

Perceptual Representation as a Mechanism of Lexical Ambiguity Resolution: An Investigation of Span and Processing Time

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In 2 experiments, the authors investigated the ability of high- and low-span comprehenders to construe subtle shades of meaning through perceptual representation. High- and low-span comprehenders responded to pictures that either matched or mismatched a target object's shape as implied by the preceding sentence context. At 750 ms after hearing the sentence describing the target object, both high- and low-span comprehenders had activated a contextually appropriate perceptual representation of the target object. However, only high-span comprehenders had perceptually represented the contextually appropriate meaning immediately upon hearing the sentence, whereas low-span comprehenders required more processing time before the perceptual representation was activated. The results are interpreted in a framework of co-occurring lexical representations and perceptual–motor representations.

Keywords: perceptual representations, lexical ambiguity, individual differences

One of the most remarkable capacities of the human mind is the ability to perceive squiggles on a page or rapid patterns of sound waves and transform this visual or auditory code into meaningful concepts and ideas. These resulting meaning representations and the process by which they are activated have been the focus of much research in cognitive psychology over the past century. There have been several recent demonstrations that reading or listening to language evokes perceptual–motor representations (Chambers, Tanenhaus, & Magnuson, 2004; Chao & Martin, 2000; Glenberg & Kaschak, 2002; Kan, Barsalou, Solomon, Minor, & Thompson-Schill, 2003; Kaschak et al., 2005; Klatzky, Pellegrino, McCloskey, & Doherty, 1989; Morrow & Clark, 1988; Pecher, Zeelenberg, & Barsalou, 2003; Richardson, Spivey, Barsalou, & McRae, 2003; Solomon & Barsalou, 2001; Stanfield & Zwaan, 2001; Tabossi, 1988; Zwaan, Madden, Yaxley, & Aveyard, 2004; Zwaan, Stanfield, & Yaxley, 2002). However, it is not clear exactly what role these representations play in language comprehension. The aim of the present study is to show how perceptual–motor representations can be viewed as a mechanism by which the contextually appropriate meaning or sense of a given word is construed during language processing.

Perceptual–motor representations are conceptualized as activations of experiential simulations of a described situation (see Barsalou, 1999; Zwaan & Madden, 2005). According to this recent framework, when comprehenders process language, they partially reactivate previous traces of experience that are distributed across multiple perceptual and motor modalities in the brain (Zwaan & Madden, 2005). A growing body of recent research has demonstrated the activation of perceptual–motor representations during language comprehension. For instance, in a study by Zwaan and colleagues (Zwaan et al., 2002), participants responded as to whether a pictured object had been mentioned in a sentence they had just read. On experimental trials, the sentence always named an object in a particular location (e.g., *There was spaghetti in the [box/pot]*), and the subsequently pictured object was always the mentioned object, requiring a yes response. However, the pictured object could either match or mismatch the contextual constraints of the preceding sentence. For instance, if a participant read the sentence *There was spaghetti in the pot*, then a picture of cooked spaghetti would be a matching picture, whereas a picture of uncooked spaghetti would be a mismatching picture. Participants were faster to respond to pictures that perceptually matched rather than mismatched the contextual constraints of the sentence, providing support for the idea that perceptual information is incorporated in language representations. In a second experiment participants did not have to respond as to whether the pictured object was mentioned in the sentence but were simply asked to name the pictured object. Again, participants were faster to name pictures that perceptually matched rather than mismatched the contextual constraints of the sentence. Furthermore, other studies have demonstrated that comprehenders routinely represent other perceptual aspects of described entities, such as the direction of motion of objects (Zwaan et al., 2004) and the orientation of objects (Stanfield & Zwaan, 2001).

Additionally, there is support for the idea that motor programs for actions are activated during language comprehension (Glenberg & Kaschak, 2002; Klatzky et al., 1989). Glenberg and Kas-

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chak (2002) found that participants were faster to respond to sentences when the response action was compatible with the direction of described motion. For instance, after reading a sentence such as *Close the drawer*, participants were faster to respond if the correct response required moving their hand away from rather than toward their body. This has been termed the action-sentence compatibility effect. Klatzky and colleagues (1989) previously demonstrated a similar effect, showing that participants are faster at reading and comprehending a sentence about throwing darts, for instance, when they are first instructed to form their hand into the pinched fingers (dart-throwing) position. This facilitation is consistent with the idea that language representations are embodied and are thus susceptible to influences from perceptual-motor systems. Recently, Zwaan and Taylor (2006, Experiment 4) have shown that the activation of motor processes during the comprehension of action sentences is rather immediate, as it occurs during processing of the verb describing the action in question.

It has certainly become evident that perceptual-motor representations are evoked during language processing. However, the precise role of these representations in the comprehension process is still unclear. The present study is an attempt to link perceptual-motor representations with established findings in the field of psycholinguistics and thus to establish these representations as a mechanism of language comprehension. Although it is clear that both perceptual and motor representations are activated during language processing, the present set of experiments focuses solely on the perceptual aspect of these representations. First, we discuss current models of ambiguity resolution and comprehension skill, and then we describe two experiments that investigate how perceptual representations act as a mechanism for construing the contextually appropriate meaning or sense of a word during language processing. Within these experiments, the time course of meaning construal through perceptual representations is investigated for comprehenders of varying skill level.

Lexical Ambiguity Resolution

Lexical ambiguity occurs very frequently in written and spoken language, as most words and phrases in the English language lead to multiple possible interpretations (Britton, 1978). How the contextually appropriate meaning of a word is selected has been the topic of much research in psycholinguistics. Theories of lexical ambiguity resolution have often focused on homonyms,¹ or words with a single identical pronunciation and orthography but two or more unrelated meanings (e.g., dog *bark* and tree *bark*). However, theorists from the field of linguistics are quick to make the distinction between this type of ambiguity and polysemy, wherein words with a single, identical pronunciation and orthography have multiple related meaning senses (Cruse, 1986; Lyons, 1977). For example, the word *twist* can be applied to knobs, ankles, limes, dancing, and the truth, each yielding a slightly different but related meaning from the next.

How comprehenders are able to resolve ambiguities with respect to homonymy is rather straightforward, as it is generally agreed that homonyms are associated with separate stored lexical entries in the mental lexicon. Theories differ on issues such as the time course of contextual influence on the meaning selection process (Conrad, 1974; Glucksberg, Kreuz, & Rho, 1986; Lucas, 1987; Onifer & Swinney, 1981; Schvaneveldt, Meyer, & Becker, 1976;

Simpson, 1981; Swinney, 1979), but there is agreement on the fact that one of the available lexical entries must be selected and integrated into the larger discourse model. The area of polysemy, however, is more complicated, in that there is not general agreement on whether all senses of a given word are stored in a single lexical entry or whether each sense has its own lexical entry in the mental lexicon. Consequently, this research area has recently provided fruitful investigations in terms of informing theories of lexical ambiguity.

Rodd, Gaskell, and Marslen-Wilson (2002) have provided evidence that the benefit for ambiguous words in lexical decision tasks is most likely due to polysemous words rather than homonyms as originally thought. In fact, once these authors empirically distinguished between words with multiple unrelated meanings and words with related senses, they found that words with multiple unrelated meanings were responded to more slowly than controls, whereas words with related senses were responded to more quickly than controls. Likewise, Frazier and Rayner (1990) have shown that polysemous words yield shorter fixations than words with multiple unrelated meanings. Furthermore, Klepousniotou (2002) has demonstrated that polysemous words are accessed more quickly than homonyms.

