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Playing on the typewriter, typing on the piano: manipulation knowledge of objects

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Abstract

Two experiments investigated sensory/motor-based functional knowledge of man-made objects: manipulation features associated with the actual usage of objects. In Experiment 1, a series of prime-target pairs was presented auditorily, and participants were asked to make a lexical decision on the target word. Participants made a significantly faster decision about the target word (e.g. 'typewriter') following a related prime that shared manipulation features with the target (e.g. 'piano') than an unrelated prime (e.g. 'blanket'). In Experiment 2, participants' eye movements were monitored when they viewed a visual display on a computer screen while listening to a concurrent auditory input. Participants were instructed to simply identify the auditory input and touch the corresponding object on the computer display. Participants fixated an object picture (e.g. "typewriter") related to a target word (e.g. 'piano') significantly more often than an unrelated object picture (e.g. "bucket") as well as a visually matched control (e.g. "couch"). Results of the two experiments suggest that manipulation knowledge of words is retrieved without conscious effort and that manipulation knowledge constitutes a part of the lexical-semantic representation of objects.

Keywords: Manipulation knowledge; Perceptual vs. functional knowledge; Sensory/motor experiences; Lexical-semantic representation

1. Introduction

A key is a small implement that is made of metal and cut into a special shape. A key is also associated with a lock or door. The function of a key is to fasten or unfasten a lock by turning

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its bolt. To this end, certain actions by hand and wrist movements are used. Even for such a simple object as a key we represent various kinds of knowledge: we not only know how the object looks or feels, but also what it is used for and how we use it. A critical question concerns what the underlying representation and structure of such knowledge is like.

Since the groundbreaking studies by Warrington (1975), many researchers have reported case studies of category-specific impairments as a source of insight into such knowledge representations. On tasks such as picture naming and word definition, patients show a disproportionate impairment with stimuli denoting living things (e.g. animals and fruits/vegetables) relative to non-living things (e.g. tools and utensils) or vice versa. The patterns of category-specific impairments seemed to indicate that lexical-semantic representations are not randomly organized, but have a certain underlying structure. Category-specific impairments have, hence, been considered a window into the structure of lexical-semantic representation.

A dominant view on category-specific impairments in the literature is the sensory-functional hypothesis, initiated by Warrington and Shallice (Shallice, 1988; Warrington & McCarthy, 1983; Warrington & Shallice, 1984) and further developed by other researchers (Farah & McClelland, 1991; Saffran & Sholl, 1999; see Forde & Humphreys, 1999, for review). The sensory-functional hypothesis claims that category-specific impairments arise because of a differential weighting of sensory and functional information in categories. In this view, sensory information, visual in particular, is important in differentiating between living things, while functional information is crucial in differentiating between non-living things. Thus, the distinction between knowledge of an object's perceptual characteristics and its function has played an important role in research on object representation in general.[1]

Although functional information is a crucial concept in explaining category-specific impairments, there is surprisingly little consensus about its definition. The operational definition of functional information has varied across studies, ranging from information about an object's usage to non-sensory information including encyclopedic information (e.g. Cree & McRae, 2003, p. 181).[2]

Postulating that the function of objects is a primary basis for categorization, Nelson (1973) noted, "Functional definitions will be found to vary in their complexity and abstraction from the earliest simple definitions in terms of action to definitions in terms of higher order properties of the most abstract type such as hormones or S–R connections" (p. 37). On this view, the "earliest simple" functional concept is derived from our intuitive interaction with an object. For instance, when we see a water gun, we think of pushing its

[1] Throughout this paper, the concept *perceptual* will be used in a broad sense, including sensory/motor states. Due to a common usage of the 'sensory-functional' dichotomy in the domain of category-specific impairments, *sensory* will be used interchangeably with *perceptual*.

[2] For instance, Garrard, Ralph, Hodges, and Patterson (2001) used the following criteria: "attributes classified as sensory were those which could be appreciated in some sensory modality […]; attributes categorized as functional were those which described an action, activity, or use of an item […]; encyclopedic attributes were considered to be those describing some other type of associative relationship (p. 131)." Although Garrard et al.'s definition of *functional* seems pretty clear, there are still disputable cases. *Powerful* is considered as functional information for an aeroplane, but not *strong* for an alligator. While 'aeroplane has engine' or 'bicycle has gears' is classified as encyclopedic knowledge, 'bicycle has brakes' is functional knowledge.

trigger to squirt a stream of water. The action of pushing the trigger of a water gun is the "earliest simple" functional concept about a water gun. Yet, the physical relations implicated in the process of how the increase of the pressure in the water gun produces a curvilinear squirt of water or its chemical impact on a person's skin and his/her response to it would belong to higher abstract functional knowledge. Thus, functional knowledge comprises multiple characteristics, ranging from heavily perceptually based to highly abstract. Functional information has been generally considered as knowledge about the intended usage or purpose of an object, namely what an object is used for ("what for" knowledge). As such, functional knowledge has been regarded as conceptual in nature. However, we also have knowledge about *how* to use an object, or more exactly, how to manipulate an object to successfully carry out its intended usage ("how" knowledge). This type of functional knowledge is presumably grounded in sensory/motor experiences.

Supporting Nelson's view that even functional knowledge has a perceptual basis, Martin, Ungerleider, and Haxby (2000) define functional knowledge as the "information about patterns of visual motion and patterns of motor movements associated with the actual use of the object. As such, this information is as dependent on sensory experience as is information about the visual form. The difference is that functional information is derived from motor movements, and visual processing of motion, rather than visual processing of form" (p. 1028). In this sense, functional information is not necessarily characterized as more abstract, conceptual or verbal than perceptual information.

As evidence for this view of functional information, Martin and colleagues showed in a series of neuroimaging studies that there is category-specific activation in the ventral premotor cortex (VPMCx) and the posterior middle temporal gyrus (PMTG) for the retrieval or recognition of manipulable artifacts such as tools and utensils (e.g. Chao & Martin, 2001; Martin, Wiggs, Ungerleider, & Haxby, 1996; see Martin & Chao, 2001, for review; also see Grabowski, Damasio, & Damasio, 1998). The middle temporal gyrus is well known to be sensitive to visual motion information and the premotor area is involved in processing motor movements. Thus, although not conclusive, the activation pattern in these areas is consistent with the hypothesis that information about patterns of visual motion and motor movements may be relevant for the retrieval or recognition of man-made objects. Patterns of visual motion and motor movements reflect the manner of interaction with objects, namely how we use an object for its intended usage. Hence, in addition to "classically functional" information ("what for"), manipulation information ("how") appears to be an important part of the lexical-semantic representation of man-made objects, and this sensory/motor-based functional knowledge seems to be represented in the VPMCx and the PMTG.

