Acta Psychologica 149 (2014) 32–39

Contents lists available at ScienceDirect

Acta Psychologica

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

Effects of relative embodiment in lexical and semantic processing of verbs

David M. Sidhu [a], Rachel Kwan [a], Penny M. Pexman [a,*], Paul D. Siakaluk [b]

[a] Department of Psychology, University of Calgary, 2500 University Drive NW, Calgary, AB T2N1N4, Canada
[b] Department of Psychology, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N4Z9, Canada

ARTICLE INFO

Article history:
Received 5 April 2013
Received in revised form 15 February 2014
Accepted 25 February 2014
Available online 22 March 2014

PsycINFO codes:
2340

Keywords:
Verb meaning
Embodiment rating
Word meaning
Lexical processing
Semantic richness
Embodied cognition

ABSTRACT

Research examining semantic richness effects in visual word recognition has shown that multiple dimensions of meaning are activated in the process of word recognition (e.g., Yap et al., 2012). This research has, however, been limited to nouns. In the present research we extended the semantic richness approach to verb stimuli in order to investigate how verb meanings are represented. We characterized a dimension of relative embodiment for verbs, based on the bodily sense described by Borghi and Cimatti (2010), and collected ratings on that dimension for 687 English verbs. The relative embodiment ratings revealed that bodily experience was judged to be more important to the meanings of some verbs (e.g., *dance*, *breathe*) than to others (e.g., *evaporate*, *expect*). We then tested the effects of relative embodiment and imageability on verb processing in lexical decision (Experiment 1), action picture naming (Experiment 2), and syntactic classification (Experiment 3). In all three experiments results showed facilitatory effects of relative embodiment, but not imageability: latencies were faster for relatively more embodied verbs, even after several other lexical variables were controlled. The results suggest that relative embodiment is an important aspect of verb meaning, and that the semantic richness approach holds promise as a strategy for investigating other aspects of verb meaning.

1. Introduction

To the skilled reader, the process by which word meaning is extracted from print feels quite simple. For visual word recognition researchers, however, explaining this process has proven considerably more complicated. One of the strategies that researchers have used to study lexical–semantic processing is to present individual words in tasks requiring simple decisions (e.g., the word/nonword judgment involved in the lexical decision task) and to examine whether different properties of the words themselves (their meaning, syntax, etc.) influence responses in systematic ways. If word recognition behavior is influenced by those properties, then inferences can be made about the processes involved in visual word recognition.

For instance, a great deal has been learned about lexical–semantic processing by examining the effects of words' *semantic richness* (for a review see Pexman (2012)). That is, there is variability in the amount of semantic information associated with different words, and this variability can be defined in different ways, as a function of the descriptions of word meaning that have been proposed. Further, this variability is related to behavior in visual word recognition tasks, such that responses are typically faster for semantically richer words. Semantic richness effects are consistent with the principle that when it comes to semantic activation in lexical processing, "more is better" (Balota, Ferraro, & Connor, 1991, p. 214).

According to variants of the embodied cognition framework, knowledge gained through perceptual (e.g., Paivio, 1991) and sensorimotor or bodily experience (e.g., Barsalou, 1999) are important components of word meaning. The embodied cognition framework holds that sensorimotor systems are integral to conceptual knowledge, such that sensorimotor states activated when we experience the world are also involved in simulation when we think about the world (e.g., Barsalou, 2008; Gallese & Lakoff, 2005). Thus, even when cognition is off-line, or decoupled from the environment, it is grounded in sensory processing and motor control (Wilson, 2002).

