining dimension (*M* = 868 ms, SE_M = 45) or for responses primed with new objects with a change on a defining dimension (*M* = 910 ms, SE_M = 58), for both comparisons: |*t*| (26) < 1.4, *p* > .16.

Ordinary referent objects with prototypical perceptual features did not cause greater priming effects than outstanding referent objects with unique perceptual features on the non-defining dimension, *t*(26) = -0.3, *p* = .79 (one-tailed). Accordingly, the assumption that participants might activate an abstract summary representation in the form of a prototype was not supported.

Distracter latencies. For control purposes, we performed an ANOVA on the latencies of correct responses to the distracter items. In this analysis, there was no significant overall effect of priming stimulus, *F*(4,104) = 0.3, *p* = .89, and none of the experimental conditions exerted a significant facilitation effect relative to the neutral condition (for all comparisons: |*t*| (26) < 0.7, *p* > .50). These additional results underscore that the systematic differences that we found for the recognition latencies of the experimental stimuli are not caused by peculiar features of the priming stimuli used in the experimental conditions.

In sum, the results of Experiment 1 corroborate the predictions of the experiential traces view whereas no evidence was found for the predictions of the multimodal schemata view. Only stimuli that participants had already encountered during training facilitated recognition of the object name whereas new but schema-congruent stimuli did not yield any priming effects.

Experiment 2

In Experiment 2, we tested the same predictions as in Experiment 1 with the more indirect task to read out loud the newly learned words. This task corresponds to word naming tasks that are common in experiments on reading and language production. Word naming only requires access to phonemic representations but it is likely that converging evidence from phonemic as well as semantic representations is used to identify the words (Plaut, McClelland, Seidenberg, & Patterson, 1996; van Orden, Pennington, & Stone, 1990; see also Balota et al., 2004). As a highly indirect task, the word naming task used in Experiment 2 provides an excellent way to replicate the findings of Experiment 1 concerning the kind of perceptual representations associated with the newly learned words.

Method

Participants. Forty-seven psychology undergraduates at Florida State University participated in Experiment 2. Three participants were excluded from the sample because they reported vision problems and were not wearing corrective lenses during the experiment. Of the remaining participants, 29 (66 %) were female and 15 (34%) were male. Their mean age was 19.0 years (*SD* = 2.1).

Stimulus material, procedure, and design. Stimulus material and design of Experiment 2 were identical to those of Experiment 1. The procedure was similar to Experiment 1 except for four changes. The first and primary difference was that participants performed a naming task on the object names and distracter nonwords. The second difference was that the pseudo- and and nonword stimuli in Experiment 2 were sampled from the ARC nonword database (Rastle, Harrington, & Coltheart, 2002). They were monosyllabic and consistent with the orthography and phonology of English. The third difference was that the training phase of Experiment 2 consisted of only three training cycles with eleven pictures of referent objects for each pseudoword to keep the experiment shorter. The fourth difference was that no cover story was used. Participants wore headsets with a built-in microphone connected to a PST Serial Response Box. We recorded the naming latencies from the onset of the presentation of the pseudoword stimulus to the triggering of the voice key by the participant's response. Throughout the experiment, the experimenter was in the same room as the participant in order to register inaccurate responses or erroneous triggering of the voice key. All other aspects of Experiment 2 including the design were identical to Experiment 1.

Results and Discussion

Power. The sample size of Experiment 2 yielded a power greater than .99 for detecting medium-sized differences (d = .60) and a power of .83 for detecting small differences (d = .40) between the experimental conditions and the neutral condition (at $\alpha = .05$, one-tailed).

Accuracy of object-name assignments. The mean proportion of referent objects correctly assigned to object names increased monotonically from the first training cycle (M = .42, SD = 0.16) over the second training cycle (M = .49, SD = 0.19) to the third training cycle (M = .58, SD = 0.21). The mean proportion of error-free pseudoword naming trials in the experimental phase was .99 (SD = 0.01).