More directly addressing the multi-dimensionality of functional knowledge, some neuropsychological case studies using picture identification, definition or semantic judgment tasks have shown dissociations in which functional knowledge could be differentiated into usage-based "what for" and manipulation-based "how" (e.g. Buxbaum, Veramonti, & Schwartz, 2000; Sirigu, Duhamel, & Poncet, 1991). Reporting on two apraxic patients, JD and WC, Buxbaum et al. (2000) investigated their patients' knowledge about the function and manipulation of manipulable objects. Apraxia has been regarded as a window into manipulation-based "how" knowledge since apraxic patients are impaired at performing and comprehending hand/body movements in spite of lack of any muscular problems–sometimes even in the presence of intact "what for" knowledge about an object (Buxbaum, Schwartz, & Carew, 1997). JD and WC performed the picture version of the Function and Manipulation Triplets Test (Buxbaum & Saffran, 1998), in which they were asked to view three pictured objects and select the two that were most similar to one another with respect to three conditions: function (e.g. "record player", "radio", "telephone"), manipulation (e.g. "typewriter", "piano", "stove") and function and manipulation together (e.g. "roller", "paintbrush", "screwdriver").[3] Both patients' performance was significantly worse in the manipulation condition (JD: 3/14, 21% correct; WC; 7/14, 50%) compared to the function condition (JD: 16/20, 80%; WC 20/20, 100%). Their performance on the function and manipulation condition was intermediate (JD: 14/20, 70%, WC: 12/20, 60%). This strong relationship between apraxia and manipulation knowledge deficits suggests that sensory/motor representations are involved not only in comprehending and producing voluntary movements, but also in thinking about them.

Nevertheless, it is worth noting that Buxbaum and colleagues used an *explicit* task. In other words, participants were explicitly asked to retrieve appropriate types of knowledge. It is possible that the dissociations they noted in their patients reflected a failure to appropriately use heuristic information or strategies to group the words appropriately. Thus, their study does not address whether manipulation knowledge would be accessed in an implicit task, and additionally, whether this knowledge is *automatically* accessed without conscious effort, reflecting its status as an intrinsic part of the lexical-semantic representation of objects.

In their neuroimaging studies, Martin and colleagues used various types of tasks including passively viewing pictures, silently naming pictures and reading written names, and found a consistent activation pattern. These results show a stable involvement of certain neural areas in manipulation knowledge and are suggestive of *automatic* access to manipulation knowledge at the neural level. Although very suggestive, neural activations in the sensory/motor areas during object identification are not direct evidence that manipulation knowledge is activated during object identification. Therefore, it is necessary to examine activation of manipulation information in a more direct manner: If clear effects of manipulation knowledge on cognitive processing can be shown in an *implicit* behavioral task in which manipulation knowledge is not explicitly called for, then it will not only provide evidence for manipulation knowledge as an intrinsic part of object representation, but will also buttress the neuroimaging results by Martin and colleagues. Yet, to date there is little behavioral evidence for the *automatic* activation of manipulation information in an *implicit* task.

Thus, the present study aimed to investigate the retrieval of manipulation knowledge in implicit behavioral tasks in normal subjects, using two different experimental methods in different modalities. The first experiment used a lexical decision task in the auditory modality and the second experiment tracked participants' eye movements to a picture display while they mapped speech input to a picture in the display.

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[3] Throughout this paper, single quotes signify a stimulus word, double quotes signify a stimulus picture, and italics signify a conceptual representation. Thus, 'typewriter' signifies the word typewriter, "typewriter" signifies a picture of a typewriter, and *typewriter* signifies the corresponding concept.

A lexical decision task has been commonly used in studies on lexical-semantic processing (e.g. Meyer & Schvaneveldt, 1971; Milberg & Blumstein, 1981; Swinney, Onifer, Prather, & Hirshkowitz, 1979) and provides a measure of priming, namely an effect of processing facilitation based on a relationship between the prime and target words (e.g. a faster reaction time latency to the target 'dog' following a semantically related prime such as 'cat' compared to a semantically unrelated prime such as 'cup'). Priming is a robust finding demonstrated for words and pictures (e.g. Carr, McCauley, Sperber, & Parmelee, 1982; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Vanderwart, 1984) and has been interpreted as reflecting the organization or operation of processes within the lexical-semantic network. Therefore, the priming paradigm has been a useful tool for research on the lexical-semantic interconnections among the units of the network.

A priming paradigm was used in Experiment 1 to determine whether significant priming would obtain in an implicit task where the relationship between the prime-target pairs was based on shared manipulation features between objects that are otherwise semantically dissimilar (e.g. 'piano'–'typewriter,' 'key'–'screwdriver'). Usually, prime and target words used in a priming experiment are semantically related or semantically associated with each other. Thus, it is useful to determine whether common manipulation features would lead to a priming effect when the prime-target pairs are not otherwise semantically or associatively related.

Experiment 2 used an eye tracking paradigm. Eye movement techniques have been increasingly used to study lexical processing due to several advantages (e.g. Allopenna, Magnuson, & Tanenhaus, 1998; Dahan, Magnuson, & Tanenhaus, 2001; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Yee & Sedivy, 2005). First, eye movements can be measured without disrupting speech or requiring participants to make a metalinguistic judgment. Second, the typical task requirements for the participant are to either look at or point to an object in the display. Thus, participants can engage in a naturalistic task. Third, eye movement techniques provide fine-grained and continuous temporal information, allowing for monitoring the temporal course of lexical-semantic processing.