These findings have been interpreted in various ways. Klepousniotou (2002) interpreted the polysemy advantage as evidence for single, semantically rich lexical entries for polysemous words (although see Klein & Murphy, 2001) that allow the multiple related senses of polysemous words to facilitate processing of the lexical entry as a whole. In contrast, multiple unrelated meanings of homonyms are stored in separate lexical entries and therefore compete for activation. Rodd et al. (2002) considered multiple interpretations for the data, favoring the idea that polysemous words have multiple representations but that these are highly correlated lexical representations in distributed semantic networks. As long as the task is noncontextual, the multiple activated representations work together to recruit patterns of overlapping activation.

Once the task becomes more contextual, however, each of these accounts necessitates the existence of a mechanism by which representations can be constrained to the contextually appropriate sense of a polysemous word. Highly correlated lexical representations in distributed semantic networks will not inhibit each other, and thus the mechanism by which one particular sense may be construed is unclear. Likewise, Klepousniotou (2002) argued for a single lexical entry specified for the base sense of a polysemous word, along with an underspecified *lexical rule* that allows for derivation of extended meanings. Exactly how a particular word sense is correctly construed in contextual language is unclear. This problem becomes even more challenging when sense ambiguity is considered for words that are thought to have only a single sense. Consider the example *There was spaghetti in the box/pot*. These two sentences refer to the same meaning of *spaghetti*. However, there are aspects of the meaning of *spaghetti* that can change from context to context, most salient in this case being the shape. Here we can see that the possibilities of subtle shades of meaning that

¹ Previous studies have also used homographs, which share the same orthography but not pronunciation, and homophones, which share the same pronunciation but not orthography.

can be construed are countless, not merely limited to the number of dictionary entries or senses of a word. There must be a mechanism of sense construal for all words if comprehenders do in fact take into account subtleties such as the shape of entities in their representations. It seems that this gap in theory can be filled by the perceptual–motor representations introduced above.

Perceptual–Motor Representations and Lexical Representations

As discussed previously, there is a growing body of evidence that comprehenders activate perceptual–motor representations during language processing. These perceptual–motor representations can be functionally divided into two types: representations of experience with the referent of a linguistic communication and representations of experience with the linguistic code itself (see Zwaan & Madden, 2005). Although according to our framework both types of representations are actually *perceptual–motor representations*, we use this term in reference to representations of the referent of a linguistic communication, whereas we use the term *lexical representations* to refer to the representations of experience with the linguistic code itself. Lexical representations are traces of experience of hearing or seeing words, as well as pronouncing, writing, or typing words.² They are interconnected with other lexical representations through co-occurrence, and they are connected to their associated perceptual–motor representations through co-occurrence as well. Thus, in addition to activating one or more stored lexical representations when a given word or concept is encountered, comprehenders also partially reactivate perceptual–motor representations, or previous traces of experience with the referent associated with that lexical representation.

The activation of perceptual–motor representations through lexical representations serves to ground the language comprehension process in one's own experiences. Because lexical representations themselves are often contextually underspecified, perceptual–motor representations may act as a mechanism to automatically construe the appropriate meaning or sense of the encountered word. Thus, encountering the words *eagle* and *fly* together in a sentence leads to activation of the lexical representations for these two words, which in turn activate a perceptual–motor representation of the referent. In the perceptual–motor representation, many senses of the flying eagle are automatically construed, such as outstretched wings and tucked talons. Thus, the activation of perceptual–motor representations by lexical representations may be a mechanism for construing word senses. However, it is still unclear exactly how and when perceptual–motor representations are used to resolve these subtle ambiguities. In particular, the time course of activating a perceptual–motor representation relative to the lexical representation is unclear, as is the extent to which comprehension skill mediates activation of the two types of representations.

Individual Differences in Lexical Ambiguity Resolution

It is not the case that all comprehenders are equally skilled and fast at selecting the appropriate meaning of a homonym, and so one would not expect that all comprehenders would be equally skilled and fast at activating perceptual–motor representations and construing the appropriate sense of a word. In their research on

lexical ambiguity resolution of homonyms, Gernsbacher and colleagues have demonstrated that more skilled comprehenders are better able to use sentence context to quickly constrain their representations than less skilled comprehenders (Gernsbacher & Faust, 1991; Gernsbacher, Varner, & Faust, 1990). In these studies, a sentence containing a homograph or homophone was followed by a test word that was related to the contextually appropriate or the contextually inappropriate meaning of the preceding homograph/homophone. Skilled comprehenders (as determined by Gernsbacher & Varner's [1988] comprehension test battery) were faster to deactivate the inappropriate meanings of the preceding homographs.

Likewise, Van Petten, Weckerly, McIsaac, and Kutas (1997) used modulations in the n400 component of event-related brain potentials to show that only high-span comprehenders (as determined by Daneman & Carpenter's [1980] Reading Span task) were able to use sentence-level context immediately upon reading a word in a sentence. Low-span comprehenders did not show immediate sensitivity to sentence-level context at normal reading speeds but rather relied on single-word associations. Thus, the phase at which sentence context is able to influence meaning selection, at least in homographs, seems to vary with the language ability of the individual.

While Gernsbacher and colleagues (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990) link the source of these individual differences in the ability to use context to the efficiency of a suppression mechanism, others have posited that the difference stems from the richness of representations and domain expertise (MacDonald & Christiansen, 2002; McNamara & McDaniel, 2004; Pearlmutter & MacDonald, 1995; Zwaan & Truitt, 2000). For instance, McNamara and McDaniel (2004) demonstrated that the activation of relevant background knowledge rather than a mechanism to suppress irrelevant meanings could explain the differential use of contextual information to select appropriate meanings. Furthermore, Zwaan and Truitt (2000) showed that the extent to which smokers were able to reject locally consistent but globally inconsistent smoking-related words was correlated with the amount of lifetime smoking experience. Finally, although their findings pertain to age-related differences, Dagerman, MacDonald, and Harm (2006) suggested that the ability to use contextual information (but not lexical frequency) is a factor of processing speed. In their study, computational models were able to simulate older and younger adults' ability to use context by means of varying a processing speed parameter. This idea of processing speed as an underlying source of individual differences might also apply to younger adults of varying comprehension skill.

² Although the current study does not provide evidence concerning the nature of lexical representations, the idea that they are perceptual representations is consistent with Goldinger's (1998) episodic theory of the lexicon, which postulates that episodic traces of perceptual input are stored in the lexicon from each individual instance of hearing words. These perceptual lexical representations (e.g., experiences with the *word spaghetti*) may then be linked to referent representations (e.g., experiences with *actual spaghetti*) through co-occurrence.

The Present Study

Bridging the gap between research on lexical ambiguity resolution, individual differences, and perceptual–motor representations in language comprehension, the present study incorporates the empirical design of both Gernsbacher’s work on comprehension skill using homographs and Zwaan and colleagues’ perceptual mismatch paradigm. The resulting design investigates the time course of meaning construal in high- and low-span comprehenders to demonstrate how perceptual–motor representations might act as a mechanism for construing the contextually appropriate meaning or sense of a word during language processing. Although high-span comprehenders are clearly expected to use sentence context to activate perceptual–motor representations more quickly than low-span comprehenders, the following set of experiments is aimed at better understanding exactly when and how lexical representations and perceptual–motor representations are activated for high- and low-span comprehenders.

