Consciousness and Cognition 21 (2012) 1563–1570

Contents lists available at SciVerse ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Short Communication

Encoding the world around us: Motor-related processing influences verbal memory

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ARTICLE INFO

Article history:
Received 20 October 2011
Available online 3 August 2012

Keywords:
Manipulability
Memory
Free recall
Imageability
Functionality
Embodied cognition

ABSTRACT

It is known that properties of words such as their imageability can influence our ability to remember those words. However, it is not known if other object-related properties can also influence our memory. In this study we asked whether a word representing a concrete object that can be functionally interacted with (i.e., high-manipulability word) would enhance the memory representations for that item compared to a word representing a less manipulable object (i.e., low-manipulability word). Here participants incidentally encoded high-manipulability (e.g., CAMERA) and low-manipulability words (e.g., TABLE) while making word judgments. Using a between-subjects design, we varied the depth-of-processing involved in the word judgment task: participants judged the words based on personal experience (deep/elaborative processing), word length (shallow), or functionality (intermediate). Participants were able to remember high-manipulability words better than low-manipulability words in both the personal experience and word length groups; thus presenting the first evidence that manipulability can influence memory. However, we observed better memory for low- than high-manipulability words in the functionality group. We explain this surprising interaction between manipulability and memory as being mediated by automatic vs. controlled motor-related cognition.

1. Introduction

Does how we think about interacting with an object influence our memory for it? A well-known finding in the memory literature is that words representing concrete concepts (i.e., objects) are remembered better than words representing abstract concepts (see Paivio, 1971). This is often described as being related to manipulation of imageability, which is an index of how conducive a word is to mental imagery with concepts, represented by concrete nouns being more easily visualized (e.g., BIKE), than abstract nouns (e.g., CLAIM), leading these words to be described as high- and low-imageability words respectively (also see Madan, Glaholt, & Caplan, 2010). However, there has been relatively little research investigating whether object-related differences can further influence memory processes. That is, does a word representing a concrete object that can be interacted with functionally enhance the memory representations for that item compared to a word representing a less manipulable object?

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http://dx.doi.org/10.1016/j.concog.2012.07.006

Recent neuroimaging research has found that words representing objects that can be functionally manipulated, such as a tool or instrument, involve more activation of motor-related brain regions than words that represent objects that are limited to basic volumetric manipulations, such as a piece of furniture or an appliance. (Rueschenmeyer, van Rooij, Lindemann, Willems, & Bekkering, 2010; also see Just, Cherkassky, Aryal, & Mitchell, 2010). For example, SPOON and CAMERA are words that represent functionally manipulable objects, since these objects are tools that can be readily manually interacted with for specific functional purposes. In contrast, SIGN and TABLE are examples of objects that are volumetrically manipulable, since they represent objects that can be manipulated, but not as a requirement of their function. In other words, a SPOON is mainly functional when it is specifically manipulated, but the main function of a TABLE does not require any manipulation. Critically, in neuroimaging studies participants were typically not asked to directly consider whether an object was manipulable or possessed motor-related properties. Rather, participants used strategies of a linguistic nature, and the results still showed more activation of motor-related brain regions for tool-words (Madan & Singhal, 2012; Pulvermüller, 2005; Zwaan & Taylor, 2006). Thus, one implication of this work is that there may be motor-related representations of certain words that are automatic in nature.

For the purposes of this paper, we will refer to words representing functionally manipulable objects, such as tools, as *high-manipulability* words, and words representing volumetrically manipulable objects, such as non-tools, as *low-manipulability* words. The main reason for this is to further distinguish between basic word imageability and other word property manipulations typically used in the memory literature.

To explain the effects of imageability on memory, Paivio (1971, 1986, 2007) proposed dual-coding theory. This theory suggests that abstract words can only be represented in a verbal 'code' in the brain, while concrete words can be represented both as a verbal and imaginal codes. Specifically, by being able to store concrete words in two distinct forms, concrete words can be remembered better than abstract words. This theory has been supported by neuroimaging results demonstrating that abstract words primarily lead to neural activation in the left hemisphere, whereas processing of concrete involves both hemispheres—as predicted by Paivio (Binder, Westbury, McKiernan, Possing, & Medler, 2005; also see Wang, Condor, Blitzer, & Shinkareva, 2010). Building on this theory, Engelkamp and Zimmer (1984) suggest the existence of a third code related to motor representations of words. Support for this comes from studies showing differential memory performance for concrete nouns compared to action verbs (e.g., nouns: BOOK, ROSE; verbs: PULL, STIR). However, one potential problem with these findings is that the noun–verb manipulation is confounded with the use of visual- and motor-related stimuli (see Madan & Singhal, 2012, for a more detailed discussion). However, the findings of recent neuroimaging studies suggest that it is possible to differentially evoke motor-related processing through the use of nouns alone (e.g., Rueschenmeyer et al., 2010), as described in the example above with SPOON, CAMERA, SIGN, and TABLE.

