Embodied semantic processing: The body-object interaction effect in a non-manual task

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Abstract

Body-object interaction (BOI) measures people's perceptions of the ease with which a human body can physically interact with a word's referent. Facilitatory BOI effects, involving faster responses for high BOI words, have been reported in a number of visual word recognition tasks using button press responses. Since BOI effects have only been observed in button-press tasks, it is possible that the effects may be due to priming by high BOI words of the motor system, rather than activation of stored motor information in the lexical semantic system. If this hypothesis is correct, BOI effects should not be observed in tasks using verbal responses. We tested this hypothesis in three versions of a go/no-go semantic categorization task: one version required button press responses, whereas the other two versions required verbal responses. Contrary to the motor priming hypothesis, we observed facilitatory BOI effects in all three versions of the semantic categorization task. These results support the inference that stored motor information is indeed an important component of the lexical semantic system.

Keywords
embodied cognition, sensorimotor knowledge, semantic processing, visual word recognition

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1. Introduction

There is increasing interest in the effects of sensorimotor knowledge on visual word recognition. From an embodied cognition perspective, imageability effects (i.e. faster and more accurate responding to words that are more imageable than to words that are less imageable; e.g. Cortese and Fugett 2004; Cortese et al. 1997; Strain et al. 1995) can be understood in the following manner. Some concepts (e.g. clouds, peaches) afford more sensory experience than other concepts (e.g. bribes, loans). Increased sensory experience leads to more detailed knowledge in the brain's primary sensory areas, such as primary visual cortex. This more detailed knowledge then allows for easier imaging of concepts like clouds and peaches than for concepts like bribes and loans. If linguistic conceptual knowledge is partly constituted by knowledge simulated in these sensory cortical areas, as proposed, for example, by Barsalou and colleagues (Barsalou 1999, 2003a, 2003b; Barsalou et al. 2003; Simmons and Barsalou 2003), then words that refer to concepts that can be imaged develop richer semantic representations that enable them to be recognized faster in visual word recognition tasks.

To further explore embodied effects, several studies have recently examined the influence of motor experience on lexical conceptual processing. In one study, Myung et al. (2006) examined priming effects of manipulation features using an auditory lexical decision task. They reported a significant priming effect such that target words preceded by a prime word that shared manipulation features (e.g. *key-screwdriver*) were responded to faster than target words preceded by a prime word that did not share manipulation features (e.g. *piano-screwdriver*).

Similarly, in a series of studies, we have examined the effects of a variable we call body-object interaction (BOI) on visual word recognition. The BOI variable measures people's perceptions of the ease with which a human body can physically interact with a word's referent. We have reported facilitatory effects of BOI (i.e. faster and more accurate responding to words rated high in BOI, such as *mask*, than to words rated low in BOI, such as *mist*) in lexical decision and phonological lexical decision tasks (Siakaluk, Pexman, Aguilera et al. 2008; Tillotson et al. 2008), and also in semantic categorization tasks (Siakaluk, Pexman, Sears et al. 2008). Importantly, in all these studies, the effects of imageability were either experimentally or statistically controlled (along with effects of other lexical and semantic variables) so that any facilitatory effects were attributed to BOI.

We have employed the following framework of visual word recognition (see Hino and Lupker 1996; and Hino et al. 2002) to account for the facilitatory effects of BOI. One assumption of this framework is that high BOI words have richer semantic representations than low BOI words. A second assumption is that there are two mechanisms by which BOI may exert an effect. The first mechanism, which we will call *semantic feedback activation*, is assumed to be involved in tasks in which responses are based primarily on the activation of either orthographic representations or phonological representations. According to this framework, high BOI words, because they have richer semantic representations, elicit greater feedback activation from semantics to orthography and to phonology, which facilitates responding in lexical decision and phonological lexical decision tasks, respectively (as observed in Siakaluk, Pexman, Aguilera et al. 2008).