Experiment 1

The present study focuses on the perceptual aspect of perceptual–motor representations activated during language processing, so the term will be shortened to *perceptual representations* in the context of our experimental manipulation. To investigate how perceptual representations act as a mechanism for construing the contextually appropriate sense of a word, we examined the time course of the perceptual representation at two levels of reading span and two levels of probe latency. In the current experiment, high- and low-span comprehenders heard sentences describing the location of a target object. Immediate and delayed picture presentations were used to probe for context-appropriate and context-inappropriate perceptual features of the target words. We expected that pictures matching the contextual constraints of the preceding sentence would be responded to more quickly than mismatching pictures, provided an adequate perceptual representation had been activated at the time the picture was presented. Thus, the match advantage was more likely to be observed for high-span comprehenders and more likely to occur at the later probe latency.

There are several possible sources for these predicted span differences. First, the high-span comprehenders may activate the appropriate perceptual representation more quickly because they have a more efficient suppression mechanism than low-span comprehenders (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990). However, this is unlikely the cause of the difference in the present design, as the disambiguation required here is not between mutually exclusive meanings, or even related senses, but rather between very subtle perceptual features of a given sense of a concept. It is unlikely that active suppression would have an influence within a given sense of a concept. Alternatively, the difference might stem from domain expertise (McNamara & McDaniel, 2004; Zwaan & Truitt, 2000), such that high-span comprehenders happen to have more experience with the content of the experimental items and thus have richer networks of lexical and perceptual–motor representations. However, this explanation is also unlikely within the context of the current study, as the sentences and pictures used here are a range of everyday items such as spaghetti, eagles, and newspapers, which should not represent an area of expertise for any given subject.

Although comprehenders would not be expected to vary immensely in expertise with these everyday concepts, they might exhibit wide differences in the degree to which perceptual–motor representations are activated as a function of seeing or hearing a word. In other words, the difference between high- and low-span comprehenders might stem from a related but more procedural source of expertise, in that the links *between* the lexical and perceptual–motor representations might be stronger in high-span comprehenders. In this case, the process of indirectly activating perceptual–motor representations through lexical representation may be reinforced through more frequent reading, and thus the efficiency of the entire comprehension process would be improved (MacDonald & Christiansen, 2002; Pearlmutter & MacDonald, 1995). It is unclear whether these strengthened links between lexical and perceptual–motor representations would allow for increased processing speed in activating representations (Dagerman et al., 2006) or greater precision in activating richer or perhaps larger networks of representations (MacDonald & Christiansen, 2002). Thus, the present study aims to provide a better understanding of the time course and relative levels of activation of the lexical and perceptual–motor representations for high- and low-span comprehenders.

Method

Participants. One hundred sixty undergraduate students enrolled at Florida State University participated in the experiment as part of a course requirement.³ All participants were native English speakers.

Materials. Twenty-eight experimental sentence pairs were adapted from Zwaan et al. (2002), each describing a target object in a location (see Appendix A for sample stimuli). The sentences were altered such that the target object was always the final word of the sentence—for example, *In the box/pot there was spaghetti*. The sentence pairs were constructed such that each target object was described in two locations that implied different object shapes (e.g., long, straight strands of uncooked spaghetti or raveled strands of cooked spaghetti). Two images, depicting the object in the two implied shapes, were also constructed to correspond to each experimental sentence pair. This yielded two sentences and two pictures for each target object. The pictures were line drawings, regular drawings, or photos, all of which were black and white and occupied a square of about 3 in. (7.62 cm) on the center of the screen. Each experimental sentence could be paired with a picture that matched or mismatched the implied shape of the target object, yielding four possible sentence–picture combinations. Participants were to see only one of these four possible combinations for each target object, and so four experimental lists were created and counterbalanced with respect to implied shape and match–mismatch condition of the 28 target objects. Between each of these four lists, the interstimulus interval (ISI) between the offset of the sentence and the presentation of the picture was varied. Pictures could appear immediately upon the offset of the final word of the sentence (0-ms ISI) or 750 ms after the offset of the final word of the sentence (750-ms ISI), now yielding eight lists. ISI was varied between lists rather than within list so that participants would not notice differences in picture onset delay from trial to trial. A given participant was exposed to only one of the eight lists.

³ A total of 184 students actually participated in Experiment 1 to yield 160 data sets that could be used in the analysis design: 10 high-span and 10 low-span comprehenders for each of the four stimulus lists at each of the two ISI presentations. Similarly, more than 160 students participated in Experiment 2 to yield the desired number of 10 high-span and 10 low-span participants per design cell.

In addition, 56 similar filler sentences and pictures were adapted from the earlier study. Each of the 112 sentences (56 filler sentences and 28 pairs of experimental sentences) was recorded to a Waveform audio format file by a female native speaker of American English, and the pictures were converted to black and white and scaled to occupy about 3 in.² (7.62 cm²) on the center of the screen. The picture was mentioned in the sentence on half of the trials (all 28 experimental trials and 14 of the filler trials). Participants were told to respond as to whether the pictured object had been mentioned in the preceding sentence, using keys labeled *Y* and *N*. On 24 of the filler trials, a question would appear after the picture-comparison response had been made. These questions required inferences about the sentences and were included to ensure that participants would make an effort to process the sentences at a relatively deep level. For instance, the sentence *There was a flower in the vase* was followed by the question *Was the vase empty?* Participants answered these questions using keys that were labeled with *Y* and *N* stickers. Because the participants did not know which sentences would be followed by a question, they had to comprehend each sentence to ensure a sufficient level of understanding. Both the experimental task and the Reading Span task described below were run on PCs with 19-in. flat-screen displays using the E-Prime stimulus presentation software (Schneider, Eschman, & Zuccolotto, 2002).

All participants completed a computer version of the Reading Span task (Conway, Cowan, Bunting, Theriault, & Minkoff, 2002). On a given trial of the Reading Span task, a participant would read aloud a sentence, answer aloud “yes” or “no” as to whether it made sense, and then read aloud the capitalized letter at the end of the sentence, remembering the letter for a later test. Participants would see two, three, four, or five of these trials in a set before having to write the final letters they could recall for that set on a formatted sheet. Participants completed 3 practice sets and 12 experimental sets. Although it is impossible to administer this test in such a way as to prohibit strategy use altogether (see McNamara & Scott, 2001), the experimenter sat with participants and controlled the progression from trial to trial to prevent participants from rehearsing the letters before they had to write them down at the end of the set. The test was scored by adding together the total number of correctly recalled letters over all sets. Participants were told to write the letters in the correct order, but letters were not counted as incorrect if they were recalled in the wrong spaces. This scoring practice was adopted because most misplaced letters ended up in the wrong space only because one early letter was omitted from recall for that set, and scoring the remainder of the letters as incorrect seemed to underestimate the true span size. On the basis of a median split of scores, participants were classified as high- or low-span comprehenders.

The Reading Span task assesses a participant’s ability to maintain linguistic information in working memory while simultaneously processing sentences. This is a crucial component of the language comprehension process, as readers and listeners constantly hold words or clauses in working memory while processing other words or clauses until both can be integrated. This measure has been used often in language comprehension experiments and correlates well with other measures of reading comprehension, such as verbal SAT (Daneman & Carpenter, 1980; Daneman & Merikle, 1996). The sentence-processing component of the Reading Span task directly taps into the efficiency of comprehension, which explains the correlation with other measures of reading comprehension. In addition, the Reading Span task indirectly measures comprehension, in that the time and resources remaining after comprehension are devoted to memory storage and maintenance. Efficient comprehenders activate representations quickly, have more time and resources available for memory storage and maintenance, and thus have higher span scores (for a discussion, see Friedman & Miyake, 2003).