For the present study, we hypothesize that participants will show an effect of processing facilitation even in implicit tasks based on the common manipulation features between objects. Both Experiments 1 and 2 investigate manipulation knowledge indirectly without explicitly asking participants to access this manipulation knowledge. In other words, manipulation knowledge about objects is not task-relevant. Furthermore, the tasks are directed at the lexical level (lexical decision and speech-to-picture-mapping) that functions as a "mediator" to the semantic representation of objects. Thus, a consistent pattern of results across these two different implicit tasks will provide strong behavioral evidence for the importance of manipulation knowledge in the lexical-semantic representation of objects.

2. Experiment 1

Experiment 1 investigated whether response time (RT) latency in an auditory lexical decision task reflects the activation of common manipulation features. If manipulation features are shared by object concepts due to their similar manner of manipulation (e.g. *piano* and *typewriter*), a priming effect would be expected for word pairs that denote those objects. Thus, the relatedness between a prime and a target in Experiment 1 is based on the common manipulation features among objects that are otherwise semantically dissimilar. In a lexical decision task, a priming effect occurs if participants make a faster lexical decision to a target word (e.g. 'typewriter') following a related prime (e.g. 'piano') than an unrelated prime (e.g. 'blanket').

2.1. Methods

2.1.1. Participants

Thirty-four male and female participants from the Brown University community took part in the experiment. All participants were native speakers of American English and had no reported hearing deficits. They were paid $5 for their participation.

2.1.2. Stimuli

Manipulation was defined operationally as general actions on an object that involve body movements and typically are associated with its intended usage. For instance, a typewriter and a piano require similar hand positions and movements despite the difference of their intended usages. A key and a screwdriver require a similar manipulation, namely similar wrist movements although their precise hand configurations and finger positions may be different. A key needs a precision grip while a screwdriver requires a power grip. Thus, it was the similarity of the general action patterns among objects rather than that of detailed finger positions that defined common manipulation movements.

A total of 53 stimulus pairs of objects were initially identified according to the criterion that they share manner of manipulation, but no other characteristics. Nonetheless, objects with similar means of manipulation tend to be also similar in visual shape (e.g. gun and drill, gavel and hammer). To control for this visual similarity, 88 participants who did not participate in the priming study were asked to rate 75 pairs of items (the initially identified 53 pairs and 22 fillers) in terms of their similarity of manipulation and their similarity of visual shape on a one to five point scale (from "not similar at all" to "very similar"). Stimuli that were rated as low in shape similarity (<3) and high in manipulation similarity (>3) were selected as the experimental stimuli. According to this criterion 28 word pairs were finally selected. The mean ratings were 3.9 for manipulation similarity and 2.2 for visual shape similarity. An equal number of prime words that were neither semantically, phonologically, nor visually similar to the targets were also selected (For the complete list of stimuli, see Appendix). The control primes were matched to the experimental primes in terms of word frequency. For lexical frequency, the database of Kucera and Francis' (1967) written frequency was used. However, many man-made objects have long compound names such as 'pencil sharpener' or 'turkey baster,' and the percentage of these words in the stimulus list was high (50/84: 60%). Since Kucera and Francis' database does not contain most of the compound words used in the experiment, Graff's (1995) North American News Text Corpus was also used to determine the frequency of all the compound words. Because two different databases were used for the lexical frequency of simple and compound words, their frequency was counterbalanced separately. In addition, the duration (ms) of the prime stimuli was also controlled.

An equal number of non-word targets was created and preceded by real word primes. The non-words were similar in phonological structure to the real word targets. However, to parallel the structure of the compound words, 12 non-word targets (12/28, 43%) were composed of a word part and a non-word part, such as *flag*vanter, *rope* flew or *comb* chella. In this way, participants could not make a lexical decision based on only the first half of the target words.

Two stimulus lists were prepared and counterbalanced in terms of frequency, stimulus duration and similarity ratings. Each participant was shown only one list so that no item was heard more than once. Trial order was randomized for each participant.

2.1.3. Procedure

Stimuli were recorded by a female native speaker of American English in a sound-attenuated booth. They were recorded onto magnetic tape using a Sony Walkman Professional tape recorder and a Sony stereo microphone and then digitized onto a VAX Station II at a sampling rate of 20 kHz with a 9.0-kHz lowpass filter and a 14 bit quantization. The experiment was controlled by a Dell computer that played out the auditory stimuli and recorded the participants' responses. Stimuli were presented over headphones. Each trial consisted of a word–word or word–non-word pair with a 50 ms interstimulus interval (ISI) and a 2000 ms intertrial interval (ITI).

Participants were instructed to make a lexical decision as quickly as possible without sacrificing accuracy. However, they were also instructed to listen carefully to the entire target stimulus before making a lexical decision. These instructions were crucial because of the high percentage of long compound words in the stimulus list. For instance, we did not want subjects to make a lexical decision based on only the first half of the compound target (e.g. 'lawn' in 'lawn mower'). Lexical decision responses were made by pressing a button marked *yes* or *no* on a box placed in front of the participant. All participants were right-handed and the dominant hand was always used for a response. RTs were measured from the onset of the target stimulus.

2.2. Results

Lexical decision responses were analyzed for both mean RT and percentage error rate. The data were compared for targets preceded by a word that shared manipulation features (Related condition) and targets preceded by an unrelated word (Unrelated condition). Outliers that were two standard deviations (SD) from the mean were excluded from the analysis. Two one-way analyses of variance (ANOVA) were conducted, one for RT latencies and one for percentage errors with participants (F_1) as a random variable. The RT results are shown in Fig. 1. The results of the ANOVA showed a significant priming effect for the Related condition (1191 ms) as compared with the Unrelated condition (1221 ms) in the latency data ($F_1(1, 33)=4.897$, $P=.034$).