The second mechanism, which we will call *semantic settling*, is assumed to be influential in tasks in which responses are based on the activation of semantic representations, and is therefore of central interest to the present study. According to this framework, high BOI words elicit richer semantic representations, and as such they are responded to faster in semantic categorization tasks (as observed in Siakaluk, Pexman, Sears et al. 2008). The facilitatory effect of BOI on semantic settling is consistent with connectionist models of visual word recognition. In Plaut and Shallice's (1993) connectionist model, for example, words with richer semantic representations activate more semantic units and thus build stronger attractors in semantic space. Words associated with stronger attractors (e.g. high BOI words) settle more quickly into a stable pattern of activation, facilitating responding in tasks involving responses based on the activation of semantic representations.

To date, we have argued that facilitatory BOI effects could be explained with the assumption that high BOI words elicit richer semantic representations than low BOI words, and that these richer semantic representations play pivotal roles in facilitating responding in visual word recognition tasks. In sum, we have argued that motor information (as captured by the BOI variable) is an integral component of lexical semantics.

One potential problem with the above account is the fact that responding in all the tasks used to date to examine the effects of BOI involved button presses. As such, instead of being due to theoretically important mechanisms in the lexical processing system (e.g. semantic feedback activation, semantic settling), facilitatory BOI effects may be due to a theoretically much less interesting possibility: It may be the case that activated motor information for high BOI words simply "primes the associated actions in motor cortex, and it is possible that these associated actions are primarily manual in nature" (Siakaluk, Pexman, Sears et al. 2008: 601). The effect could also arise in the opposite direction, with button pressing priming the motor information associated with high BOI words, at least after the first few trials of the task. In either case, the result could be faster button presses for high BOI words than for low BOI words. Stated another way, it is possible that facilitatory BOI effects are due to extra-lexical causes and not to the activation of motor knowledge in the lexical semantic system.

To test for the possibility that facilitatory BOI effects may be due to general manual motor priming, in Experiment 1 we designed a go/no-go semantic categorization task in which we manipulated response modality. This manipulation allowed us to determine whether BOI effects are limited to conditions in which manual responses are made. In one experimental condition, which we will call the button press 'yes' condition, participants responded by the usual means of pressing a button. In the other experimental condition, which we will call the pronunciation condition, participants responded by pronouncing aloud the stimuli. Importantly, the other experimental characteristics of both response modality conditions were held constant. First, the same decision category was used (does the word refer to something imageable?). We used this decision category in the present study because we have observed facilitatory BOI effects with this category in previous research (Siakaluk, Pexman, Sears et al. 2008), and wanted to provide the best opportunity to determine if facilitatory BOI effects could be observed in a semantic categorization task using verbal responses. Second, the same sets of high BOI words, low BOI words, and less imageable filler words were used (both the high and low BOI words were imageable). Third, the same set of go/no-go instructions were used. That is, participants were instructed to (a) respond (i.e. make either a button press or a pronunciation) only to the imageable words, and (b) *not* respond (i.e. do not make either a button press or a pronunciation) to the less imageable filler words.

We acknowledge that verbalizations are motor responses. However, it seems plausible to assume that the motor programs involved in verbalizations are not strongly related to the motor programs involved when people physically interact with objects. We were especially careful not to include stimuli in our high BOI and low BOI sets for which people use their vocal apparatus to interact with the object (e.g. flute, phone).

This experimental design allowed us to test three alternative predictions. First, if facilitatory BOI effects are due primarily to general manual motor priming, then there should be an interaction between response modality and BOI, such that facilitatory BOI effects should be observed only in the button press 'yes' condition. Second, if facilitatory BOI effects are due primarily to the activation of motor knowledge in the lexical semantic system, then there should be no interaction between response modality and BOI, such that comparable facilitatory BOI effects should be observed in each response modality condition. Third, if facilitatory BOI effects are due to a combination of general manual motor priming and the activation of motor knowledge in the lexical semantic system, then a response modality by BOI interaction may be observed. In this case, however, facilitatory effects of BOI should be observed in each response modality condition, but such effects would be larger in the button press 'yes' condition.

2. Experiment 1

2.1. *Participants*

Two groups of 25 undergraduate students from the University of Northern British Columbia participated in the experiment for bonus course credit: One group participated in the button press 'yes' condition and the other group participated in the pronunciation condition. All were native English speakers and reported normal or corrected-to-normal vision.