Procedure. Participants were met one at a time in the laboratory and asked to sign a consent form. Then the participant was shown to another room to complete the Reading Span task. The experimenter sat next to the participant as he or she completed this task, advancing the participant from trial to trial so that rehearsal or other memory strategies would be avoided.

After completing the Reading Span task, participants began the picture-response experiment. On a given trial, participants pressed the spacebar to hear a sentence over headphones (e.g., “In the box, there was spaghetti”). The sentence was followed by a picture presentation either immediately after the offset of the final word (0 ms between sentence offset and picture presentation) or after a delay (750 ms between sentence offset and picture presentation). The participant’s task was to make a response as to whether the pictured object had been mentioned in the preceding sentence. If the pictured object had been mentioned in the sentence, the participant was to press the *J* key, which was covered by a *Y* sticker. All 28 of the experimental trials (both matching and mismatching pictures) and 14 of the filler trials required a yes response. If the pictured object had not been mentioned in the preceding sentence, as was the case for the 42 remaining filler trials, the participant was to press the *F* key, which was covered by an *N* sticker for “no.” Once the experiment was finished, participants were debriefed, assigned partial course credit for their participation, and dismissed.

Design. Experiment 1 incorporated a 2 (match vs. mismatch) \times 2 (ISI: 0 ms vs. 750 ms) \times 2 (Reading Span: high vs. low) mixed design, with match as a within-subject variable and ISI and reading span as between-subjects variables. On all 28 experimental trials, the presented image depicted the final word of the sentence (the target object) and thus required a yes response. However, on these experimental trials, the target object could be pictured in a shape that either matched or did not match the contextual constraints of the sentence. For example, if the participant heard “In the box there was spaghetti,” a matching picture would be spaghetti that was uncooked and a mismatching picture would be cooked spaghetti. The participant should respond yes in either case, because the pictured object was mentioned in the sentence, but we expected the responses to be faster for matching than for mismatching pictures.

To summarize, the current experiment was designed to detect differences in the time course of construing subtle shades of meaning for unambiguous words in high- and low-span comprehenders. We predicted that when the perceptual properties of the pictured object matched the contextual constraints of the preceding sentence, responses would be facilitated relative to when the picture mismatched the contextual constraints of the preceding sentence. Thus, responses should be faster for matching than for mismatching pictures. However, this would be the case only if an adequate perceptual representation had been activated at the time of the picture presentation. Depending on the time course of activating perceptual-motor representations relative to lexical representations and the demand on resources for the two types of representations, it would be more likely for a match advantage to be observed in the later ISI condition and in the high-span group.

Results and Discussion

The dependent measure of interest was the participant’s time to respond to the presented picture. Analyses using response accuracy were also conducted and are reported in Appendix B. Although list was included as a factor in all analyses for both experiments, effects for the list variable are not reported given the lack of theoretical relevance (Pollatsek & Well, 1995; Raaijmakers, Schrijnemakers, & Gremmen, 1999). All analyses were conducted both with variability due to subjects and with variability due to items in the error term. These analyses are indicated by the subscripts *1* and *2*, respectively, for both experiments. Incorrect responses were not included in the reported analyses, and any response time above or below two standard deviations from a participant’s mean for a given condition was removed prior to running the analyses. This constituted removal of about 5% of the data.

To ensure that the reported analyses reflected processes of true sentence comprehension, 10 participants who scored less than 75%

correct on the comprehension questions were excluded from the analyses. In all but 3 of these cases, extra participants had been run in the particular condition, and the low-accuracy data were replaced (high span: 0-ms $n = 40$, 750-ms $n = 40$; low span: 0-ms $n = 40$, 750-ms $n = 37$). In addition, one picture yielded particularly low accuracy in both experiments. This item was a rather amorphous fillet of fish, which, we realized in hindsight, must have been difficult for participants to recognize and was therefore excluded from the analyses in Experiments 1 and 2.

The means and standard deviations for the response times from Experiment 1 are displayed in Table 1. Participants were classified as high- or low-span comprehenders according to a median split of scores on the Reading Span task ($M = 31.6$, $SD = 4.2$; for high-span comprehenders, $M = 35.0$, $SD = 2.5$; for low-span comprehenders, $M = 28.2$, $SD = 2.5$). The overall mixed analysis of variance (ANOVA) with list as a between-subjects factor showed a clear effect of match, indicating that participants were faster to respond to the picture when it matched rather than mismatched the contextual constraints of the preceding sentence: $F_1(1, 141) = 28.82$, $p < .001$, $MSE = 8,868$; $F_2(1, 51) = 34.38$, $p < .001$, $MSE = 15,423$. This effect was qualified by a three-way interaction among match, ISI, and reading span, indicating that the effect of match varied for high- and low-span comprehenders at the two ISIs: $F_1(1, 141) = 4.04$, $p < .05$; $F_2(1, 51) = 4.79$, $p < .05$, $MSE = 6,462$.

To understand the nature of this three-way interaction, separate analyses were conducted for the 0-ms ISI and the 750-ms ISI. The overall effect of match was observed in both the 0-ms ISI analysis, $F_1(1, 72) = 11.95$, $p < .001$, $MSE = 9,482$; $F_2(1, 51) = 19.27$, $p < .001$, $MSE = 10,178$, and the 750-ms analysis, $F_1(1, 69) = 17.37$, $p < .001$, $MSE = 8,227$; $F_2(1, 51) = 2,317$, $p < .001$, $MSE = 16,145$. However, the 0-ms ISI analysis revealed an interaction between match and reading span, $F_1(1, 72) = 4.61$, $p < .05$; $F_2(1, 51) = 3.89$, $p = .05$, $MSE = 9,154$, whereas no such interaction was present in the 750-ms ISI analysis ($F_1 < 1.6$; $F_2 < 0.5$). This suggests that high-span comprehenders showed a larger difference between match and mismatch responses than low-span comprehenders only in the 0-ms ISI condition. Within-group comparisons for high- and low-span comprehenders at each ISI were conducted to confirm this observation. Indeed, at the 0-ms ISI the high-span comprehenders showed the predicted match effect, $F_1(1, 36) = 10.50$, $p < .01$, $MSE = 14,142$; $F_2(1, 51) = 18.56$, $p < .001$, $MSE = 10,745$, whereas low-span comprehenders did not show a significant difference between responses to the matching and mismatching pictures at the early ISI by subjects ($F_1 < 1.7$), although this comparison almost reached significance by items,

$F_2(1, 51) = 3.77$, $p = .06$, $MSE = 8,587$. At the 750-ms ISI both high- and low-span comprehenders showed the predicted match effect: high span, $F_1(1, 36) = 7.53$, $p < .01$, $MSE = 6,957$; $F_2(1, 51) = 15.91$, $p < .001$, $MSE = 8,717$; low span, $F_1(1, 33) = 9.64$, $p < .01$, $MSE = 9,612$; $F_2(1, 51) = 16.77$, $p < .001$, $MSE = 12,487$.