In the present study, we predicted that even though both high- and low-manipulability words are associated with both verbal and imaginal representations, the high-manipulability words would evoke stronger motor representations than low-manipulability words, and thus will be remembered better. Furthermore, in our study we adopted a depth-of-processing design (Craik & Lockhart, 1972, also see Lockhart & Craik, 1990). In this type of design, participants incidentally encode words and the extent to which participants encode the words is manipulated. The key assumption with this approach is that a greater depth of processing implies that semantic and cognitive analyses of the stimuli are performed to a greater degree (i.e., there is a continuum ranging from superficial to elaborative processing). This presumably leads to an increase in the amount of effort involved in the encoding process. Thus, in addition to investigating the influence of manipulability on memory, we also sought to test if the depth of processing of the words would affect any observable manipulability-on-memory effects. For example, it is possible that manipulability would only influence memory performance if the words are processed deeply at a semantic level, but not if they are processed in a relatively superficial manner. On the other hand, it is also possible that these effects will only be present in situations where the words are not processed very deeply, as deep and elaborative processing may take precedence over processes related to the potential effects of manipulability on memory. Nevertheless, we also predicted that a greater depth-of-processing will lead to better memory performance.

In the current study, participants were presented with a series of high- and low-manipulability words and were asked to judge the words based on one of three measures, in a between-subject design. Words were judged either as: (a) representing objects they have seen in the last three days (personal experience group), (b) representing manipulable objects (functionality group), or (c) having either an odd or even number of letters (word length group). We reasoned that participants in the personal experience group would process the words most deeply since they had to access the meaning of the word, imagine the object that the word represents, as well as reflect on their own experiences and autobiographical memories with the object. We also reasoned that participants in the word length group likely processed the words at a more superficial level, and did not necessarily have to access the meaning of the word. However, participants in the functionality group likely had to process the meaning of the word, imagine the corresponding object, and consider how easily they could functionally manipulate the object. Compared to the personal experience and word length groups, the functionality instruction served as an intermediate level-of-processing (also see Table 1). These word judgment tasks served as our incidental encoding task (see Appendix for exact instructions) and were followed by a lexical decision task as a test of implicit memory, as well as a free recall task as a test of explicit memory.

Table 1
Summary of experimental design and results.

Participant group	Personal experience	Functionality	Word length
Experimental design			
Judgment instruction[a]	Have you seen the object represented by word within last three days? (yes/no)	Is the object represented by word functionally manipulable with your hands? (yes/no)	Does word have an odd or even number of letters? (odd/even)
Depth of processing	Deep	Intermediate	Shallow
Results: word judgment			
RT difference	n.s.	+161 ms	n.s.
Results: free recall			
P(Recall) Mean (SD)	.249 (.077)	.176 (.098)	.092 (.048)
P(Recall) NormDiff[b]	+.208	−.184	+.363
Interpretation			
Automaticity of motor processing	Automatic	Intentional	Automatic

[a] Paraphrased from instructions given to participants. See Appendix for exact instructions.
[b] NormDiff (normalized difference) is calculated as: (High – Low)/[.5 (High + Low)]. Positive values indicate more high-manipulability words were recalled than for low-manipulability words; negative values indicate more low-manipulability words were recalled than high-manipulability words. (Also see Fig. 1B.)

2. Methods

2.1. Participants

139 introductory psychology students (mean age ± sd = 19.3 ± 1.7; 96 female; 129 right-handed) at the University of Alberta participated for partial fulfillment of course credit. All participants were required to have learned English before the age of six and were required to be comfortable typing. Participants gave written informed consent prior to beginning the study, which was approved by a University of Alberta Research Ethics Board.