Naming latencies. Naming latencies deviating more than three standard deviations from the mean of the experimental condition (less than 3.8% of all latencies) were treated as outliers and removed from the data set. Type of priming stimulus had a medium-sized overall effect on the adjusted naming latencies, $F(4,172) = 2.7$, $p < .05$, $\eta^2 = .06$. Planned comparisons (simple contrasts) with the neutral condition as reference condition (Figure 2b) revealed that naming responses primed with old ordinary referent objects were faster (M = 649 ms, $SE_M = 22$) than responses in the neutral condition (M = 669 ms, $SE_M = 24$), $t(43) = -3.0$, $p < .0125$ (one-tailed, Holm-Bonferroni correction), $d = 0.45$. Similarly, naming responses primed with old outstanding referent objects were faster (M = 644 ms, $SE_M = 21$) than those in the neutral condition, $t(43) = -2.9$, $p < .0167$ (one-tailed, Holm-Bonferroni correction), $d = 0.45$. The latencies of responses primed with new objects with a change on a non-defining dimension (M = 666 ms, SE_M = 25) or new objects with a change on a defining dimension (M = 658 ms, SE_M = 26) did not differ from the neutral condition (for both comparisons: $|t|$ (16) < 1.1, p > .13, one-tailed). Replicating the findings of Experiment 1, these results support the prediction implied by the experiential traces view that only those stimuli that participants had already encountered as referent objects of a particular pseudoword would facilitate naming of that pseudoword. New objects did not facilitate naming responses, even if they were congruent with a schema or prototype that participants may have abstracted during training.

The additional hypothesis implied by the multimodal schemata view that ordinary referent objects with more prototypical perceptual features might cause larger facilitation effects than outstanding referent objects could not be supported as there was no difference between the two conditions, t(43) = 0.7, p = .24 (one-tailed).

Naming latencies for the distracter items. Similarly to Experiment 1, we performed an ANOVA on the naming latencies of the distracter pseudowords. There was no significant overall effect of priming stimulus, F(4,172) = 0.3, p = .85. None of the experimental conditions was significantly different from the neutral condition (for all comparisons: $|t|$ (43) < 1.3, p > .11). These additional results support the conclusion that the systematic differences found for the learned object names are indeed based on associations of the newly learned words with referent objects.

General Discussion

Our goal was to investigate the type of modal representations that become associated with words that refer to concrete objects when these words are learned. In two experiments, recognition or naming of newly learned (pseudo)words was facilitated only when these tasks were primed with pictures of three-dimensional objects that participants had encountered as referent objects of the newly learned words. New stimuli did not have any facilitation effects even if they fully matched the extensional definition of the object names. Thus, both experiments corroborated the assumption that experiential traces are associated with category names. In addition, no support was found for the assumption that abstract summary representations such as multimodal schemata are associated with category names. Along the same lines, no support was found for the prediction of the multimodal schemata view that objects with more frequent and, hence, more prototypical perceptual features (ordinary referent objects) exert greater facilitation effects than referent objects with infrequent, unique perceptual features (outstanding referent objects).

These findings are reminiscent of work by Allen and Brooks (1991) on the role of non-analytic cognition in rule-based classification learning. Allen and Brooks demonstrated that the speed and accuracy of classifying new objects depended on their similarity to previously encountered objects, despite the fact that participants had learned a perfectly predictive classification rule that made reliance on specific instances unnecessary. The present experiments differed from typical category learning experiments in that the test phase did not involve a classification task but a task that resembled lexical decision and word naming tasks. For this reason, the results might be informative with regard to the kind of perceptual representations involved in early stages of language comprehension (Zwaan, 2004). Although we did not study natural language concepts directly, the results reported here bear some relevance on the question how words from natural languages are comprehended. The results of both experiments consistently suggest that memory traces of experiences and perceptions of particular referent objects that a comprehender has encountered in the past are associated with words referring to these objects, even if these words have clear extensional definitions that can be described by simple rules. Given the fast-and-frugal character of ordinary comprehension processes, it is conceivable that comprehension relies to a substantial extent on specific experiential traces rather than abstract summary representations. In understanding generic assertions such as *Beer is tasty*, comprehenders may activate the memory traces associated with the most recent beer drinking experience they had rather than a schematic or prototypical representation that represents the average of all their past beer drinking experiences. Despite the fact that comprehension of generic concepts by activating experiential traces necessarily remains incomplete to some extent, such a non-analytic way of understanding the extensions of words may often yield a representation that is sufficiently accurate given the comprehenders' goals (just as the instantiation principle often yields appropriate generalizations of typicality relations, Heit & Barsalou, 1996).