In addition to the analysis by participants, an item analysis was also conducted. Because the outliers that were removed were not distributed evenly across the items, median RTs were used for this analysis. In particular, long items, which have a high

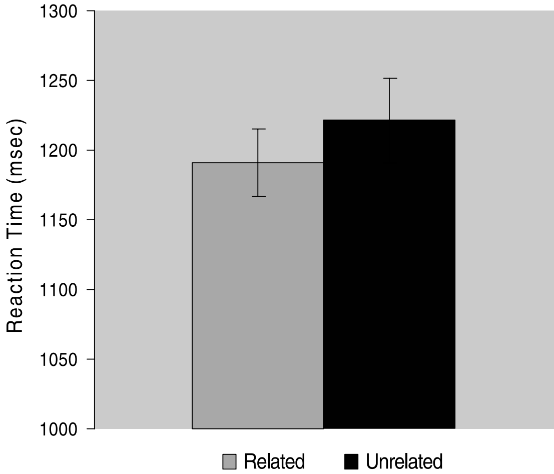

Fig. 1. Mean lexical decision latencies as a function of priming condition in Experiment 1 (by participant): bars indicate standard errors.

susceptibility to variability in RTs, had more outliers and fewer data points than short items. Thus, the median RTs were entered into the ANOVA with items (F_2) as a random variable. The analysis showed a marginally significant priming effect for the Related condition (1175 ms) as compared with the Unrelated condition (1201 ms) ($F_2(1, 27)=3.305$, $P=.080$).

When looking at the data by item, item (target) duration appeared to be an important factor since there was variability in RT latencies caused in part by the differences in target durations. Target durations varied considerably, ranging from 450 to 1200 ms. Indeed, there was a linear relationship between target durations and RT latencies ($r=.699$ for the related condition, $r=0.543$ for the unrelated condition). This linearity is not surprising given that the participants were instructed to listen carefully to the whole word so that they did not miss any part of the compound words.

In order to take into account the effects of target duration on RTs in the item analysis, an ANCOVA was conducted using the median RT latencies with target duration as a covariate in the analysis. After eliminating the variability caused by target durations, the ANCOVA was significant ($F_2(1, 26)=4.196$, $P=.052$). Fig. 2 shows the results graphically:

2.3. Discussion

The results of Experiment 1 indicate that there is a reliable priming effect for manipulation features. Participants were faster to make a lexical decision to a target word following a prime word that was related to the target in terms of the manner of manipulation. This finding supports the notion that sensory-based functional knowledge is an intrinsic part of the lexical-semantic representation of objects and that this manipulation knowledge is activated in an implicit task. This is a significant addition to previous

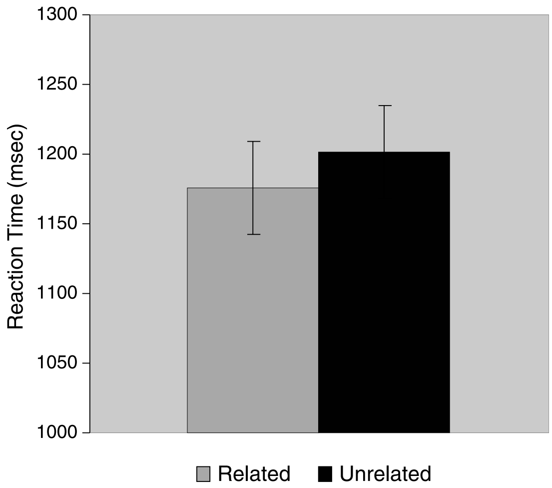

Fig. 2. Median lexical decision latencies as a function of priming condition in Experiment 1 (by item): bars indicate standard errors.

findings from explicit tasks such as semantic judgment (e.g. Buxbaum et al., 2000), picture description and gestural response (e.g. Sirigu et al., 1991) that used explicit tasks. Explicit tasks require participants to *consciously* access their knowledge. The current results suggest that participants access manipulation knowledge even without being overtly required to do so.

The main goal of Experiment 1 was to determine whether manipulation features shared by object concepts would produce a priming effect. Nonetheless, it is controversial whether priming reflects purely automatic processing or whether it is influenced by postlexical processing involving the participants' strategies such as relatedness checking or participants' expectations (e.g. Shelton & Martin, 1992). In fact, it is generally assumed that semantic priming in a lexical decision task reflects both automatic and controlled processing routines (Neely, 1976, 1977, 1991). Thus, in Experiment 2 an eye tracking methodology was used, which not only may be less susceptible to strategic processing routines but which also gives an on-line measure, providing continuous fine-grained temporal information.

3. Experiment 2

Experiment 2 aimed to replicate the findings of Experiment 1 using a different experimental method (eye tracking) and a different paradigm (speech-to-picture mapping). The goal of Experiment 2 was to determine whether eye movements would show sensitivity to an object related to a given spoken target in terms of manipulation features, and if so, when this happens.

Eye movement techniques have been increasingly used in research on lexical processing since they continuously monitor on-going processing on a millisecond scale and participants are engaged in a more naturalistic task without being required to make a metalinguistic judgment. Using pictorial stimuli with auditory word presentation, Yee and Sedivy (2005) showed that words semantically related to the uttered word become active as it is being pronounced. Participants followed recorded instructions to point to one of four pictures (the target picture) displayed on a computer screen. In the semantically related condition, not only the target (e.g. "hammer"), but also the related item (e.g. "nail") was shown on the screen. From about 200–900 ms after the onset of the target word, participants were more likely to fixate a picture semantically related to the target word than an unrelated picture (e.g. "monkey") ($t_1(29)=6.9$, $P<0.01$, and $t_2(23)=5.3$, $P<0.01$ for participants and items, respectively). It is important to note that even for a visual display paradigm in which the possible locations of the target are known in advance, a saccadic eye movement takes about 180 ms to initiate in response to linguistic input (Altmann & Kamide, 2004; Matin, Shao, & Boff, 1993). Thus, Yee and Sedivy's result suggests that semantically related items start to become active after minimal acoustic input. Given such an early time course, it is very unlikely that participants' fixations on semantically related pictures reflect their strategic or conscious processing of the semantic relationship between the target and the related picture. Therefore, an eye tracking method with several advantages, especially its fine-grained and continuous temporal information about the ongoing process, is ideal for our aim of the study.

3.1. Methods

3.1.1. Participants

Thirty male and female participants from the Brown University community took part in the experiment. All participants were native speakers of American English and had normal or corrected-to-normal vision and no reported hearing deficits. They were paid $5.00 for their participation.

3.1.2. Apparatus

EyeLink, a head-mounted eye tracking system by SR Research, was used to monitor participants' eye movements. It has a high resolution (noise-limited at $<0.01°$) and a fast data rate (250 samples per second). Stimuli were presented on a 15″ Elo Entuitive 1525C touch screen monitor with the PsyScript 5.1 (Bates & Oliveiro, 2003).