Support for the embodied cognition framework has been provided by studies showing that performance in visual word recognition tasks is facilitated for words that refer to concepts that are easily imageable (imageability effects; e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004) or with which the human body can easily interact (body–object-interaction (BOI) effects; Hargreaves et al., 2012; Siakaluk, Pexman, Aguilera et al., 2008; Siakaluk, Pexman, Sears et al., 2008; Tousignant & Pexman, 2012). These semantic richness effects certainly do not explain all of the variance in lexical–semantic processing, and they can be observed alongside other semantic richness effects that

* Corresponding author. Tel.: +1 403 220 6352.
E-mail address: pexman@ucalgary.ca (P.M. Pexman).

http://dx.doi.org/10.1016/j.actpsy.2014.02.009
0001-6918/

are less obviously derived from the embodied cognition framework, such as semantic neighborhood effects (Buchanan, Westbury, & Burgess, 2001). As such, work using the semantic richness approach suggests that word meaning is not fully explained by models that assume that one type of information comprises the basic unit of meaning (e.g., Burgess & Lund, 1997; McRae, de Sa, & Seidenberg, 1997). Rather, word meaning seems to be multidimensional, consistent with a number of recent proposals (e.g., Barsalou, Santos, Simmons, & Wilson, 2008; Dove, 2009).

Semantic richness effects have been explained in terms of semantic feedback activation (e.g., Hino & Lupker, 1996; Pexman, Lupker, & Hino, 2002) in a fully-interactive visual word recognition system that includes separate but interconnected sets of units representing orthographic, phonological, and semantic information. That is, processing in the model involves feedforward and feedback activation between units in order that the system settles into a stable state (e.g., Harm & Seidenberg, 2004). Words with richer semantic representations are assumed to generate more semantic activation; visual recognition of words associated with relatively more semantic information involves activation of more semantic units (e.g., for concrete words in the model of Plaut & Shallice (1993)) and more efficient neural processing (e.g., for words with a high number of associates, in the fMRI study of Pexman, Hargreaves, Edwards, Henry, and Goodyear (2007)).

Importantly, increased semantic activation can have different consequences for lexical processing, as a function of task demands. That is, task demands shift focus around the visual word recognition system in terms of the kind of information on which responses are primarily based. In a lexical decision task, it is argued that the activity in orthographic representations is the primary basis for responding (Balota et al., 1991; Hino, Lupker, & Pexman, 2002). In order to explain the fact that BOI and imageability effects have been observed in lexical decision it is assumed that these words evoke stronger semantic activation (because they are associated with relatively more sensorimotor information; Pexman et al., 2002), which provides stronger feedback activation from semantics to orthography and, as a result, stronger evidence for a “word” response. In a naming task, it is assumed that stronger semantic activation would provide stronger feedback activation to phonological representations, which are the primary basis for responding when a vocal response is required (e.g., Bennett, Burnett, Siakaluk, & Pexman, 2011). Lastly, in a task that is more directly focused on semantic activation per se (e.g., a meaning classification task), processing would be facilitated for semantically richer concepts, because faster settling of semantic representations is associated with words with richer semantic representations (e.g., Pexman, Holyk, & Monfils, 2003; Siakaluk, Pexman, Sears et al., 2008).

While the semantic richness approach has provided important clues about dimensions of word meaning and the nature of lexical–semantic processing, the approach has only been applied to noun stimuli. Thus, we now know much about the multidimensional structure of semantic memory for nouns, particularly concrete nouns (e.g., Amsel, Urbach & Kutas, 2013; Grondin, Lupker & McRae, 2009; Hargreaves & Pexman, 2014; Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008; Yap, Pexman, Wellsby, Hargreaves, & Huff, 2012; Yap, Tan, Pexman, & Hargreaves, 2011). The goal of the present study was to investigate the structure of semantic memory for verbs by extending the semantic richness approach to verb stimuli. Although there is reason to believe that semantic richness effects could be observed for verbs, there is also reason to believe that verbs may be represented differently than nouns.