2.2. *Stimuli*

Based on previous BOI ratings (Siakaluk, Pexman, Aguilera et al. 2008) 32 words were selected for use in the experiment: 16 of the words were rated as being high in BOI (e.g. *bench*) and the other 16 words were rated as being low in BOI (e.g. *booth*). All the words had only one entry in the *ITP Nelson Canadian Dictionary* (1997) and all had noun definitions listed first. These two word groups were matched for initial phoneme, word length, Celex print frequency (Baayen et al. 1995), subjective familiarity (Balota et al. 2001), number of orthographic neighbours and number of phonological neighbours (Davis 2005), feedforward and feedback inconsistency (Ziegler et al. 1997), semantic distance (Buchanan et al. 2001), number of associates (Nelson et al. 1998), number of senses (ITP Nelson 1997), and importantly, imageability (Cortese and Fugett 2004) (all ps > .20). The high BOI and low BOI stimuli are listed in the Appendix, and their descriptive statistics are presented in Table 1. There were an additional 10 word fillers that were imageable (the data for these stimuli were not analyzed) and 42 word foils that were less imageable (selected from Siakaluk, Pexman, Sears et al. 2008), for a total of 84 trials.

2.3. *Apparatus and procedure*

The stimuli were presented simultaneously on two colour VGA monitors (one for the participants and one for the experimenter) driven by a Pentium-class microcomputer running E-prime software (Schneider et al. 2002). A trial was initiated by a fixation marker that appeared at the center of the computer display until the participant pressed a button on a response box, at which time the fixation marker was replaced by a word. The participants' task was to decide whether each word referred to something that was imageable. Participants were instructed to respond only to the words that were imageable ("go" response), and to make their responses as quickly and as accurately as possible. They were further instructed not to make any response to the words that were less imageable ("no-go" response). In the button press 'yes' condition participants responded by pressing a button on a response box, whereas in the pronunciation condition participants responded by pronouncing the word into a

Table 1. *Mean characteristics for word stimuli*

Word type	BOI	Length	Freq	SubF	N	PN	FFI	FBI	SemD	NumA	NumS	Image
High BOI	5.0	4.4	15.8	3.4	7.6	18.1	1.3	2.5	313.0	15.6	5.3	6.2
Low BOI	3.2	4.5	15.9	3.3	5.5	15.3	1.5	2.6	317.9	14.9	4.2	6.1

Note. BOI = body-object interaction; Freq = printed CELEX frequency; SubF = subjective familiarity; N = orthographic neighbourhood size; PN = phonological neighbourhood size; FFI = feedforward inconsistency; FBI = feedback inconsistency; SemD = semantic distance; NumA = number of associates; NumS = number of senses; Image = imageability.

microphone. In both response modality conditions, items not responded to remained in the display for 2,500 msec and were then replaced by a fixation marker. Response latencies were measured to the nearest millisecond. The order in which the stimuli were presented was randomized separately for each participant.

Each participant first completed 10 practice trials, consisting of 5 words that were imageable and 5 words that were less imageable. All practice stimuli were similar in normative frequency to the experimental stimuli.

2.4. *Results and discussion*

Response latencies faster than 250 msec or slower than 2,000 msec were treated as outliers and removed from the data set. In addition, for each participant, response latencies greater than 2.5 *SD*s from the cell mean of each condition were treated as outliers and removed from the data set. A total of 4.13% of the data and 2.88% of the data were removed by this procedure from the button press 'yes' condition and the pronunciation condition, respectively. In order to make the accuracy analyses comparable between the two response modality conditions, for the pronunciation condition trials on which participants stuttered, failed to trigger the voice key, or made a mispronunciation were also removed from the data set (an additional 4.88% of the data). Thus, the only critical stimuli trials considered errors were those when a "no-go" response (i.e. no response) was made when a "go" response (i.e. either a button press or a pronunciation) should have been made. Mean response latencies of correct responses and mean accuracy are shown in Table 2. Unless noted, all effects are statistically significant at $p < .05$.

Response latencies and accuracy were submitted to a 2 (BOI: high, low) × 2 (Response Modality: button press 'yes', pronunciation) mixed-model analysis of variance (ANOVA). In the subject analysis (F_1), BOI was a within-subjects variable and response modality was a between-subjects variable; in the item analysis (F_2), response modality was a within-items variable and BOI was a between-items variable.