3.1.3. Stimuli

A total of 28 stimulus pairs used in Experiment 1 were initially selected for the manipulation-related stimuli, namely stimuli that have common manipulation features (e.g. "piano"–"typewriter", "key"–"screwdriver"). For the displays, color pictures were selected from a commercial clip art collection and from a picture library (Rossion & Pourtois, 2004). Since Experiment 2 used pictures instead of words, visual similarity or confusability was especially critical. To minimize the possibility that participants would mistake the picture of the manipulation-related item for the target, an identification task as well as a discrimination task was conducted in a pre-test.

The identification task sought to determine whether the pictures clearly represented what they were intended to represent. Thirty-seven participants, different from the experimental participants, were presented with each picture and a label (either the picture's intended name or a randomly selected name), and were asked to judge whether they matched. Two selection criteria were taken into consideration to ensure that pictures and their intended names corresponded to each other. First, the average RT latency for participants to decide that the picture and the intended name matched was analyzed. Then, the picture items that rendered RTs beyond two SDs of the mean RT (611 ms) were excluded. Second, for each item its average error rate, namely the percentage by which participants responded that the picture and the intended name did not match, was computed. The items beyond two SDs of the mean error rate (0.2%) were also rejected.

The goal of the discrimination task was to determine whether the target pictures and the manipulation-related pictures were visually similar or confusable. Participants saw each target picture with a different exemplar of the target, with a manipulation-related picture, or with an unrelated picture for a brief period (500 ms). They were then asked to decide whether or not the two pictures were different exemplars of the same object (for instance, two different exemplars of a "piano" or two different objects, such as a "piano" and a "typewriter"). The underlying logic was that unless the manipulation-related pictures (e.g. "typewriter") were either visually similar to or confusable with the target pictures (e.g. "piano"), the error rate and the RT latencies should be comparable between the target pictures with their related pictures (e.g. "piano"–"typewriter") and those with their unrelated pictures (e.g. "piano"–"couch"). Based on the results of this pre-test, 20 pairs of manipulation-related stimuli were selected. Also, the unrelated pictures used in the pre-test were selected as the visual control items in the experiment (e.g. "couch" as a visual control for the "piano"). Two stimulus lists were prepared and counterbalanced in terms of target frequency and duration. Each participant was presented with only one list so that no item was repeated.

Fig. 3 shows sample displays from each condition. In the manipulation-related condition (10 of 60 trials), there was one picture in the display that was related to the target in terms of manipulation features. In the control condition (10 of 60 trials) and in filler trials (40 of 60 trials) no pictures in the display were related. In each control trial, one of the non-target items was matched to the manipulation-related item of the target in terms of visual similarity (e.g. "couch" as a visual match for the "piano"–"typewriter" pair). The control trials were included to determine whether the manipulation-related pictures drew fixations merely due to their visual similarity to the targets. Eliminating the potential effect of visual similarity was crucial in that objects sharing manipulation features tend to be also visually similar. If fixations to the manipulation-related pictures are purely attributed to their visual similarity to the target pictures, a similar pattern of fixations to the visually matched control items will be expected in the control trials because these contain non-target items matched to the manipulation-related items in terms of visual similarity. Picture positions were balanced so that each item type was equally distributed in each corner of the display. Trial order was randomized for each participant.

3.1.4. Procedure

Stimuli were recorded in the same manner as for Experiment 1 except that they were recorded by a male native speaker of American English. For each trial in Experiment 2, participants were presented with four pictures on a 3×3 array, with one picture in each corner (see Fig. 3). Each cell in the array was approximately 2×2 in. Participants were seated

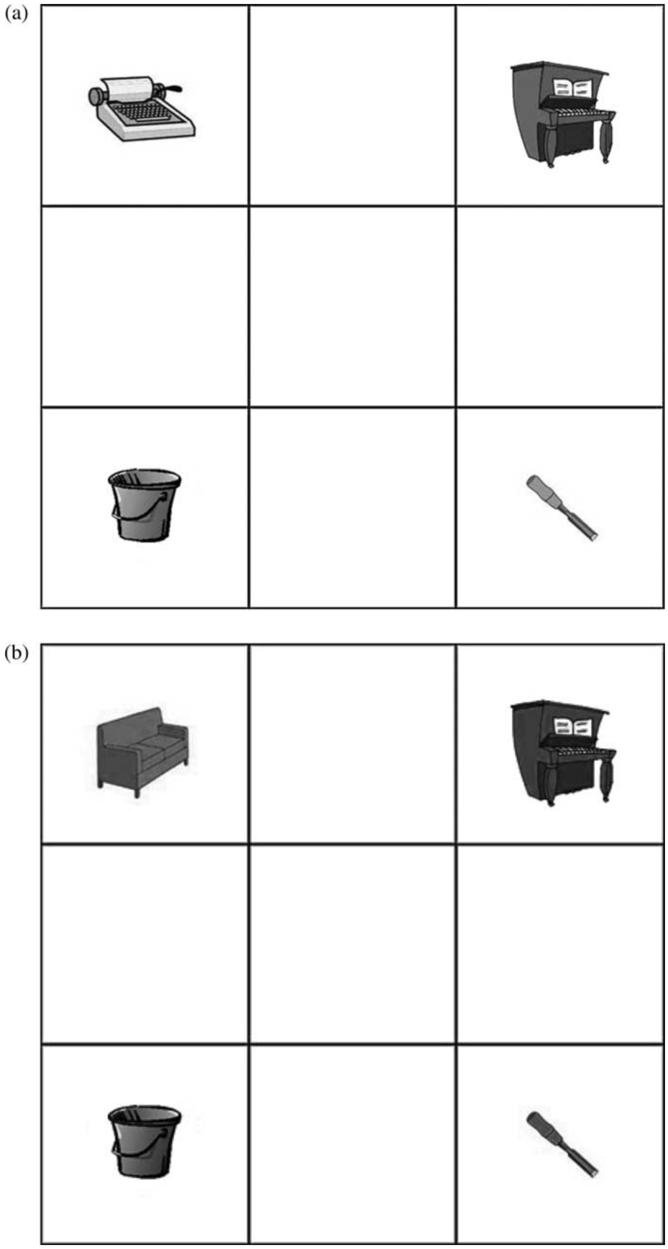

Fig. 3. Sample display from each condition. (a) *Manipulation-related* condition. One item ("typewriter") is related to the target ("piano") in terms of manipulation features. (b) *Control* condition. No items are related to each other or the target ("piano"). One unrelated item ("couch") is visually matched to the manipulation-related item ("typewriter") of the manipulation-related condition.

about 16 in. away from the monitor that was placed at eye height. Thus, the visual angle of each cell was about 7°. To ensure that participants were not looking at any specific location of the pictures in the display, they were asked to touch a red square in the center of the grid that appeared 1000 ms after the display appeared. As soon as participants touched the red square, they heard the target word. They were instructed to touch the target item as quickly as possible upon hearing the target without sacrificing accuracy. There were six practice trials.