The notion that nouns and verbs may be associated with different semantic information has been explored in a number of lexical decision studies (e.g., Cordier, Croizet, & Rigalleau, 2013; Kauschke & Stenneken, 2008; Rösler, Streb, & Haan, 2001). These studies have generally reported a noun advantage; that is, faster responses to nouns than to verbs. One suggested explanation for this effect is that nouns tend to be more imageable than verbs (Allport & Funnell, 1981). Another suggestion made by Cordier et al. (2013) is that semantic feedback or semantic activation might be lower for verbs than for nouns. They compared lexical processing for French nouns and verbs, and in addition to showing the standard noun advantage, did not find that any semantic variables predicted lexical decision latencies for verbs. They acknowledged that their small sample size (only 26 verbs) could have limited power to detect semantic effects for their stimuli.

Only a handful of other studies have examined the influence of lexical–semantic variables for verbs. In one of the few studies to separately examine lexical processing of verbs, Colombo and Burani (2002) showed that word frequency and age of acquisition (AoA) were both related to lexical decision latencies for Italian verbs. That is, latencies were faster for more frequent verbs and for verbs rated as having been learned earlier in life. Somewhat different findings were reported by Boulenger, Décoppet, Roy, Paulignan, and Nazir (2007) with French verbs; in their lexical decision experiment only frequency was related to action verb latencies, with AoA not accounting for any additional variability in latencies.

Thus, the research to date offers very little evidence that semantic richness influences lexical processing of verb stimuli. However, there is strong evidence that recognition of *goal-directed action verbs* evokes sensory and motor processing. For instance, Hauk, Johnsrude, and Pulvermuller (2004) presented participants with action words referring to arm, face, or leg actions (e.g., *pick*, *lick*, *kick*). Passive viewing of these verbs was associated with activation in corresponding motor and premotor areas linked to arm, face, and leg movements. Ruschemeyer, Brass, and Friederici (2007) also examined the neural correlates of lexical processing for action verbs using fMRI, and compared activation associated with German motor verbs and abstract verbs. Results showed greater activation in motor and somatosensory cortices for motor verbs, suggesting, again, a functional relationship between lexical processing of action verbs and the sensorimotor system. Similarly, Nazir et al. (2008) showed that making lexical decisions to action words disrupted concurrent reaching movements, suggesting overlap between the lexical and motor systems.

More compelling evidence for this link is provided by a recent study reported by Repetto, Colombo, Cipresso, and Riva (2013). In the Repetto et al. study participants made semantic decisions (concrete/abstract) to hand-related action verbs (e.g., *catch*, *peel*) and more “abstract” verbs (e.g., *forget*, *terrify*). The authors used rTMS to disrupt processing in the hand portion of primary motor cortex, and showed that this slowed semantic decisions for hand-related action verbs but not for abstract verbs. As such, they concluded that the motor cortex plays a functional role in comprehension of action verbs, consistent with a strong version of the embodied cognition framework (e.g., Gallese & Lakoff, 2005).

These studies suggest that the motor system is important in processing the meanings of specific, goal-directed action verbs, and reflect the focus on action that has characterized much of the empirical and theoretical work on embodied cognition: “In this perspective the body is always considered as an *acting* body” (Borghi & Cimatti, 2010, p. 763). Importantly, Borghi and Cimatti point out that meaning derived through embodiment is grounded in multiple ways, not only through action; the body could play a role in language and conceptual processing that goes beyond its involvement in specific, goal-directed actions (e.g., *pick*, *peel*). Borghi and Cimatti argue that body perception could be construed as more than overt, voluntary actions, to involve passive movements and internal sensory experience (e.g., proprioceptive experience), and that these sources could also ground meaning. A body sense does not require agency but a feeling of being an individual body, situated in place and time, experiencing multisensory input. Further, the bodily sense is not an all-or-none construct but, instead, one that develops by degrees.

Importantly, the Borghi and Cimatti (2010) characterization of the body sense (which we will call *relative embodiment* in the present study) can be applied to *all* verbs, not just those that describe goal-directed action. Thus, this seemed a good candidate semantic richness dimension for verb meaning. In addition, rated imageability (i.e., how easily words arouse mental images) also seemed a good candidate. Although imageability ratings for verbs have been obtained in previous studies (Bird, Franklin, & Howard, 2001; Chiarello, Shears, & Lund, 1999), relative embodiment ratings have not. Thus, we first collected relative embodiment ratings for a large set of verb stimuli. Then, we examined semantic richness effects for the relative embodiment and imageability dimensions, in lexical decision (Experiment 1), action picture naming (Experiment 2), and syntactic classification (Experiment 3) of verbs in order to test whether relative embodiment and imagery are integral dimensions of verb meaning.