The pattern of results for Experiment 1 demonstrates that the high-span comprehenders were more quickly able to activate a perceptual representation of the target object in the appropriate context. The interactions and within-group comparisons show that the match effect at the immediate ISI was largely due to the high-span comprehenders, who showed a stronger effect of match than the low-span comprehenders. High-span comprehenders were faster to verify pictures when the preceding sentence context matched rather than mismatched the shape of the depicted object, whereas low-span comprehenders showed only a weak advantage for matching versus mismatching pictures, significant only in the contrast by items. At the 750-ms ISI, both high- and low-span comprehenders were faster to verify matching pictures than mismatching pictures. Thus, the current experiment showed that when context is sufficiently constraining, high-span comprehenders were able to use sentence context to quickly activate a perceptual representation of the appropriate context, whereas low-span comprehenders could do so only after the delay.

The observed pattern of responses supports the idea that construal of the contextually appropriate meaning of a sentence requires the activation of a perceptual representation. At the immediate ISI, the low-span comprehenders had not yet activated a perceptual representation of the sentence, evidenced by a lack of an effect for matching versus mismatching pictures. Thus, they had not construed the more subtle aspects of the sentence's meaning at the immediate ISI. However, by the time the picture was presented in the 750-ms ISI, they had had enough time to activate a contextually appropriate perceptual representation of the described situation. At this point, the low-span comprehenders had fully construed the sentence meaning, as they showed the predicted match effect just as the high-span comprehenders did. The relatively fast responses of the low-span comprehenders to both matching and mismatching pictures at the immediate ISI is considered in the General Discussion.

A potential criticism of the present experiment is that the forced-choice task taps into the comprehension processes relatively late. Thus, the perceptual representation at the time of response is susceptible to many postaccess influences (see Simpson, 1994). It is possible that the high-span comprehenders would also show a lack of match effect at the early interval if the task were to tap the process of perceptual representation at an earlier stage. Indeed, less skilled readers have shown impaired performance relative to skilled readers on tasks that require explicit comparison between the test item and the preceding context, yet these groups show similar performance on a naming task that does not require explicit comparison (Long, Seely, & Oppy, 1999). To address this issue, we conducted another experiment in which a naming task was used in place of the forced-choice task. The naming task is thought to assess the comprehension process in its early stages, decreasing its susceptibility to postaccess influences (Forster, 1981; Simpson, 1994) and minimizing response conflict (Long et al., 1999).

Table 1
Means (and Standard Deviations) for Response Times in
Experiment 1

ISI	High-span comprehenders		Low-span comprehenders	
	Match	Mismatch	Match	Mismatch
0 ms	791 (144)	875 (260)	782 (139)	802 (165)
750 ms	801 (192)	859 (196)	828 (226)	898 (295)

Note. ISI = interstimulus interval.

Experiment 2

Experiment 2 was identical to Experiment 1 except that instead of making a response as to whether the pictured object was mentioned in the sentence, participants were instructed to name the pictured object as quickly as possible. The naming task is a more direct measure, designed to tap into the comprehension process at lexical access, thus eliminating some of the cognitive processes that are required for the task used in Experiment 1. The decision task in Experiment 1 required recognition of the picture, lexical access of the name of the object, comparison of that name to the words in the sentence that preceded the picture, and an affirmative or negative response based on that comparison. In contrast, the naming task in Experiment 2 required only recognition of the pictured object, lexical access of the name of that object, and a vocal response, reporting the accessed name. It is important to note that any comparison of the pictured object to the preceding sentence is eliminated in the naming task of Experiment 2.

Method

Participants. One hundred sixty undergraduate students enrolled at Florida State University participated in the experiment as part of a course requirement. All participants were native English speakers, and none had participated in the previous experiment.

Materials and procedure. The materials and procedure for Experiment 2 were identical to those of Experiment 1, except that during the sentence-picture experiment, participants were told to simply name the pictured object as fast as possible, regardless of whether the picture was related to the sentence. A microphone attached to the headphone set relayed the voice input to a response box, where E-Prime software logged the latency of voice onset for each trial. An experimenter sat with the participant during the experiment to record any misnamed trials or trials in which the microphone did not record the response correctly. Given that it is possible for participants to perform this naming task without actually attending to the sentences, it was especially important that the same yes-no inference questions on 24 of the filler trials from Experiment 1 were again used in Experiment 2. Participants answered these questions using keys that were labeled with Y and N stickers. Because the participants did not know which sentences would be followed by a question, they had to comprehend each sentence to ensure a sufficient level of understanding.

Design. The design for Experiment 2 was identical to that for Experiment 1. It was a 2 (match vs. mismatch) × 2 (ISI: 0 ms vs. 750 ms) × 2 (Reading Span: high vs. low) mixed design, with match as a within-subject variable and ISI and reading span as between-subjects variables. Just as in Experiment 1, we predicted that when the perceptual properties of the pictured object matched the contextual constraints of the preceding sentence, responses would be facilitated relative to when the picture mismatched the contextual constraints of the preceding sentence. Thus, responses should be faster for matching than for mismatching pictures, but only if an adequate perceptual representation has been activated at the time of the picture presentation.

Results and Discussion

The dependent measure of interest in Experiment 2 was the participant's time to name the presented picture. Misnamed trials and trials in which the microphone did not record the response correctly were not included in the reported analyses. Because it was impossible to distinguish between misnamed trials and equipment error (microphone and response box), accuracy data were not analyzed for Experiment 2. Naming latencies over 3 s as well as

naming latencies over or under two standard deviations from a participant's mean for a given condition were removed prior to running the analyses. This constituted removal of less than 6% of the data. The data from 2 of the 160 participants were excluded for having too few usable trials (misnames or equipment error), and 2 new participants were run to replace them. The data from 5 of the 160 participants were excluded for responding too slowly (having at least one of their condition means above 1,000 ms), and 5 new participants were run to replace these data. Finally, as in Experiment 1, 7 participants who did not answer at least 75% of the comprehension questions correctly were replaced (high span: 0-ms $n = 40$, 750-ms $n = 40$; low span: 0-ms $n = 40$, 750-ms $n = 40$).

The means and standard deviations for the naming times from Experiment 2 are displayed in Table 2. Participants were classified as high- or low-span comprehenders on the basis of a median split of scores on the Reading Span task, which yielded values very similar to those observed in Experiment 1 ($M = 31.5$, $SD = 4.7$; for high-span comprehenders, $M = 35.3$, $SD = 2.6$; for low-span comprehenders, $M = 27.6$, $SD = 2.7$). As in Experiment 1, the overall mixed ANOVA with list as a between-subjects factor showed a clear effect of match, indicating that participants were faster to name the pictured object when it matched rather than mismatched the contextual constraints of the preceding sentence: $F_1(1, 144) = 10.19$, $p < .01$, $MSE = 2,338$; $F_2(1, 51) = 18.05$, $p < .001$, $MSE = 2,902$. The predicted three-way interaction among match, reading span, and ISI did not reach conventional levels of significance: $F_1(1, 144) = 3.50$, $p = .06$; $F_2(1, 51) = 2.52$, $p = .12$, $MSE = 1,832$. Nonetheless, separate analyses for the 0-ms ISI and the 750-ms ISI were conducted.