2.2. Materials

Stimuli were sampled from two pools of object nouns: high-manipulability and low-manipulability. Each pool contained 80 English words, ranging between three and ten letters in length (inclusive). Both pools were matched on word length, imageability, concreteness, familiarity, and number of syllables, using the MRC Psycholinguistic database (Wilson, 1988). Classifications of high- and low-manipulability were obtained from six different sources (Arévalo, Perani, Cappa, Butler, Bates, & Dronkers, 2007; Buxbaum & Saffran, 2002; Just et al., 2010; Kellenbach, Brett, & Patterson, 2003; Magnié, Besson, Poncet, & Dolisi, 2003; Rueschenmeyer et al., 2010).

2.3. Procedure

Participants were randomly assigned to one of three groups based on the word judgement task instructions: personal experience ($n = 45$), functionality ($n = 47$), and word length ($n = 47$).

The experiment consisted of three sequential tasks: word judgement, lexical decision, and free recall. Participants were not informed about the subsequent task until the current task was completed.

2.3.1. Word judgement

In all three groups, participants were presented with 80 words (40 high-manipulability and 40 low-manipulability). Words were presented in the centre of the computer screen for 3000 ms per word (regardless of judgement response time), followed by a 500 ms blank inter-stimulus interval. Presentation order was randomized. All stimuli were presented in a white "Courier New" font, which ensured fixed letter width, on a black background.

In the personal experience group, participants were asked to rate the 80 words as either objects they have or have not seen within the past three days by pressing the 'Z' or 'M' key, respectively.

In the functionality group, participants were presented with instructions explaining the concept of manipulability. Participants were then asked to rate the 80 words as either high- or low-manipulability by pressing the 'Z' or 'M' key, respectively.

In the word length group, participants were asked to rate the 80 words as having either on even or odd number of letters by pressing the 'Z' or 'M' key, respectively.

See Appendix for the exact judgment instructions.

2.3.2. Lexical decision

80 additional words (40 high-manipulability and 40 low-manipulability), selected from the same pools as the judged words, were included as 'new' words. Participants were then asked to judge the lexical status of 320 items: 80 'old' words (from the previous encoding task), 80 new words and 160 non-words. The participant pressed either 'M' on the computer keyboard to indicate that the item was a word, or 'Z' to indicate that the item was a non-word. A fixation cross ('+') was presented for 500 ms to separate each decision prompt. After every 50 decisions, participants were given the option to take a brief break.

The 320 items were preceded by an additional 8 items (four words/four non-words). These 8 items were presented prior to the 320 items to attenuate a possible recency effect over the last words from the preceding encoding phase. These four words were not presented in the encoding phase and performance on these 8 items was not included in the analyses. Another 8 items followed the 320 items to attenuate possible recency effects in the subsequent free recall phase.

2.3.3. Free recall

Participants were given 5 min to recall all of the words they could remember from the task. After each response, a blank screen was presented for 500 ms. Misspellings or variants of the correct word were scored as incorrect responses. Extra-experimental intrusions and repetitions of correct responses were ignored.

3. Data analysis

Effects are considered significant based on an alpha level of 0.05. For response time analyses, only correct responses were analyzed. As response time distributions are not normally distributed, all response times were log-transformed prior to statistical comparisons. In the lexical decision phase, only responses made between 200 ms and the individual participant's mean plus three standard deviations were included in the analysis.

4. Results

4.1. Word judgment

Across all participants, every of the 160 words in the study was rated an average of 22 times (min = 19; max = 26).

In the personal experience group, participants reported seeing the objects represented by the high- and low-manipulability words equally often within the past three days [$t(158) = 1.42$].

In the word length group, there was no difference in accuracy between high- and low-manipulability words [$t(158) = 0.96$].

In the functionality group, participants rated the high-manipulability words as higher manipulability than the low-manipulability words [$t(158) = 12.65$, $p < .001$]. Importantly, this result confirms that our two word pools indeed differed in manipulability. As a crosscheck, we tested the correlation between participants' manipulability ratings with our own discrete categories of high- and low-manipulability and found a strong correlation between the two measures [$r(159) = .71$, $p < .001$]. Nonetheless, further analyses of manipulability are based on a median-split from participant ratings, rather than our initial categorization, to maximize statistical power and measurement validity.

Additionally, log-transformed judgement response times were analyzed in a 3 (GROUP: personal experience, functionality, word length) × 2 (MANIPULABILITY: high, low) repeated-measures ANOVA. There was no significant main effect of GROUP. In other words, all judgments took an equal amount of time. MANIPULABILITY was a significant main effect, where high-manipulability words were judged faster than low-manipulability words [$F(1,136) = 19.68$, $p < .001$]. A significant interaction of GROUP × MANIPULABILITY was also observed [$F(2,135) = 20.95$, $p < .001$], where participants were significantly slower to judge the high-manipulability words than the low-manipulability words in the functionality group ($M_{diff} = 161$ ms; also see Table 1). No significant difference was found between response times in the personal experience and word length groups.