2. Experiment 1

The goals of Experiment 1 were to: 1) characterize a dimension of relative embodiment for English verb stimuli, 2) collect ratings on that dimension, and 3) test the effects of that dimension and others on lexical decision processing, for a large number of verb stimuli.

2.1. Method

2.1.1. Participants

A total of 80 participants were tested in the rating task. The data for 13 of the participants in the rating task were excluded for failing to use the rating scale as instructed (see below for elaboration on this criterion), so the data for 67 participants (57 female; mean age = 20.40, $SD = 2.41$) were included in analyses, with 30 participants rating one half of the verb list and 37 rating the other half. There were 30 participants (17 female; mean age = 20.73, $SD = 2.52$) in the lexical decision task, none of whom had participated in the rating task. All participants were undergraduate students at the University of Calgary who participated in exchange for bonus credit in a psychology course, had normal or corrected-to-normal vision, and reported English proficiency. Prior to participation, informed consent was obtained from all participants.

2.1.2. Stimuli and procedure

2.1.2.1. Rating task. The Bird et al. (2001) and Chiarello et al. (1999) norms provide imageability ratings for verb stimuli. We began by selecting the items from those norms that had a primary verb meaning (703 items). We further excluded verbs that we considered to be highly unfamiliar for an undergraduate population (e.g., *fetter*, *impel*, *tut*). This was a somewhat subjective assessment on our part, but we felt it was important in order to collect meaningful ratings, and involved exclusion of only 16 items, resulting in a final list of 687 verbs. To avoid participant fatigue, the verbs were randomly divided in two lists. Half of the participants made ratings for the first list and the other half of the participants made ratings for the second list. The same instructions were presented for each list (see Appendix for verbatim instructions): participants were asked to judge the degree to which the meaning of each verb involved the human body, on a 1–7 scale. Participants completed the rating task individually, as an on-line survey. The verbs were presented in a different random order for each participant. Participants could return to previous ratings at any time during the task, but could not advance to the next item until a rating had been provided for the previous item. We examined rating task data and excluded participants who failed to use the rating scale as instructed. Our criteria for exclusion were: 1) giving the same rating for 7 consecutive items or 2) using only two points on the 7-point scale for the entire set of items. Mean ratings for 687 verbs presented in the rating task are available at http://psychology.ucalgary.ca/languageprocessing/node/22.

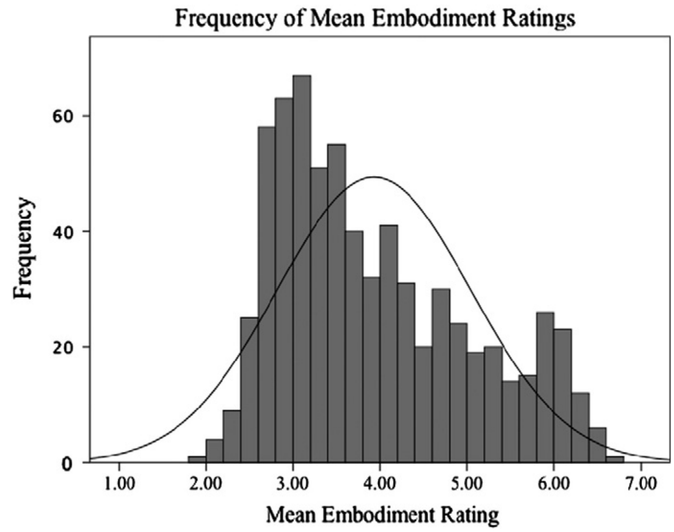

Fig. 1. Histogram displays the frequency of relative embodiment ratings for the 687 verbs used in the ratings task of Experiment 1.