In the analysis of the response latency data, there was a main effect of BOI, $F_1(1, 48) = 22.11$, $MSE = 3{,}203.18$, $\eta^2 = .32$; $F_2(1, 30) = 7.89$, $MSE = 5{,}650.59$, $\eta^2 = .21$, such that responses to the high BOI words were an average of 53 ms faster than responses to the low BOI words. There was a main effect of response modality that was significant only in the item analysis, $F_1 < 1$; $F_2(1, 30) = 16.73$, $MSE = 1{,}810.19$, $\eta^2 = .36$, such that responses in the pronunciation condition were an average of 37 ms faster than responses in the button press 'yes' condition. Interestingly, there was no interaction between BOI and response modality, $F_1 < 1$; $F_2 < 1$. In the analysis of the accuracy data, there was no main effect of BOI, $F_1(1, 48) = 2.07$, $MSE = 0.002$, $p = .16$; $F_2(1, 30) = 1.83$, $MSE =$

Table 2. *Mean response latencies (in milliseconds) and standard errors, and mean response accuracy and standard errors*

Word type	Response latencies					
	Exp 1: BP 'Yes'		Exp 1: Pronunciation		Exp 2: Verbal 'Yes'	
	M	*SE*	*M*	*SE*	*M*	*SE*
High BOI	752	23.8	722	26.7	865	22.2
Low BOI	813	30.4	768	31.6	903	24.3
BOI effect	61		46		38	
Less imageable words	N/A		N/A		N/A	
Word type	**Accuracy**					
	Exp 1: BP 'Yes'		Exp 1: Pronunciation		Exp 2: Verbal 'Yes'	
	M	*SE*	*M*	*SE*	*M*	*SE*
High BOI	.99	.01	.99	.00	.95	.02
Low BOI	.98	.01	.97	.01	.96	.01
BOI effect	.01		.02		−.01	
Less imageable words	.83	.01	.89	.01	.84	.01

Note: Exp 1: BP = Experiment 1 button press condition; Exp 1: Pronunciation = Experiment 1 pronunciation condition; Exp 2: Verbal 'Yes' = Experiment 2 verbal 'yes' condition; BOI = body-object interaction.

0.001, $p = .19$, no main effect of response modality, $F_1 < 1$; $F_2 < 1$, and, again, no interaction between BOI and response modality, $F_1 < 1$; $F_2 < 1$.

We also conducted planned comparisons to examine the effects of BOI in each response modality condition separately. For the button press 'yes' condition, there was an effect of BOI in the analysis of the response latency data, $t_1(24) = 3.35$, $SE = 18.02$, $\eta^2 = .32$; $t_2(30) = 2.72$, $SE = 23.17$, $\eta^2 = .20$, but not in the analysis of the accuracy data, $t_1 < 1$; $t_2 < 1$. For the pronunciation condition, there was an effect of BOI in the analysis of the response latency data, $t_1(24) = 3.36$, $SE = 13.70$, $\eta^2 = .32$; $t_2(30) = 2.14$, $SE = 19.89$, $\eta^2 = .15$, but not in the analysis of the accuracy data, $t_1(24) = 1.45$, $SE = 0.01$, $p = .16$; $t_2(30) = 1.89$, $SE = 0.01$, $p = .07$.

The response latency results from Experiment 1 are clear. There were comparable significant facilitatory BOI effects on the time it took to make semantic categorization decisions in each response modality condition. This finding strongly supports the second prediction we provided above: namely, that facilitatory BOI effects are due primarily to the activation of motor knowledge in the lexical semantic system.

There is, however, a potentially important confound in Experiment 1.[1] Although the decisional component was the same in both response modality conditions (i.e. to decide if the words were imageable or not), the nature of the required response differed. More specifically, for the button press 'yes' condition, responding to the imageable items was always the same; that is, participants simply made a button press. For the pronunciation condition, on the other hand, responding was not consistent in that a unique pronunciation was required for each word. One could therefore argue that responding in the pronunciation condition included different processing demands and that the comparison to the button press 'yes' condition is not ideal.