Of course, this is not to say that more analytic ways of language processing are irrelevant for comprehension. For example, the comprehension of compound words and other types of comprehension processes that rely on conceptual combination are perhaps more naturally explained by the multimodal schemata view. Whenever comprehenders encounter descriptions of novel objects or events for which they cannot retrieve experiential traces, they might use modal schemata that are productively combined with each other into an integrated perceptual simulation (e.g., Barsalou, 1999). Thus, although the results reported here provide support for the experiential view but not the multimodal schema view, they do not rule out the possibility that both types of perceptual representations are acquired and stored during word learning. Whittlesea et al. (1994) have shown that people use schematic and instance-based knowledge in a flexible manner, depending on the task they are tested on. In a similar way, the nature of perceptual representations used during language processing might depend on the type of comprehension task.

Our experiments simulated the learning of extensions of words by way of examples of referent objects, which is one major way of how children and adults acquire word meanings (either in just one trial as in fast mapping, Carey & Bartlett, 1978, or by exploiting cross-situational co-occurrences, Smith & Yu, 2007; Yu & Smith, 2007). Nevertheless, the experiments differed from real-world language learning in a multitude of ways. For example, participants acquired only a relatively small number of well-defined word-referent relations by assigning visual stimuli to pseudowords and receiving feedback on their decisions. In real-world language learning, word learning is often embedded in a more complex lexical domain and takes place within a richer perceptual, behavioral, and linguistic context (e.g., Carey, 1978). In the light of these differences, it seems appropriate to say that the research reported in this article is not more than a first step in clarifying the role that experiential traces might play in language comprehension. More experiments are needed to establish a firmer connection between category learning experiments of the kind reported in this article and real-world language comprehension.

Two aspects deserving particular attention in such experiments are the conceptual structures of the categories used and the amount of practice that participants receive with a word's referent. Despite the fact that the words used in our experiments corresponded to linearly separable categories and had a clear, schematic conceptual structure, they consisted of relatively few referent objects that were repeated quite often in the training phase. Among others, Minda and Smith (1998; Smith & Minda, 2001) have argued that using small categories together with a repetitive training setting might create particularly strong experiential traces, with the result that summary representations such as prototypes are put at a disadvantage. Accordingly, it would be worthwhile to try out categories that consist of larger and more diverse sets of instances in future research. The length of the training session is a related problem. In our experiments, participants were given relatively little time to make experiences with the referent objects of the newly learned words. In Experiment 2, the classification accuracy at the end of the training phase was only modest, indicating that participants might have needed more time to learn the underlying rule. It is possible that a modal schema needs more time to develop and the sole reliance on experiential traces reflects a transitional stage of learning (for the role of practice in schema abstraction, see Homa, 1978). For example, the concept of *beer* that is evoked by a sentence such as *Beer is tasty* is in many cases the result of beer-drinking experiences accumulated over several years. Our results do not rule out the possibility that the rather long learning history that is characteristic of many natural language categories leads to the formation of a modal schema. For this reason, future experiments should also test predictions of the multimodal schemata view and the experiential traces view with actual words referring to real-world objects. In these experiments, one could test the predictions of the experiential traces view by manipulating the salience of specific instances and testing the effects of this manipulation on the activation of perceptual representations during language processing. However, their limitations notwithstanding, the results of the present experiments provide indirect but clear evidence that experiential traces of a word's referents are associated with the word form when new words are learned by way of positive examples.

References

Allen, S.W., & Brooks, L.R. (1991). Specializing in the operation of an explicit rule. *Journal of Experimental Psychology: General, 120*, 3-19.

Anderson, J.R., & Betz, J. (2001). A hybrid model of categorization. *Psychonomic Bulletin & Review, 8*, 629-647.

Ashby, F.G. & Waldron, E.M. (1999). The nature of implicit categorization. *Psychonomic Bulletin & Review, 6*, 363-378.

Ashby, F.G., Alfonso-Reese, L.A., Turken, A.U., & Waldron, E.M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychological Review, 105*, 442-481.

Balota, D.A., Cortese, M.J., Sergent-Marshall, S.D., Spieler, D.H., & Yap, M.J. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General, 133*, 283-316.

Barsalou, L.W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*, 577-660.

Brooks, L.R. (1978). Nonanalytic concept formation and memory for instances. In E. Rosch & B. Lloyd (Eds.), *Cognition and categorization* (pp. 169-211). Hillsdale, NJ: Erlbaum.