3.2. Results

The data from four participants were not included in the analysis for the following reasons. For one participant, a technical failure occurred during the experiment. Two participants failed the calibration and the fourth participant did not follow the instructions. Thus, 26 participants were included in the analysis.

The proportions (across trials) of fixations on each picture type (target, manipulation-related, unrelated) were computed in each 32 ms frame of each condition. Fixation proportions that deviated from the mean by more than two SDs were substituted with the mean of the remaining fixation proportions for that frame of that condition (4.6 and 4.8% of fixation proportions for participants and items respectively). One item pair ("clip"–"clothespin") was excluded from the analysis due to an error rate above two SDs of the mean error rate by item (0.22%).

Fig. 4 shows the mean proportion of trials in which participants fixated each of the picture types over time (from target onset to 1000 ms after onset) in the manipulation-related condition. The proportions do not sum to 1 because fixations outside of the critical regions are not plotted and because fixations on the two unrelated pictures are averaged. The average proportion was used for simplicity since there was no difference in fixations on the two unrelated pictures. The trial was defined as starting 200 ms after the onset of the target word and ending at 1000 ms after target onset. We decided to end the time window at 1000 ms because by this point most participants had fixated on the target for the last time before touching on it. Average fixations over the entire trial show that the manipulation-related picture was looked at more than the unrelated pictures in the same display, $t_1(25)=2.98$, $P<.01$, $t_2(18)=2.09$, $P<.05$ for participants and items, respectively. The related picture in the manipulation-related condition was also looked at more than was the visual match in the control condition, $t_1(25)=2.73$, $P<.01$, $t_2(18)=1.13$, $P=.14$ for participants and items, respectively. Although the analysis by items did not reach statistical significance, the tendency was in the right direction. The small number of items ($n=10$) may have weakened the statistical power. More importantly, when the analysis was done with a smaller time window, there was a significant difference between the manipulation-related condition and the visual match in the control condition from 500 to 800 ms, namely the critical time range for lexical-semantic access given the average target duration (701 ms). Fig. 5 plots the mean proportion of trials in the control condition. As can be seen from the graph, fixations on the unrelated pictures and the visual controls were not distinguishable from each other.

It is of particular interest to investigate the time course of lexical-semantic activation. Previous work suggests that semantic information about a word becomes available even before the word can be uniquely identified (e.g. Marslen-Wilson, 1987).

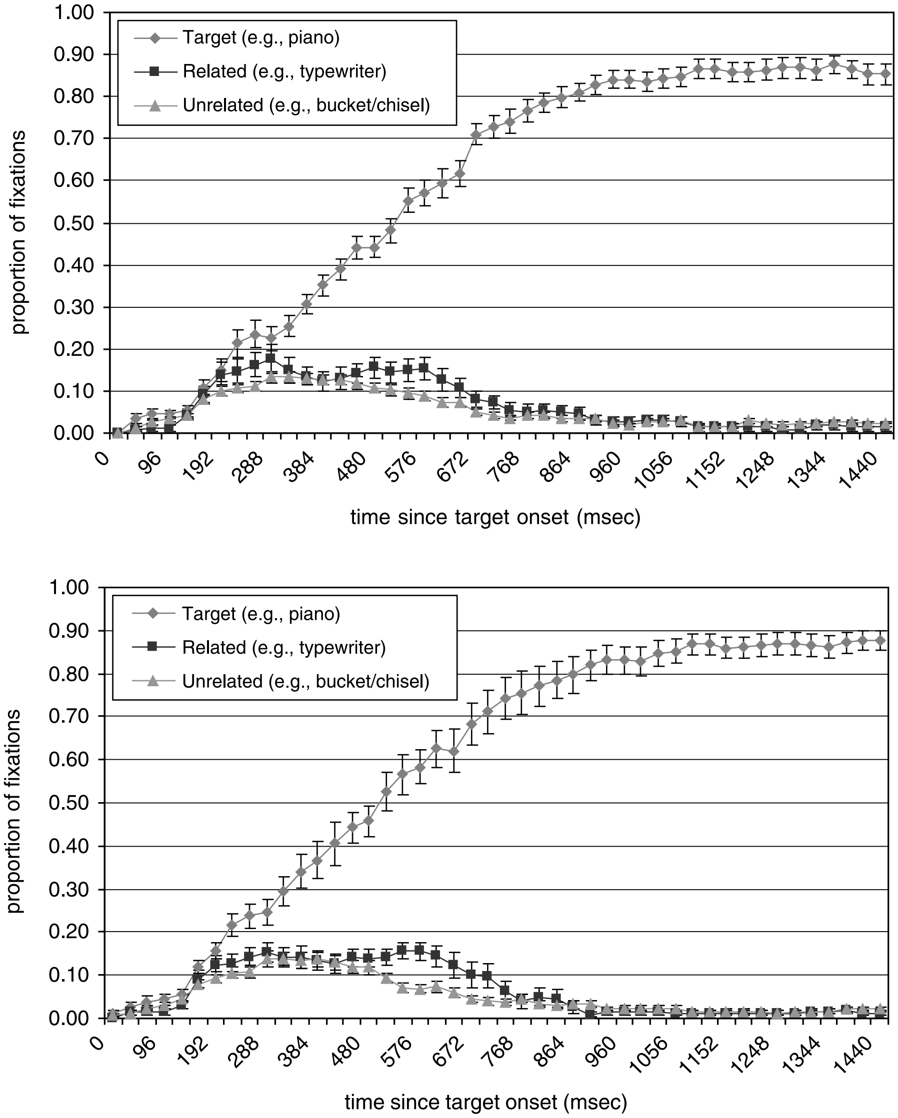

Fig. 4. Proportion of fixations over time on the target, the related item, and the average of the two unrelated items (top: by participant, bottom: by item). Bars indicate standard errors.