To address the above criticism to Experiment 1, we conducted a second semantic categorization task using the verbal response modality, which we will call the verbal 'yes' condition (Experiment 2). The verbal 'yes' condition was identical to the pronunciation condition of Experiment 1 (i.e. same stimuli, same imageable decision category, same go/no-go instructions) except for the following: instead of pronouncing the imageable words, participants were instructed to simply say "yes" to these stimuli (they were again instructed not to respond to the less imageable filler words). As such, the verbal 'yes' condition affords a better comparison to the button press 'yes' condition.

3. Experiment 2

3.1. *Participants*

Twenty-five undergraduate students from the University of Calgary participated in the experiment for bonus course credit. All were native English speakers and reported normal or corrected-to-normal vision.

3.2. *Stimuli*

The stimuli were those used in Experiment 1.

3.3. *Apparatus and procedure*

The procedure was the same as that described for Experiment 1 (pronunciation condition), except that here the participants were instructed to say "yes" aloud if the word was imageable.

3.4. *Results and discussion*

Response latencies faster than 250 msec or slower than 2,000 msec were treated as outliers and removed from the data set. In addition, for each participant,

1. We thank Ben Bergen and Diane Pecher for bringing this to our attention and for suggesting Experiment 2.

response latencies greater than 2.5 *SD*s from the cell mean of each condition were treated as outliers and removed from the data set. A total of 4.50% of the data were removed by this procedure. Trials on which participants stuttered or failed to trigger the voice key were also excluded (an additional 0.50% of the data). Again, the only critical stimuli trials considered errors were those when a "no-go" response (i.e. no response) was made when a "go" response (i.e. saying "yes" aloud) should have been made. Mean response latencies of correct responses and mean accuracy are shown in Table 2.

There was an effect of BOI in the analysis of the response latency data, $t_1(24) = 3.42$, $SE = 11.12$, $\eta^2 = .33$; $t_2(30) = 1.90$, $SE = 19.62$, $p = .067$, $\eta^2 = .11$, but not in the analysis of the accuracy data, $t_1(24) = 1.42$, $SE = .01$, $p = .17$; $t_2 < 1$. The results from the present experiment replicate the results from Experiment 1: responses to the high BOI words were faster than responses to the low BOI words.

To compare the facilitatory BOI effects on the response latency data between the button press 'yes' condition of Experiment 1 and the verbal 'yes' condition of Experiment 2, we conducted a 2 (BOI: high, low) × 2 (Response Modality: button press 'yes', verbal 'yes') mixed-model ANOVA. In the subject analysis (F_1), BOI was a within-subjects variable and response modality was a between-subjects variable; in the item analysis (F_2), response modality was a within-items variable and BOI was a between-items variable.

There was a main effect of BOI, $F_1(1, 48) = 21.61$, $MSE = 2{,}803.36$, $\eta^2 = .31$; $F_2(1, 30) = 6.33$, $MSE = 6{,}361.60$, $\eta^2 = .17$, such that responses to the high BOI words were an average of 49 ms faster than responses to the low BOI words. There was a main effect of response modality, $F_1(1, 48) = 8.83$, $MSE = 29{,}367.73$, $\eta^2 = .16$; $F_2(1, 30) = 161.51$, $MSE = 1{,}012.91$, $\eta^2 = .84$, such that responses in the button press 'yes' condition were an average of 102 ms faster than responses in the verbal 'yes' condition. Importantly, there was no interaction between BOI and response modality, $F_1(1, 48) = 1.12$, $MSE = 2{,}803.36$, $p = .30$; $F_2(1, 30) = 2.58$, $MSE = 1{,}012.91$, $p = .12$. In addition to the above analysis, it should be noted that the effect sizes for the button press 'yes' condition and the verbal 'yes' condition were virtually identical (.32 and .33, respectively).

4. General discussion

The findings of the present study rule out the possibility that faster button press responses to high BOI words in semantic categorization are due simply to greater general manual motor priming elicited for these words. Instead, the results of the current study extend the findings of Siakaluk, Pexman, Sears et al. (2008) by demonstrating that facilitatory BOI effects in semantic categorization can be observed under two experimental conditions in which responses are made verbally: either when pronouncing aloud or when saying "yes" aloud. More generally, the results support the supposition that motor knowledge, as measured by BOI, influences the *semantic settling* mechanism responsible for responding in the type of semantic categorization task used in the present study. In addition, because any effects of imageability (and other lexical and semantic variables) were experimentally controlled, the observed facilitatory effects can be attributed to BOI.