Carey, S. (1978). The child as word learner. In M. Halle, J. Bresnan, & G.A. Miller (Eds.), *Linguistic theory and psychological reality* (pp. 264-293). Cambridge, MA: MIT Press.

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Papers and Reports on Child Language Development, 15,* 17–29.

Chumbley, J.I., & Balota, D.A. (1984). A word's meaning affects the decision in lexical decision. *Memory and Cognition, 12*, 590-606.

Collins, A.M., & Quillian, M.R. (1969). Retrieval time from semantic memory. *Journal of Verbal Learning and Verbal Behavior, 8*, 240-247.

Erickson, M.A., & Kruschke, J.K. (1998). Rules and exemplars in category learning. *Journal of Experimental Psychology: General, 127*, 107-140.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Glaser, W.R. (1992). Picture naming. *Cognition, 42*, 61-105.

Glenberg, A.M., & Kaschak, M.P. (2002). Grounding language in action. *Journal of Memory & Language, 43*, 379-401.

Heit, E., & Barsalou, L.W. (1996). The instantiation principle in natural categories. *Memory, 4*, 413-451.

Holm, S (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*, 65–70.

Homa, D. (1978). Abstraction of ill-defined form. *Journal of Experimental Psychology: Human Learning and Memory, 4*, 407-416.

Jolicoeur, P. (1985). The time to name disoriented natural objects. *Memory & Cognition, 13*, 289-303.

MacWhinney, B. (1999). The emergence of language from embodiment. In B. MacWhinney (Ed.), *Emergence of language* (pp. 231-256). Hillsdale, NJ: Erlbaum.

Medin, D.L., & Schaffer, M.M. (1978). Context theory of classification learning. *Psychological Review, 85*, 207-238.

Minda, J.P., & Smith, J.D. (2001). Prototypes in category learning: The effects of category size, category structure, and stimulus complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 775-799.

Nosofsky, R.M. (1986). Attention, similarity, and the identification-categorization relationship. *Journal of Experimental Psychology: General, 115*, 39-57.

Plaut, D.C., McClelland, J.L., Seidenberg, M.S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*, 56-115.

Pulvermüller, F. (1999). Words in the brain's language. *Behavioral and Brain Sciences, 22*, 253-279.

Rahman, R.A., & Mehlinger, A. (2007). When bees hamper the production of honey: Lexical interference from associates in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 604-614.

Rastle, K., Harrington, J., & Coltheart, M. (2002). 358,534 nonwords: The ARC Nonword Database. *Quarterly Journal of Experimental Psychology, 55A*, 1339-1362.

Reed, S.K. (1972). Pattern recognition and categorization. *Cognitive Psychology, 3*, 382-407.

Richter, T., & Zwaan, R.A. (in press). Integration of perceptual information in word access. *Quarterly Journal of Experimental Psychology*. [DOI: 10.1080/17470210902829563]

Rosch, E, & Mervis, C.B. (1975). Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology, 7*, 573-605.

Rumelhart, D.E. (1980). Schemata: The building blocks of cognition. In R.J. Spiro, B.C. Bruce, & W.F. Brewer (Eds.), *Theoretical issues in reading comprehension* (pp. 33-58). Hillsdale, NJ: Erlbaum.

Smith, J.D., & Minda, J.P. (1998). Prototypes in the mist: The early epochs of category learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 1411-1430.

Smith, L., & Yu, C. (2008). Infants rapidly learn word-referent mappings via cross-situational statistics. *Cognition, 106*, 1558-1568.

Sperber, R.D., McCauley, C., Ragain, R.D., & Weil, C.M. (1979). Semantic priming effects on picture and word processing. *Memory & Cognition, 7*, 339-345.

Storms, G. (2004). Exemplar models in the study of natural language concepts. In B.H. Ross (Ed.), *The psychology of learning and motivation, Vol. 44* (pp. 1-39). Academic Press, New York.

Strain, E., Patterson, K., & Seidenberg, M.S. (1995). Semantic effects of single-word naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 1140-1154.

Tanaka, J., Weiskopf, D., & Williams, P. (2001). The role of color in high-level vision. *Trends in Cognitive Science, 5*, 211-215.