4.2. Lexical decision

Two participants performed less than 70% accuracy on the lexical decision task and were excluded from analyses on this task. Log-transformed lexical decision response times were analyzed in a 3 (GROUP: personal experience, functionality, word length) × 2 (MANIPULABILITY: high, low) × 2 (WORD TYPE: old, new) mixed repeated-measures ANOVA. In the Word Type factor, words judged during encoding were designated as 'old'; words first presented during lexical decision were designated as 'new'. The main effect of WORD TYPE was a significant, with old words being identified as words faster than new words [$F(1,134) = 70.93$, $p < .001$]. No other significant effects were found. Response times for old words, collapsing across GROUP, were 643 ms and 629 ms for high- and low-manipulability words, respectively. For new words, lexical decision response times were 660 ms and 663 ms, respectively, for high- and low-manipulability words.

4.3. Free recall

Proportion of words in each word type were analyzed in a 3 (GROUP: personal experience, functionality, word length) × 2 (MANIPULABILITY: high, low) × 2 (WORD TYPE: old, new) mixed repeated-measures ANOVA.

The main effect of GROUP was significant [$F(2,136) = 27.09$, $p < .001$] (see Fig. 1A). Post hoc *t*-tests indicated that participants in the functionality and personal experience groups recalled more words in total than participants in the word length group [both p's < .001]. Participants in the personal experience group recalled more words in total than participants in the functionality group [$p < .01$].

The main effect of WORD TYPE was also found to be significant main, with participants recalled more old words than new words [$F(1,136) = 300.02$, $p < .001$]. MANIPULABILITY was also a significant main effect, with more high-manipulability words were recalled than low-manipulability words [$F(1,136) = 15.90$, $p < .001$]. The interaction of WORD TYPE × MANIPULABILITY was also significant [$F(2,136) = 28.80$, $p < .001$]. This was further qualified by a significant interaction of GROUP × MANIPULABILITY × WORD TYPE [$F(2,136) = 4.20$, $p < .05$]. Post hoc pairwise comparisons found that in the functionality group, more low-manipulability words were recalled than high-manipulability words, for old words [$p < .01$], but that there was no significant difference in recall for high- and low-manipulability new words [$p > .1$]. For the personal experience, more high-manipulability words recalled than low-manipulability words, for both old and new words [both p's < .001]. For the word length group, more high-manipulability words recalled than low-manipulability words for the