Although the BOI effect was numerically smaller in both of the verbal response conditions (the pronunciation condition of Experiment 1 and the verbal 'yes' condition of Experiment 2) than in the button-press 'yes' condition (Experiment 1), we did not observe significant interactions between manual and verbal conditions. That is, the manual response did not significantly enhance the BOI effect. This suggests that the manual response of button pushing is not a necessary condition for the BOI effect. Thus, BOI and button pressing do not seem to produce the type of manual compatibility effects observed in previous studies on sentence processing and motor responses: the ACE effect studies (Glenberg and Kaschak 2002; Glenberg et al. 2008). This is in some ways not surprising, as the motor information captured by BOI likely involves many different motor affordances. Consider a concept like *bench*, which appeared in our stimulus set as a high BOI item. The bodily experiences associated with benches likely include sitting, leaning, and tactile information about bench surfaces. None of these are obviously related to the motor behaviors involved in pushing buttons on a response box. Instead, our data suggest that the rich set of experiences associated with a bench (and other high BOI items) are represented as part of conceptual knowledge and enhance semantic processing, regardless of whether the semantic judgment involves a button press or verbal response. Our suggestion is that the present BOI effects are therefore different from ACE effects, and that in order to observe ACE-type effects for BOI one would need to devise tasks involving motor responses that were much more specific than those associated with the concepts themselves.

Barsalou's (1999) perceptual symbol systems theory provides a theoretical framework for how lexical semantics could be grounded in sensorimotor processing. According to the theory, conceptual knowledge of objects is gained from bodily-environmental interactions via many different modalities. Of special relevance to the present study is the notion that motor, kinesthetic, and proprioceptive modalities (e.g. grasping and manipulating objects, internal feedback from muscles and joints) capture important features of objects, which are incorporated into the lexical semantic system. Retrieval of motor knowledge involves mental simulations (i.e. partial neural reenactments) of the motor states that were active during various encoding episodes. For example, when processing the high BOI word *bench*, a mental simulation would partially involve the reenactment of knowledge contained in neural systems dedicated to encoding motor, kinesthetic, and proprioceptive information about benches.

Finally, we propose that connectionist models of visual word recognition are consistent with the notion of a *semantic settling* mechanism, which is facilitated by semantic richness, and are thus able to provide theoretical frameworks for how facilitatory BOI effects may arise in semantic categorization tasks. As noted above, in Plaut and Shallice's (1993) connectionist model, high BOI words have richer semantic representations, activate more semantic units, and build stronger attractors in semantic space than do low BOI words. The stronger attractors associated with high BOI words settle more quickly into stable patterns of activation, which leads to the facilitation of responding for these words. Incorporating Barsalou's (1999) perceptual symbol systems theory with these types of models yields the insight that part of a high BOI word's richer semantic representation would involve motor knowledge. Thus, the richer semantic representations of high BOI words lead to faster responding in semantic categorization tasks, even when manual responses are not required.

5. Conclusion

The results of the present study indicate that response modality does not modulate the facilitatory effects of BOI, since comparable facilitatory BOI effects were observed in semantic categorization tasks that required either button press or verbal responses. These findings support the notion that facilitatory BOI effects are due to the activation of motor knowledge that influences the *semantic settling* mechanism in the visual word recognition system, rather than to general manual motor priming.

Appendix: BOI items used in the experiments

High BOI Words
bench, bike, cane, chalk, cloth, cord, cream, curb, mask, rope, soap, shell, stool, thorn, vest, wart

Low BOI Words
booth, bulb, cone, chain, clerk, coal, creek, cube, maid, rust, cell, shelf, storm, thief, vase, witch

References

Baayen, R. H., R. Piepenbrock & L. Gulikers. 1995. *The CELEX lexical database* [CD-ROM]. Philadelphia: Linguistic Data Consortium, University of Pennsylvania.