More interestingly, such early access to semantic information applies not only to the uttered word, but also semantically related concepts that have not been mentioned. Yee and Sedivy (2005) demonstrated an early emergence of the semantic activation of items related to the targets: Semantically related, but not uttered items became active after around 200 ms of acoustic input. Thus, to obtain information about the time course of participants' fixations in the manipulation-related condition, the trial was divided into

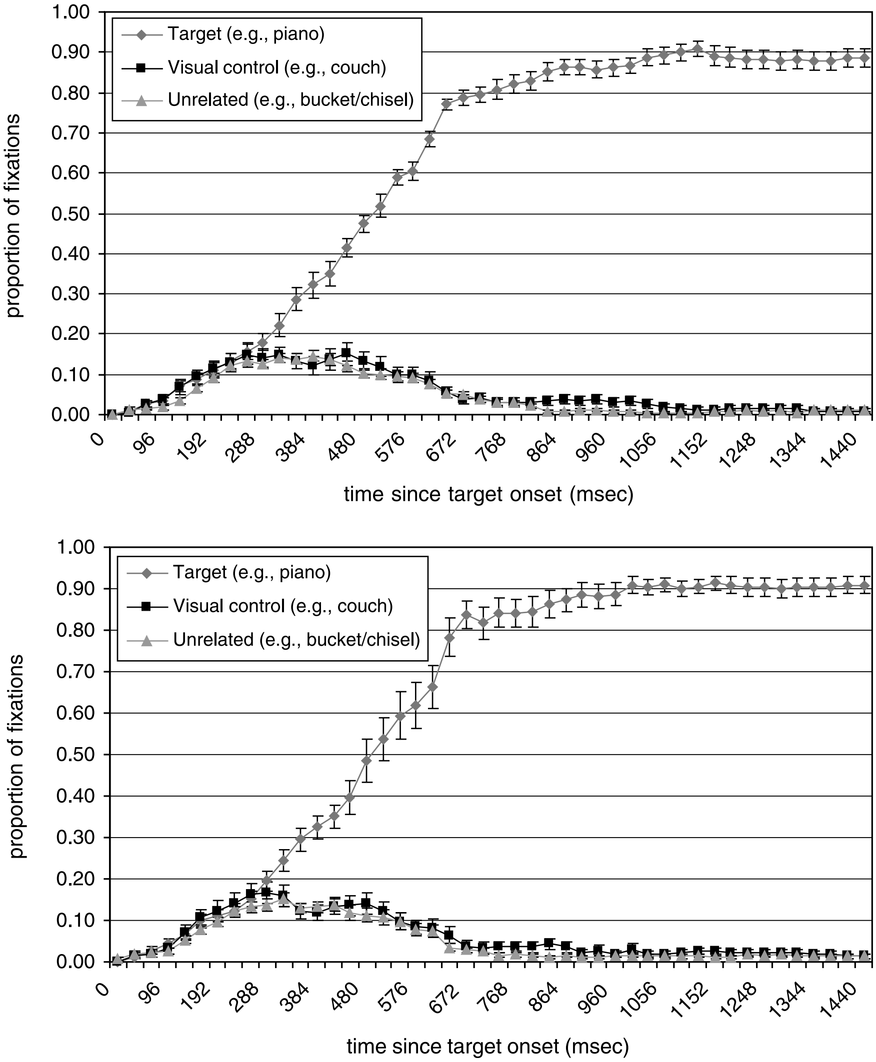

Fig. 5. Proportion of fixations over time in the control condition (top: by participant, bottom: by item). Bars indicate standard errors.

eight 100 ms time windows and separate planned comparisons were conducted on each window. All differences reported below were reliable at $P < .05$ for both participants and items unless otherwise specified. Fixations on the manipulation-related pictures were not different from those on the unrelated pictures in the same display before 500 ms after target onset. From 500 to 800 ms, however, the manipulation-related pictures were looked at more often than unrelated pictures in the display. The pattern of more fixations on manipulation-related pictures than on unrelated ones was significant in analyses by participants: $t_1(25)=2.25$, $P=.0168$ (from 500 to 600 ms), $t_1(25)=2.42$, $P=.0117$ (from 600 to 700 ms) and $t_1(25)=1.92$, $P=.033$ (from 700 to 800 ms). The analysis by items showed a similar pattern and was also significant: $t_2(18)=2.64$, $P=.008$ (from 500 to 600 ms), $t_2(18)=3.16$, $P=.003$ (from 600 to 700 ms) and $t_2(18)=1.86$, $P=.04$ (from 700 to 800 ms). Taken together, the results show that manipulation-related object concepts are accessed early enough to affect the participants' eye movements.

3.3. Discussion

When hearing the auditory target 'piano,' participants looked at "typewriter" more often than the unrelated objects, such as "bucket" or "chisel" in the same display. More importantly, the picture related to the target based on the manner of manipulation drew more fixations than the visually matched picture in the control condition, such as "couch", suggesting that the greater number of fixations on the manipulation-related picture was not caused by either visual similarity to or confusability with the target picture. This point is crucial because objects with a similar manner of manipulation tend to have a similar visual shape as well.

A major implication of the results relates to the implicit nature of the task used in Experiment 2. Since the task of Experiment 2 (as well as the auditory lexical decision task of Experiment 1) did not require explicit retrieval of manipulation features, the results support the notion that manipulation features are accessed in an implicit task and that object concepts sharing them are interconnected in the lexical-semantic network, producing a facilitation effect.