Tarr, M.J., & Bülthoff, H.H. (1998). Image-based object recognition in man, monkey, and machine. In M.J. Tarr & H.H. Bülthoff (Eds.), *Object recognition in man, monkey, and machine* (pp. 1-20). Cambridge, MA: MIT Press.

Yu, C., & Smith, L.B. (2007). Rapid word learning under uncertainty via cross-situational statistics. *Psychological Science, 18*, 414-420.

van Orden, G.C., Pennington, B.F., & Stone, G.O. (1990). Word identification in reading and the promise of subsymbolical psycholinguistics. *Psychological Review, 97*, 488-522.

Zwaan, R.A. (2004). The immersed experiencer: Toward an embodied theory of language comprehension. In B.H. Ross (Ed.), *The Psychology of Learning and Motivation, Vol. 44* (pp. 35-62). New York: Academic Press.

Appendix: Sample Stimulus List (Extensional Definitions of Referent Objects Presented during Training and New Objects)

		Perceptual dimension		
	Stimulus Type	Color	Shape	Orientation
Category 1	old ordinary	blue	cuboid	upright
	old ordinary	red	cuboid	upright
	old outstanding	orange	cuboid	upright
	new irrelevant change	purple	cuboid	upright
	new relevant change	blue	cuboid	right
Category 2	old ordinary	green	cuboid	right
	old ordinary	green	cuboid	left
	old outstanding	green	cuboid	diagonal-left
	new irrelevant change	green	cuboid	diagonal-right
	new relevant change	green	pyramid	left
Category 3	old ordinary	green	sphere	upright
	old ordinary	green	pyramid	upright
	old outstanding	green	polyedric 1	upright
	new irrelevant change	green	polyedric 2	upright
	new relevant change	green	pyramid	right
Category 4	old ordinary	blue	sphere	right
	old ordinary	green	sphere	right
	old outstanding	purple	sphere	right
	new irrelevant change	orange	sphere	right
	new relevant change	blue	sphere	left

Category 5	old ordinary	red	sphere	left
	old ordinary	red	sphere	upright
	old outstanding	red	sphere	diagonal-right
	new irrelevant change	red	sphere	diagonal-left
	new relevant change	red	pyramid	left
Category 6	old ordinary	red	cuboid	right
	old ordinary	red	pyramid	right
	old outstanding	red	polyedric 2	right
	new irrelevant change	red	polyedric 1	right
	new relevant change	red	cuboid	left

Note. Old ordinary: stimulus presented in the training phase with frequent value on the non-defining dimension; old outstanding: stimulus presented in the training phase with unique value on the non-defining dimension; new irrelevant change: stimulus presented only in the test phase with a change on a non-defining dimension; new relevant change: stimulus presented only in the test phase with a change on a defining dimension; sphere: conical shape with sphere attached; cuboid: conical shape with cuboid attached; pyramid: conical shape with pyramid attached; polyedric 1: complex polyeder 1; polyedric 2: complex polyeder 2. The examples given in the table correspond to one stimulus list. Three different stimulus lists were created by permutations of ordinary values for color (blue, green, red), shape (cuboid, pyramid, sphere), and orientation (left, right, upright).

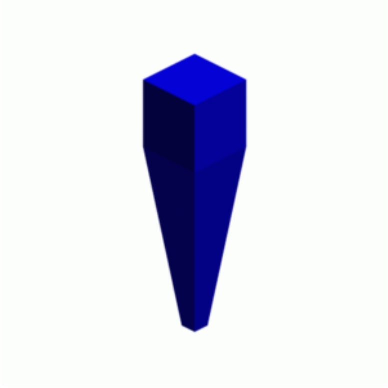
Figure Captions

Figure 1. Examples for ordinary referent objects (a and b) and outstanding referent objects (c) presented in the training phase of Experiments 1 and 2 (categories 1, 3, and 5 from stimulus list 1 in the Appendix).

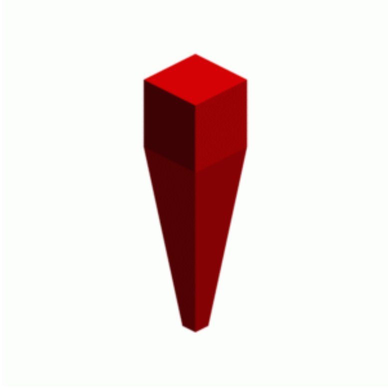
Figure 2. Response latencies (differences to neutral condition) in (a) Experiment 1 (pseudoword recognition task) and (b) Experiment 2 (pseudoword naming task) after priming with old ordinary referent objects, old outstanding referent objects, new objects with a change on a non-defining dimension (irrelevant change), and new objects with a change on a defining dimension (relevant change). Error bars represent the standard error of the mean.