In the immediate ISI analysis, the main effect of match reached significance only in the analysis by items, suggesting that participants were already able to name the pictured objects more quickly when they matched rather than mismatched the contextual constraints of the preceding sentence: $F_1(1, 72) = 2.73$, $p = .10$, $MSE = 2,428$; $F_2(1, 51) = 7.77$, $p < .01$, $MSE = 2,560$. This main effect was qualified by a significant interaction between match and reading span, $F_1(1, 72) = 5.72$, $p < .05$; $F_2(1, 51) = 5.97$, $p < .05$, $MSE = 2,487$. This indicated that just as in Experiment 1 the marginal match effect at the immediate ISI was largely due to the high-span comprehenders. Contrast tests for high- and low-span comprehenders confirmed this notion, as the high-span comprehenders showed a significant match effect, $F_1(1, 36) = 6.57$, $p < .05$, $MSE = 3,039$; $F_2(1, 51) = 10.73$, $p < .01$, $MSE = 3,219$, whereas low-span comprehenders showed no difference in naming the matching and mismatching pictures at the immediate ISI (both $F_s < 1$).

Table 2
Means (and Standard Deviations) for Response Times in Experiment 2

ISI	High-span comprehenders		Low-span comprehenders	
	Match	Mismatch	Match	Mismatch
0 ms	655 (91)	687 (117)	681 (101)	674 (81)
750 ms	662 (110)	681 (120)	701 (98)	724 (117)

Note. ISI = interstimulus interval.

The 750-ms ISI analysis again yielded a main effect of match, indicating that overall, participants were faster to name the pictures when they matched rather than mismatched the contextual constraints of the preceding sentence: $F_1(1, 72) = 8.34, p < .01, MSE = 2,248$; $F_2(1, 51) = 12.97, p < .001, MSE = 2,574$. However, the 750-ms ISI analysis did not reveal an interaction between match and reading span (both $F_s < 1$), suggesting that both high- and low-span comprehenders were contributing to the match effect in this condition. The contrast tests for both high- and low-span comprehenders showed an effect of match: high span, $F_1(1, 36) = 5.23, p < .05, MSE = 1,543$; $F_2(1, 51) = 8.93, p < .01, MSE = 2,431$; low span, $F_1(1, 36) = 3.65, p = .06, MSE = 2,953$; $F_2(1, 51) = 4.52, p < .05, MSE = 2,730$.

The pattern of results for Experiment 2 was largely the same as the pattern observed for Experiment 1. The high-span comprehenders perceptually represented the target object in the appropriate context immediately upon hearing the sentence and therefore showed a significant match effect at both the immediate ISI and the 750-ms ISI. Low-span comprehenders, however, were equally fast to name both the contextually appropriate and inappropriate pictures at the immediate ISI. Only after 750 ms did they exhibit the predicted match effect.

Given the task differences between the two experiments, the effects in Experiment 2 were expected to be weaker. In Experiment 1 participants were forced to compare the response-eliciting picture with the preceding sentence, so it is more likely that participants' representations would affect the response to the picture. The task in Experiment 2 did not require the comprehenders to refer to the preceding sentence while responding to the picture. Speeded naming of the pictured object could have been executed without associating it in any way with the preceding sentence, whereas in Experiment 1, the pictured object needed to be compared with the preceding sentence before a response could be made. Even though the sentences had to be kept active in short-term memory in order to answer the comprehension questions that sometimes followed, the comprehender might have been able to perform the naming task independently of the sentence comprehension task. In fact, it might have been possible for comprehenders to activate a perceptual-motor representation of the sentence only after the fact, when a question was encountered. Thus, it is likely that the match effect was constrained by the somewhat shallow level of processing that the sentence received as participants settled into the task demands of Experiment 2. Given that the task deemphasized the sentence context and the naming task assessed the comprehension process at an earlier stage than in Experiment 1, Experiment 2 provided a stronger test of the hypothesis than Experiment 1.

In sum, although the task in Experiment 2 was not as explicitly tied to comprehension of the preceding sentence context as it was in Experiment 1, the results looked qualitatively similar in the two experiments. In both experiments, only the high-span comprehenders showed the match effect at the immediate ISI, whereas both high- and low-span comprehenders showed the match effect at the 750-ms ISI. The fact that the pattern of results was similar, even when a more shallow naming task was used, provided an important manipulation check with regard to the comparison-response task used in Experiment 1. The consistent pattern of results from Experiment 2 addressed the possible criticism that the nature of the comparison-response task used in Experiment 1 tapped into the

comprehension process at a late stage of comprehension and that thus the effects might have been caused merely by task demands.⁴

General Discussion

The current study was aimed at investigating how high- and low-span comprehenders activate perceptual representations as a mechanism for construing the contextually appropriate sense of a word. The two experiments presented here used sentence-picture tasks to assess the time course of perceptual representations in high- and low-span comprehenders. Experiment 1 used a comparison-response task that was modeled after lexical ambiguity studies using homographs. However, in this experiment, rather than encountering a homograph in a biasing sentence context, participants had to disambiguate the shape of a described object during comprehension on the basis of the preceding sentence context. This experiment yielded a three-way interaction among contextual match, ISI, and reading span, whereby only the high-span comprehenders showed the predicted match effect at the immediate ISI, but all comprehenders showed the match effect at the later ISI. Experiment 2 provides an extension of these findings, in that a more direct measure, naming time, was used. This experiment qualitatively replicated the pattern of results reported in Experiment 1, despite decreased reference to the preceding sentence while performing the task.

The present pattern of results is consistent with previous studies of lexical ambiguity from the field of psycholinguistics. In both of the current experiments, the pattern of results for low-span comprehenders parallels studies that have used homographs to show that the time course of contextual constraint is often delayed, such that multiple meanings are initially activated, followed by the deactivation of the inappropriate meanings (Conrad, 1974; Lucas, 1987; Onifer & Swinney, 1981; Swinney, 1979). In contrast, the pattern of results for the high-span comprehenders is consistent with studies that show immediate contextual constraint on representations (Chambers, Tanenhaus, Eberhard, Filip, & Carlson, 2002; Chambers et al., 2004; Dahan & Tanenhaus, 2004; Glucksberg et al., 1986; Hess, Foss, & Carroll, 1995; MacDonald, 1994; Schvaneveldt et al., 1976; Simpson, 1981). Also, the interaction between reading span and processing time (ISI) is consistent with homograph studies showing that more skilled/experienced/younger/high-span comprehenders are better able to use sentence context to quickly constrain their representations than less skilled/experienced/older/low-span comprehenders (Dagerman et al., 2006; Gernsbacher & Faust, 1991; Gernsbacher et al., 1990; McNamara & McDaniel, 2004; Van Petten et al., 1997).