Furthermore, the fine-grained temporal resolution of the eye tracking method provided information about the time course of activation of manipulation features since it was possible to monitor the ongoing process on a millisecond time scale. A significant difference between fixations on manipulation-related pictures and those on unrelated pictures was observed from 500 to 800 ms. Since the average target duration was 701 ms, the effect based on common manipulation features emerged even before the target offset. Moreover, it should be taken into account that it takes approximately 180 ms to execute an eye movement once a signal to move the eyes has been given. Thus, the manipulation-related effect emerged around 300 ms after target onset. This result is consistent with the findings of Yee and Sedivy (2005) that semantically related items become active very early after minimal acoustic input. The emergence of the effect around 300 ms after target onset provides strong evidence that manipulation-related concepts are activated early enough to affect the participants' eye movement before target offset. Given such an early time course, it is very unlikely that the manipulation-related effect in Experiment 2 reflects postlexical strategic processing. Instead, the early emergence of the effect suggests that manipulation knowledge of objects are accessed automatically even in cases where participants are not required to explicitly retrieve such information.

4. General discussion

Experiments 1 and 2 used different stimulus modalities as well as different experimental paradigms. Despite these differences, both Experiments 1 and 2 showed evidence of activation of shared manipulation features across otherwise semantically dissimilar stimuli. In Experiment 1, this was observed as a facilitatory priming effect, and in Experiment 2, as a heightened tendency to fixate objects with shared manipulation features. This pattern of results suggests that sensory/motor-based functional knowledge, namely manipulation, is a part of the lexical-semantic representation of objects and is accessed without conscious effort or explicit instructions. Rooted in sensory/motor experiences, manipulation knowledge is not an abstract property, but is as concrete as perceptual knowledge about shape, form and color.

The importance of manipulation features for objects is intuitively plausible considering the fact that we initially acquire object concepts through our sensory/motor experiences and constantly interact with those objects in our daily life. Children and even adults often learn about an object's function by exploring the object. Piaget (1955) postulated that during cognitive development an initial identity exists between action and object, and action patterns are used to make deductions about the environment. Exploration is a reliable "tool" for children to make sense of the objects in their world and active sensory/motor experiences facilitate conceptualization of the environment. Thus, there appears to exist a close relationship between perception and conceptualization (e.g. Goldstone & Barsalou, 1998).

In fact, evidence has been accumulating in support for the claim that conceptual knowledge is grounded in perception and thus shares the neural (and potentially the cognitive) mechanisms with the perceptual system. For instance, Zwaan, Stanfield, and Yaxley (2002) demonstrated an effect of a perceptual simulation in language comprehension. Participants read sentences about an animal or object in a certain location (e.g. 'eagle in the sky' vs. 'eagle in a nest'). After reading a sentence, they were shown a line drawing of the object in question and were asked to judge whether the object had been mentioned in the sentence (Experiment 1) or to name the object (Experiment 2). In both situations, participants made a faster response when the object's shape on display matched the shape implied by the sentence than when it did not, although the shape itself was not task-relevant. This suggests that perceptual simulations are routinely involved in language processing, which has generally been considered highly abstract and conceptual. When reading a sentence, participants employed a perceptual simulation and obtained a perceptual representation of the sentence, which affected their performance on object verification and naming tasks.

Similarly, Glenberg and Kaschak (2002) showed that in a sentence verification task in which participants were asked to decide whether 'open the drawer' is a sensible sentence, participants made a faster judgment when the response action was a pulling motion (and hence consistent with the motion indicated by the target sentence) than when it was a pushing motion. It is intriguing that a "mediated" perception of an action via a sentence affects the actual motor response. Based on such findings, Barsalou (1999) put forward the theory of perceptual symbol systems: Cognition is "inherently perceptual, sharing systems with perception at both the cognitive and the neural levels" (p. 577). Our current study with the finding of a manipulation feature effect in lexical processing lends further support to a sensory-motor based view of conceptualization.

A crucial finding of this paper is that manipulation features are activated without conscious effort even if participants are not required to do so. Such automatic activation is reflected at the behavioral level in the participants' faster RTs to and more fixations on the manipulation-related stimuli than the unrelated ones. The results reported herein complement current neuropsychological studies that have only used explicit tasks such as semantic judgment (Buxbaum et al., 2000), picture description and gestural response (Sirigu et al., 1991). In their study, Buxbaum et al. (2000) demonstrated that in an explicit semantic judgment task, apraxic patients showed impaired performance on manipulation knowledge compared to functional knowledge. Based on this result, they concluded that there might be a link between apraxia and manipulation knowledge. It would be illuminating to test apraxic patients on implicit tasks, such as Experiments 1 and 2 in the current study in order to strengthen any such conclusions. In particular, it would be important to determine whether impaired performance involving manipulation knowledge is limited to explicit judgment tasks. Further research is certainly needed to illuminate the exact relationship between apraxia and manipulation knowledge. As yet, we know relatively little about the underlying representation of objects that we use and observe everyday. However, further research will contribute to elucidating our understanding of the lexical-semantic representation of those common objects. Temporally sensitive experimental methods such as those used in the current study have significant potential to complement and add to knowledge gleaned on the basis of neuropsychological studies.

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Appendix A

Related	Unrelated	Target	Non-word
piano	blanket	typewriter	skeezenter
lighter	heater	stopwatch	*checkmilge
baby carriage	safety pin	lawn mower	soanipher
doorknob	pendant	egg timer	*wigplufer
camera	needle	hairspray	*hornblaw
flush	shelf	toaster	glucher
shoehorn	saucepan	spade	stad
telephone	newspaper	calculator	naizelipple
whistle	helmet	balloon	akend

(*continued on next page*)

(Appendix A table continued)

Related	Unrelated	Target	Non-word
nutcracker	tambourine	gas pump	*strawneph
pencil eraser	hand puppet	glue stick	boosheck
can opener	mouse pad	twist tie	*ropeflew
dart	kite	paper plane	*yarnmaben
clothes iron	floor lamp	cello bow	wadelblaw
faucet	napkin	jar cap	wharkibb
pliers	dynamite	handbrake	*cointarp
plug	pipe	seatbelt	beaweeds
clothespin	headphone	clip	brup
shopping cart	garbage bag	wheelchair	*bellfreen
fishing reel	tea strainer	egg beater	*flagvanter
key	bar	screwdriver	*combchella
corkscrew	tooth pick	lightbulb	quallips
broom	chalk	hockey stick	*lightbetcher
turkey baster	extension cord	bicycle horn	*pearlitaprand
drill	net	spray gun	messry
bottle cap	stick shift	wing nut	telect
grenade	leaflet	baseball	consool
fishing rod	salad bowl	whip	foop

*Indicates non-words made up of a word part and a non-word part.

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