Balota, D. A., M. Pilotti & M. J. Cortese. 2001. Subjective frequency estimates for 2,938 monosyllabic words. *Memory and Cognition* 29. 639–647.
Barsalou, L. W. 1999. Perceptual symbol systems. *Behavioral and Brain Sciences* 22. 577–660.
Barsalou, L. W. 2003a. Abstraction in perceptual symbol systems. *Philosophical Transactions of the Royal Society of London: Biological Sciences* 358. 1177–1187.
Barsalou, L. W. 2003b. Situated simulation in the human conceptual system. *Language and Cognitive Processes* 18. 513–562.
Barsalou, L. W., W. K. Simmons, A. K. Barbey & C. D. Wilson. 2003. Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences* 7. 84–91.
Buchanan, L., C. Westbury & C. Burgess. 2001. Characterizing semantic space: Neighborhood effects in word recognition. *Psychonomic Bulletin and Review* 8. 531–544.
Cortese, M. J. & A. Fugett. 2004. Imageability ratings for 3,000 monosyllabic words. *Behavior Research Methods, Instruments, and Computers* 36. 384–387.
Cortese, M. J., G. B. Simpson & S. Woolsey. 1997. Effects of association and imageability on phonological mapping. *Psychonomic Bulletin and Review* 4. 226–231.
Davis, C. J. 2005. N-Watch: A program for deriving neighborhood size and other psycholinguistic statistics. *Behavior Research Methods* 37. 65–70.
Glenberg, A. M. & M. P. Kaschak. 2002. Grounding language in action. *Psychonomic Bulletin and Review* 9. 558–565.
Glenberg, A. M., M. Sato, L. Cattaneo, L. Riggio, D. Palumbo & G. Buccino. 2008. Processing abstract language modulates motor system activity. *The Quarterly Journal of Experimental Psychology* 61. 905–919.
Hino, Y. & S. J. Lupker. 1996. Effects of polysemy in lexical decision and naming: An alternative to lexical access accounts. *Journal of Experimental Psychology: Human Perception and Performance* 22. 1331–1356.
Hino, Y., S. J. Lupker & P. M. Pexman. 2002. Ambiguity and synonymy effects in lexical decision, naming, and semantic categorization tasks: Interactions between orthography, phonology, and semantics. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 28. 686–713.
ITP Nelson Canadian dictionary of the English language: An encyclopedic reference. 1997. Scarborough, ON: ITP Nelson.
Myung, J.-Y., S. E. Blumstein & J. C. Sedivy. 2006. Playing on the typewriter, typing on the piano: Manipulation knowledge of objects. *Cognition* 98. 223–243.
Nelson, D. L., C. L. McEvoy & T. A. Schreiber. 1998. *The University of South Florida word association, rhyme, and word fragment norms*. Retrieved March 15, 2006, from http://www.usf.edu/FreeAssociation/.
Plaut, D. C. & T. Shallice. 1993. Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology* 10. 377–500.
Schneider, W., A. Eschmann & A. Zuccolotto. 2002. *E-Prime user's guide*. Pittsburgh, PA: Psychology Software Tools, Inc.
Siakaluk, P. D., P. M. Pexman, L. Aguilera, W. J. Owen & C. R. Sears. 2008. Evidence for the activation of sensorimotor information during visual word recognition: The body-object interaction effect. *Cognition* 106. 433–443.
Siakaluk, P. D., P. M. Pexman, C. R. Sears, K. Wilson, K. Locheed & W. J. Owen. 2008. The benefits of sensorimotor knowledge: Body-object interaction facilitates semantic processing. *Cognitive Science* 32. 591–605.
Simmons, W. K. & L. W. Barsalou. 2003. The similarity-in-topography principle: Reconciling theories of conceptual deficits. *Cognitive Neuropsychology* 20. 451–486.
Strain, E., K. Patterson & M. S. Seidenberg. 1995. Semantic effects in single-word naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21. 1140–1154.

Tillotson, S. M., P. D. Siakaluk & P. M. Pexman. 2008. Body-object interaction ratings for 1,618 monosyllabic nouns. *Behavior Research Methods* 40. 1075–1078.
Ziegler, J. C., G. O. Stone & A. M. Jacobs. 1997. What's the pronunciation for *–ough* and the spelling for /u/? A database for computing feedforward and feedback inconsistency in English. *Behavior Research Methods, Instruments, and Computers* 29. 600−618.