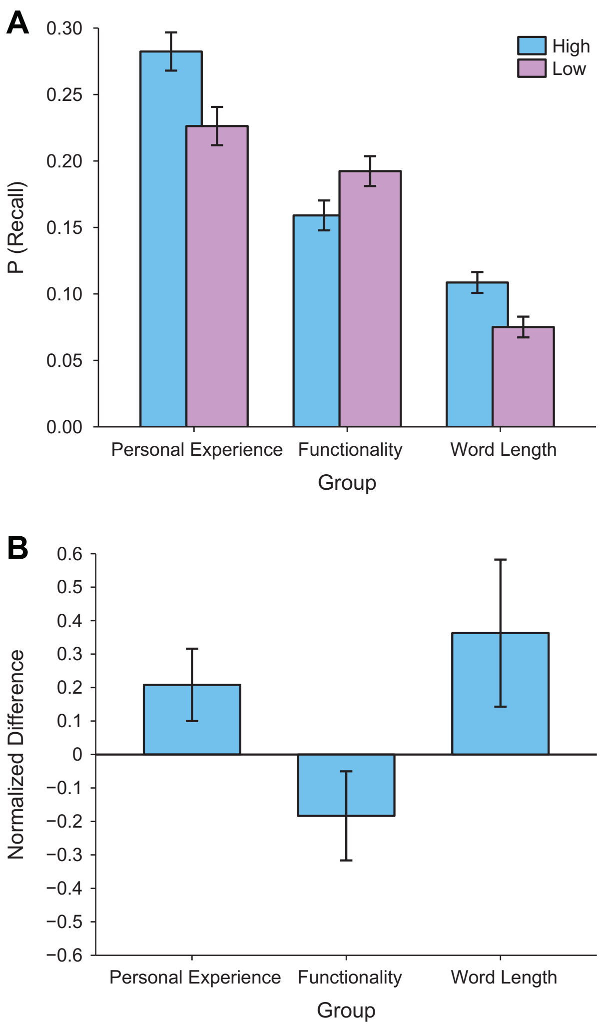

Fig. 1. Free recall performance for each group. (A) Proportion of high- and low-manipulability words recalled relative to total number of presented words. (B) Difference in number of recalled high- and low-manipulability words, divided by the average number of recalled words (normalized difference, also see Table 1). If participants recalled more high-manipulability words than low-manipulability words, their proportion of responses that were high-manipulability would be significantly greater than zero. Only data for words first presented during the word judgment task (old words) is shown. Error bars are 95% confidence intervals, corrected for inter-individual differences.

old words [$p < .001$], but found no significant difference in recalled new words due to manipulability [$p > .1$]. Fig. 1B illustrates this difference in recall rates for high- and low-manipulability words, relative to the average recall rate, for each group; also see Table 1.

After accounting for spelling errors and other non-word responses, the proportion of extra-experimental intrusions was extremely low, e.g., less than 1%.

5. Discussion

In the present study we sought to investigate whether the manipulability level of words combined with the depth of processing of those words would influence memory performance. We found evidence that participants were able to remember high-manipulability words better than low-manipulability words in both the personal experience and word length groups. To our knowledge, this is the first evidence that manipulability can be used as a word property to influence memory performance. We also observed a strong depth-of-processing effect, where participants who processed words elaborately and to a greater extent during encoding (i.e., the word judgment task) were able to remember more words than those who only had to process words in a relatively superficially manner.

With regards to the interaction between the effects of manipulability (within-subject) and depth of processing (between-subject), we found a surprising result where the superior memory performance effect for high-manipulability words found in the personal experience and word length groups was *reversed* in the functionality group. That is, we observed better memory for low-manipulability words when the encoding task involved judging whether the words were manipulable or not. To disentangle the cause of this reversed effect we will first discuss the reasons why memory was enhanced for high-manipulability words in the personal experience and word length groups, and provide an interpretation to explain why memory for low-manipulability words was able to exceed that of high-manipulability words in the functionality group.

Numerous neuroimaging studies have shown that processing words and images representing high-manipulability items evoke greater neural activation in motor-related regions of the brain than the processing of low-manipulability items (Chao & Martin, 2000; Just et al., 2010; Martin, Wiggs, Ungerleider, & Haxby, 1996; Rueschenmeyer et al., 2010; Saccuman, Cappa, Bates, Arévalo, Della Rosa, Danna, & Perani, 2006). To explain these findings, it has been proposed that in order to comprehend the meaning of high-manipulability words and images they must be processed semantically, which *automatically* activates neural representations of the respective object as well as its function (Buccino, Sato, Cattaneo, Rodà, & Riggio, 2009; Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003; Pulvemüller, 2001, 2005; also see Gibson's theory of affordances, Gibson, 1977, 1979) through imagery-based processes (see Madan & Singhal, 2012, for a review). Here we present the first evidence that one's ability to remember an object-word can also be influenced by the object's ease of manipulability. We suggest that this is primarily due to a basic increase in motor-related processes that influence memory operations. However, this memory enhancement effect was only observed for two of our encoding tasks. The third task requiring participants to encode the words with a strategy designed to more directly activate motor-related imagery was associated with an opposite effect – enhanced memory performance for the low-manipulability items.

We argue that it is unlikely that the reversed effect found in the functionality group could be driven merely by the influence of the depth-of-processing. Instead, we provide a *post hoc* interpretation of this interaction, suggesting that it is more likely driven by differences in automatic cognitive processes that are fundamental to memory operations when there are motor-imagery requirements during encoding.