However, this study also represents a departure from previous research. The perceptual match effects in the current experiments

⁴ It might be argued that the very presence of a picture in the task changes the comprehension process from what it might have been, given the sentence alone. Thus, perhaps perceptual representations are activated here only because the picture cue was presented. Although this explanation cannot be ruled out given the current data set, we find it unlikely that the perceptual representations evident in Experiment 2 are cue dependent, given that the picture-naming task does not require reference to the preceding sentence. Furthermore, there is evidence from our lab that perceptual representations are activated during language processing in the absence of pictures (see Zwaan & Yaxley, 2003, 2004).

demonstrate that comprehenders are in fact perceptually representing linguistic input in order to construe subtle shades of meaning, even for so-called single-meaning words. To adequately represent a linguistic description, each described entity needs to be disambiguated in terms of aspects such as temporal specification, perceptual properties, spatial region, perspective, highlighted features, and relation to other entities. These experiments suggest that the construal or disambiguation of these aspects can be realized through the activation of perceptual-motor representations. This entails the partial reactivation of traces of our previous experiences (see also Zwaan & Madden, 2005). This process of activation occurs in similar fashion to the memory model proposed by Hintzman (1986, 1988), in which activation continuously and automatically flows to any memory traces that are sufficiently similar to the retrieval environment. Furthermore, this model also assumes that when context matching occurs between the memory traces and the currently attended situation, memory retrieval is facilitated (Hintzman, 2002; Hintzman, Block, & Summers, 1973). It would be too cumbersome for comprehenders to store all possible construals of all known words in the mental lexicon, so the activation of more distributed perceptual-motor representations based on context is required as a mechanism to construe subtle shades of word meaning. Other studies from our lab and other labs support this idea and suggest that these perceptual-motor representations are embodied and distributed throughout the various perceptual and motor modalities (Chao & Martin, 2000; Glenberg & Kaschak, 2002; Kan et al., 2003; Kaschak et al., 2005; Klatzky et al., 1989; Pecher et al., 2003; Richardson et al., 2003; Solomon & Barsalou, 2001; Stanfield & Zwaan, 2001; Zwaan et al., 2002, 2004).

The observed match effect at the immediate ISI for the high-span comprehenders demonstrates that they activate a perceptual representation of the described object immediately upon hearing that word in a sentence, and thus the respective word can be construed. In contrast, the low-span comprehenders do not activate a perceptual representation of the described situation immediately upon hearing that word, as there was no difference in responses to pictures that match rather than mismatch the contextual constraints of the sentence at the 0-ms ISI. However, at the 750-ms ISI, the low-span comprehenders had activated a perceptual representation of the described situation. Although the perceptual representation takes longer for low-span comprehenders to activate, once it is activated, it does not appear to be inferior to that of the high-span comprehenders, as the match effect was equally large for the low-span comprehenders at the 750-ms ISI as it was for the high-span comprehenders at either ISI.

One intriguing aspect of the pattern of data concerns the low-span comprehenders' responses at the immediate picture probe. They did not show the match effect at the 0-ms ISI, demonstrating that they had not yet activated an adequate perceptual representation of the described situation. However, the mere fact that they were able to perform the task indicates that they must have had some representation available with which they could compare the probe picture. The underspecified representation of the low-span comprehenders is consistent with findings from studies of polysemy (Frazier & Rayner, 1990; Frisson & Pickering, 1999; Pickering & Frisson, 2001), suggesting that words with multiple senses initially activate an underspecified representation. The current data suggest that this representation is lexical in nature and is not

contextually specified. Otherwise, a difference between the matching and mismatching pictures would be observed at the immediate ISI for this group. These results support the idea discussed in the introduction that two separate types of representation are active and can potentially affect the response—namely, the perceptual-motor representation as well as a noncontextual lexical representation of the target word. The contribution of these two types of representations over time is outlined below.

Lexical representations are obligatorily activated when a given word is read or heard. In the current experiments, the lexical representation for the target concept is very quickly activated by automatic priming from the sound of the target word during sentence presentation. In addition, the lexical representation receives backward priming from the picture probe. As soon as the picture is perceived, the lexical representation associated with that concept is activated automatically. This lexical representation is noncontextual and is activated regardless of the shape of the target object in the picture probe. Thus, the lexical representation is highly activated both from mention in the preceding sentence and through backward activation from the picture probe.

As the lexical representation receives automatic activation from the sound of the word as well as backward activation from the picture probe, it sends activation to the associated perceptual representations. Depending on the speed of the perceptual representation, either the lexical representation or the perceptual representation will have a greater effect on the response. Because the perceptual representation is a higher level representation, it will dominate the response if it is completed in time. If the perceptual representation is not yet fully activated at the time the picture probe is recognized, then the response will be made on the basis of the lexical representation. Although perceptual representations are automatic, they can be delayed or forgone when insufficient contextual information is present (see Frazier & Rayner, 1990) or insufficient time or resources are present. In these experiments, if new information had been presented to the low-span comprehenders before they had a chance to activate a perceptual representation of the preceding sentence, perceptual representations might have been forgone completely.

So what is it that causes problems for low-span comprehenders in activating perceptual-motor representations? As discussed in the introduction, there are several possible sources for the span difference. Because the disambiguation required here is between very subtle perceptual features of a given sense of a concept rather than mutually exclusive meanings or even related senses, it is unlikely that active suppression would be the cause. Likewise, it is unlikely that domain expertise can offer a plausible explanation within the context of the current study, as the variety of everyday concepts used here does not represent an area of expertise for any given subject. However, it is highly plausible that the process of indirectly activating perceptual-motor representations through lexical representations is reinforced through more frequent reading and thus that the links between the lexical and perceptual-motor representations become stronger in more experienced comprehenders. In the current experiments, whereas low-span comprehenders had no problems activating lexical representations, they demonstrated a clear disadvantage in their ability to use these lexical representations to activate perceptual representations.

Strengthened links between lexical and perceptual-motor representations might affect the comprehension process in two ways.

First, the stronger links might allow for greater precision in activating richer or perhaps larger networks of representations (MacDonald & Christiansen, 2002). However, this is not likely the case, because a richer or larger network of perceptual representations would most likely increase the size of the mismatch effect, whereas the observed effect was equally large for the low-span comprehenders at the 750-ms ISI and the high-span comprehenders at either ISI. A more likely explanation is that the stronger links between lexical and perceptual–motor representations increased processing speed in activating representations (Dagerman et al., 2006). According to this idea, activation flows more readily from the lexical representations for *spaghetti* and *box* to their associated perceptual–motor representations in high-span than in low-span comprehenders.

It is also likely that the strengthened links between lexical and perceptual–motor representations facilitate the flow of activation among activated perceptual–motor representations. For instance, hearing the word *box* will automatically activate the lexical representation for *box*, which will automatically activate various perceptual–motor representations that are linked to that lexical representation. Likewise, hearing the word *spaghetti* will automatically activate its lexical representation as well as various perceptual–motor representations. Within an interconnected network, the perceptual–motor representations for uncooked spaghetti and the perceptual–motor representations for long, skinny pasta boxes will support each other, whereas the perceptual–motor representations for cooked spaghetti and moving boxes will receive only the initial activation from the lexical representations and then quickly lose support. Thus, the context and the target actually serve to constrain each other in a bidirectional manner (Dagerman et al., 2006). Because low-span comprehenders have weaker links between lexical and perceptual–motor representations, this process of constraining activation flow takes longer. An alternative to this idea is suggested by McKoon and Ratcliff's (1992; Ratcliff & McKoon, 1995) compound-cue retrieval theory, in which long-term memory is searched using a compound of the items in short-term memory. In this case, the lexical representations for *box* and *spaghetti* would form a compound cue that sends activation to perceptual–motor representations that are most related. It is unclear exactly how activation flows to the appropriate perceptual–motor representations, but it is evident that the activation arrives at the perceptual–motor representations more quickly in high-span than in low-span comprehenders.