Category 1

a)



b)



c)

Category 3

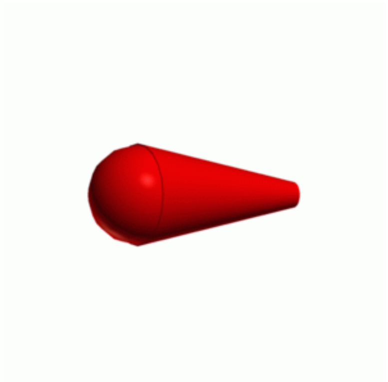
a)

b)

c)

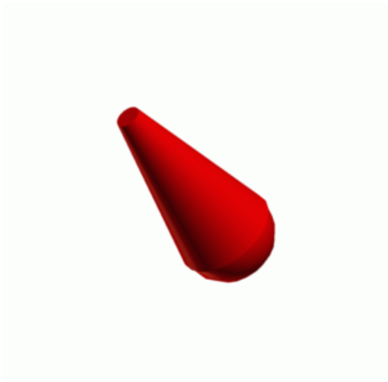
Category 5

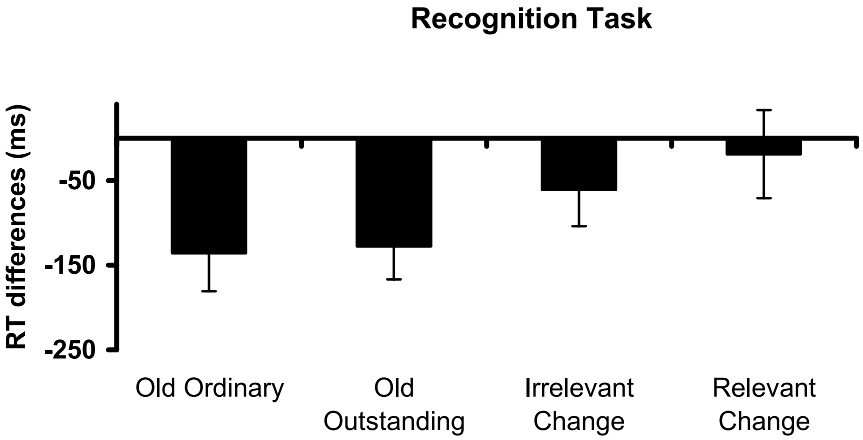
a)



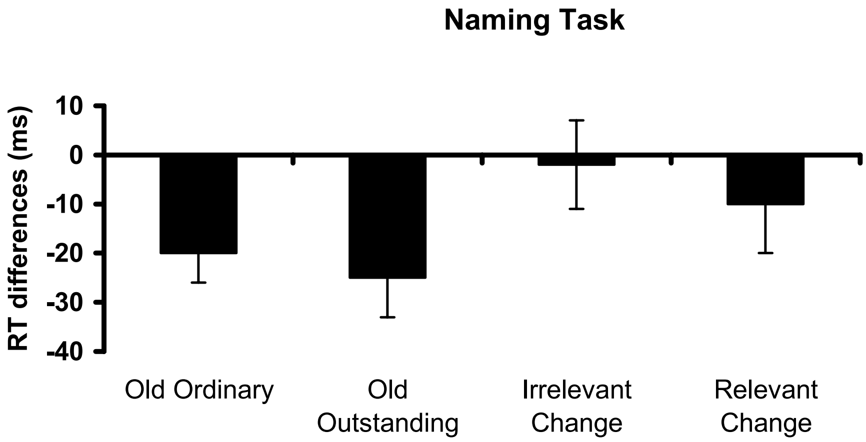
b)

c)




Recognition Task
RT differences (ms)
-50
-150
-250
Old Ordinary
Old Outstanding
Irrelevant Change
Relevant Change

a)


Naming Task
RT differences (ms)
10
0
-10
-20
-30
-40
Old Ordinary
Old Outstanding
Irrelevant Change
Relevant Change

b)