In our study, participants in the personal experience and word length groups were not required to directly attend to the motor-related properties of the words they were presented with. We argue here that the differences we observed in memory performance associated with the motor-related properties of the stimuli likely occurred automatically. That is, motor representations were activated by the stimuli themselves without conscious awareness of the words. In contrast, participants in the functionality group were required to directly attend to the motor-related properties of the presented words since they were instructed to decide if the represented object could be functionally interacted with or not. Thus, in this case participants were required to consciously process the motor-related properties of each word in a top-down fashion (also see Bargh, 1984; Hasher & Zacks, 1979). Since the low-manipulability words represented objects that were less prototypical members of the category of ''manipulable objects'', it stands to reason that the participants may have allocated more of their attentional resources to those stimuli during encoding because they could not as easily imagine interacting with them in the first place. Moreover, this effect superseded the basic automatic memory enhancing effect associated with high-manipulability stimuli that we observed in the other two conditions. Automaticity in cognition has been described as lying along a continuum that spans from purely-automatic to purely-controlled processes, with a mid-point involving processes described as ''goal-directed automaticity'' (Bargh, 1996, 1997; Bargh & Chartrand, 1999). It has been further argued that a memory-based link in automaticity may occur at such a mid-point of goal direction during automatic processing and this link involves minimal cognitive control (Dijksterhuis & Bargh, 2001). Thus, data from our functionality group may show evidence of a link between controlled memory processes and more automatic perceptual processes that, when operating together, facilitate memory performance for the low-manipulability objects, over that for high-manipulability objects, because controlled processes during encoding are more involved compared to the other two encoding conditions.

Additionally, when making the functionality judgment, low-manipulability words may have been more atypical and conceptually incongruent, leading participants to be significantly slower to respond to the low- than high-manipulability words in the word judgment task, likely because they found the low-manipulability words more difficult to judge. Previous research has shown that reading motor-related phrases that are less typical led to increased neural activation (van Elk, van Schie, Zwaan, & Bekkering, 2010) and that, more generally, semantic incongruence can enhance memory (e.g., O'Brien & Myers, 1985; Waddill & McDaniel, 1998).

While previous studies have not investigated the influence of manipulability on memory, numerous fMRI studies have examined the effects of manipulability on the processing of word and image stimuli. Given the results of the current study, we would predict that greater neural activation in motor-related brain areas should be observed for high- than low-manipulability stimuli if participants do not need to directly attend to the motor-related properties of the stimuli. However, this effect should be reversed, with greater motor-related neural activation associated with low-manipulability stimuli when manipulability is deliberately processed. Several fMRI studies have indeed found that processing of high-manipulability stimuli (relative to low-manipulability stimuli) leads to greater activation of the primary motor and primary somatosensory cortices, as well as the inferior parietal lobule in the case of word stimuli (Chao & Martin, 2000; Just et al., 2010; Rueschenmeyer et al., 2010; Saccuman et al., 2006). Critically, participants in these studies were given object naming (image stimuli: Chao & Martin, 2000; Saccuman et al., 2006), lexical decision (word stimuli: Rueschenmeyer et al., 2010), or elaborative semantic processing (word stimuli: Just et al., 2010) tasks. In all of these tasks, participants were not required to deliberately process the motor-related properties of the stimuli. Thus, the effects of manipulability in these studies may have been driven by the automatic activation of brain regions due to manipulability (see also Pulvemüller, 2001, 2005). In contrast, Kellenbach et al. (2003) asked participants to make judgments regarding the functionality of objects and found that both high- and low-manipulability stimuli activated regions that are considered to be part of an extended tool network. Based on our own findings, we propose that the task used by Kellenbach et al. (2003) likely involved more deliberate processing of the stimuli's motor-related properties, and thus led to significant neural activation for both high- and low-manipulability stimuli.

To summarize, our study is unique in that is shows two distinct effects of words that have varied "manipulability-representations" of objects. When participants deeply or shallowly encode the words, their memory was better for the high-manipulability stimuli. We suggest that these effects are the result of automatic processing of motor-related representations that predominantly occur outside of awareness. However, when participants were required to encode the stimuli with attention to the functional properties of the object-words, we found that the automatic motor-processing was overridden by more controlled processes resulting from a basic incongruency that was present when the stimuli themselves were less obviously manipulable. We suggest that our data represent an important interaction between automatic and controlled processes that subserve basic memory performance.

Acknowledgments

We would like to acknowledge Yvonne Chen for insightful discussions. This research was partly funded by a Discovery grant from the National Science and Engineering Research Council of Canada held by AS.

Appendix A. Judgment instructions

A.1. Personal experience

Your task will be to judge whether these words represent objects that you remember seeing within the past three days.

A.2. Functionality

Your task will be to judge whether these words represent objects that you can manipulate with your hands. In other words, consider if the object is something you can interact with functionally, such as a screwdriver or a computer keyboard.

A.3. Word length

Your task will be to judge whether these words have an even or odd number of letters.

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