The activation of perceptual–motor representations as a mechanism for meaning construal is consistent with nonmodular parallel interactive models (Glucksberg et al., 1986; Schvaneveldt et al., 1976; Simpson, 1981), because lexical access (activation of the lexical representation) and contextual integration (activation of perceptual–motor representations) occur at the same time, and these two phases can affect each other as they are in progress. In addition, as lexical representations and perceptual–motor representations are activated together, meaning construal can be constrained by many types of information, such as syntactic and thematic roles, word frequency, and situational context, all of which stem from our embodied experiences with words and their referents. This idea of representing multiple types of information in our meaning representations is inconsistent with traditional models of the mental lexicon but is similar to the more recent

constraint-based approach to comprehension (MacDonald, Pearlmutter, & Seidenberg, 1994; Seidenberg & MacDonald, 1999).

According to the constraint-based approach (MacDonald et al., 1994; Seidenberg & MacDonald, 1999), the lexicon contains distributional information on many dimensions, such as syntax, grammar, argument structure, and semantic context. Some of this probabilistic information, such as the relative frequencies of words, may be stored at the level of lexical representations, whereas other more contextual information is stored at the level of perceptual–motor representations. Furthermore, some information may be stored at the intersection of the two types of representations. For instance, the verb *arrested* might occur more often as a reduced relative than as a main verb in most contexts. However, if the word *officer* precedes the word *arrested*, then the distributional information about semantic roles (e.g., officers being agents of the main verb *arrest*) will instead favor the main verb interpretation. In this sense, many dimensions of distributional information are taken into account during meaning selection, and comprehenders with stronger links between lexical and perceptual–motor representations are better able to make use of this information quickly (Dagerman et al., 2006; Pearlmutter & MacDonald, 1995). It is possible that meaning can be successfully selected without the activation of perceptual–motor representations when the probability of a given meaning is highly favored by purely lexical factors such as word frequency. However, this will result in superficial comprehension, whereas construal of subtle shades of meaning and deep, contextual comprehension are contingent on the activation of perceptual–motor representations.

The current pattern of data suggests that the high-span comprehenders use a faster mechanism of meaning construal. Immediately upon hearing the final word of the sentence, the high-span comprehenders are able to activate a perceptual representation of the described situation. The picture probe is compared with this representation, and the match effect emerges when the mismatching picture takes longer to align with the representation. In contrast, the low-span comprehenders are slower to use the mechanism of meaning construal. At the immediate ISI, this group has not finished activating the perceptual representation, and therefore, the lexical representation determines the response. The lexical representation is noncontextual, and so responses to both matching and mismatching pictures are facilitated, as they both match the activated lexical representation. At the later ISI, the perceptual–motor representation dominates the response for both high- and low-span comprehenders. Here, only the response to the matching picture is facilitated. If the picture were compared with a noncontextual lexical representation, then the mismatching response would be facilitated to the same extent that the matching response was. However, the response to the mismatching picture is slowed for both span groups, indicating that each group has activated a perceptual representation and that the picture was compared with this rather than the lexical representation.⁵

⁵ Low-span comprehenders did exhibit a slight delay in responding as compared with high-span comprehenders, which could be attributed to difficulty in comparing the pictured object with a poor-quality perceptual representation. However, this delay would likely have been accompanied by a weakening of the match effect if the quality of the perceptual representation had been impaired.

Conclusion

The current study investigated how high- and low-span comprehenders use perceptual-motor representations as a mechanism by which the contextually appropriate meaning of a given word can be construed during language processing. The results indicate that speed of perceptual-motor representation differentiates high-span comprehenders from low-span comprehenders. The low-span comprehenders in this study were university students and thus are certainly not the poorest sample of comprehenders that could be tested. These low-span comprehenders were able to activate a perceptual representation comparable to that of high-span comprehenders well within a second of hearing the sentence's final word, and perhaps would have been able to activate a perceptual representation even more quickly if the manipulation of context had been stronger (here it was merely the implied location in a simple sentence). However, the slowdown in construal reported here may be expected to increase with samples of even lower span comprehenders. In the current sample, it is easy to see how comprehension problems could occur for the low-span group when linguistic information is presented at a rapid rate. It is important to increase the external validity of this finding to even lower span comprehenders in order to understand at what point comprehension suffers even at slow presentation rates and how the process of activating perceptual-motor representations can be facilitated.

The experiments reported here suggest that two systems of representation are at work to construe subtle shades of meaning upon hearing a sentence—namely, lexical representations and perceptual-motor representations. Furthermore, the extent to which each type of representation influences subsequent thoughts and actions varies for different span groups over time. The most likely source of this difference is the strength of the links between the two types of representations. This finding informs theories of language comprehension and highlights important questions for future research. The next challenge is to further investigate the nature of the relationship between lexical representations and perceptual-motor representations in order to better understand the process of meaning construal.

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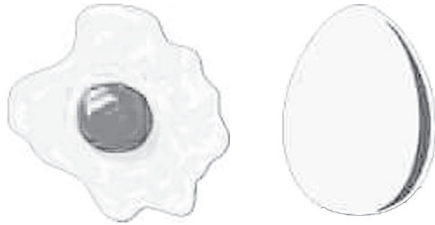
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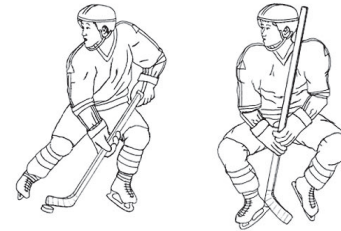
Appendix A

Samples of Sentence–Picture Pairs

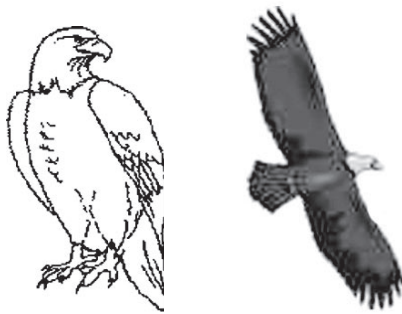
In the [skillet/refrigerator] there was an egg.



On the [ice/bench] there was a hockey player.



In the [nest/sky] there was an eagle.



On the [floor/rack] there was a towel.



Appendix B

Accuracy Data for Experiment 1

The accuracy data for Experiment 1 are displayed in Table B1. The overall mixed analysis of variance with list as a between-subjects factor showed an effect of match whereby responses were

more accurate for matching than for mismatching pictures: $F_1(1, 141) = 22.59, p < .001, MSE = 1.781^{E-03}$; $F_2(1, 51) = 13.96, p < .001, MSE = 4.274^{E-03}$. In addition, there was an interaction between match and interstimulus interval (ISI), indicating that the match effect was stronger at the earlier ISI: $F_1(1, 144) = 4.80, p < .05$; $F_2(1, 51) = 4.98, p < .05, MSE = 2.641^{E-03}$. There was an effect of match (but no interactions) at both the 0-ms ISI: $F_1(1, 72) = 18.15, p < .001, MSE = 2.413^{E-03}$; $F_2(1, 51) = 16.68, p < .001, MSE = 3.862^{E-03}$; and the 750-ms ISI: $F_1(1, 69) = 5.12, p < .05, MSE = 1.120^{E-03}$; $F_2(1, 51) = 2.75, p = .10, MSE = 3.053^{E-03}$.

Table B1
Mean Percentages (and Standard Deviations) for Accuracy Data in Experiment 1

ISI	High-span comprehenders		Low-span comprehenders	
	Match	Mismatch	Match	Mismatch
0 ms	99 (03)	95 (08)	99 (03)	96 (05)
750 ms	98 (03)	97 (05)	98 (03)	97 (05)

Note. ISI = interstimulus interval.

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