The relative embodiment ratings had a mean of 3.93, and a standard deviation of 1.11. The distribution of embodiment ratings had a moderate positive skew ($G_1 = .63$), with 59% of the items rated below the median of the rating scale. Fig. 1 shows the distribution of relative embodiment ratings for our set of 687 verbs.

2.1.2.2. Lexical decision task. From the relative embodiment ratings we selected 400 verbs with relatively low *SD* values (<1.75) to be presented in the lexical decision task. Low *SD* values for these items suggested that there was relatively good agreement among participants as to the words' relative embodiment. In addition, 400 nonwords (none of which sounded like a real word if pronounced, i.e., there were no pseudohomophones used) were selected such that they were the same length as our word stimuli. Thus, there were a total of 800 lexical decision trials for each participant, presented in a different random order for each participant. Participants were tested in our laboratory. Words and nonwords were presented in 22-point Times New Roman font in black letters (1 cm high) on a white screen, using Eprime 2.0 software. Each trial began with an asterisk in the middle of the 20″ computer screen as a fixation point, which was then replaced by a letter string after 1500 ms. Every word and nonword was presented along with the word "to" (e.g., *to leap*, *to foss*) to ensure that participants focused on the verb meaning of each item. Participants sat at a viewing distance of approximately 50 cm from the screen. Participants responded using a button box, and all were instructed to press the far right button to respond "word" and the far left button to respond "nonword". Participants used their right index finger to push the "word" button and their left index finger to push the "nonword" button. Participants were asked to respond as quickly and as accurately as possible. Each participant completed 20 practice trials with feedback before the experiment proper, including 10 verbs and 10 nonwords. Participants were given a break halfway through the experimental trials.

2.2. Results and discussion

In the analysis of lexical decision latencies, eight words (*allot*, *admonish*, *brood*, *berate*, *coax*, *gouge*, *gargle*, *splutter*) were excluded from the analysis because accuracy for these items was less than 70%. In addition, incorrect trials (3.45%) and trials on which latencies were more than 2.5 *SD* from the participant's mean were excluded from the analysis (<1% of trials). Mean characteristics for the remaining 392 verbs are presented in Table 1.

Table 1
Mean descriptive statistics (standard deviations in parentheses) for verb stimuli in Experiments 1 (LDT) and 2 (action picture naming).

Variable	LDT (n = 392)	Action picture naming (n = 82)
Log frequency	8.54 (1.89)	9.32 (1.59)
Length	5.62 (1.55)	n/a
OLD	1.93 (0.54)	n/a
Morphemes	1.29 (0.49)	n/a
Age of acquisition	7.94 (2.44)	5.46 (1.40)
Objective visual complexity	n/a	24240.05 (8422.37)
Imageability	4.21 (1.00)	5.23 (0.65)
Relative embodiment	4.01 (1.55)	5.02 (0.99)
LDT latency (words)	609.12 (56.58)	
LDT latency (nonwords)	686.57 (89.50)	
IPNP latency		1251.78 (213.49)

Note. OLD = orthographic Levenshtein distance (Yarkoni et al., 2008); LDT = lexical decision task.

Table 3
Regression coefficients from item-level regression analyses for standardized LDT latencies, Experiment 1.

Variable	*B*	*SEB*	β	*sr*	R^2	ΔR^2
Step 1					.49***	.49***
Control variables						
Log frequency	−.09	.01	−.44	−.37***		
Length	−.08	.01	.00	.00		
OLD	.08	.05	.14	.07		
Morphemes	−.10	.03	−.13	−.11**		
Age of acquisition	.04	.01	.31	.23***		
Step 2					.51***	.02**
Semantic variables						
Imageability	.00	.00	−.04	−.03		
Relative embodiment	−.03	.01	−.13	−.09*		

Note. OLD = orthographic Levenshtein distance (Yarkoni et al., 2008).
* $p < .05$.
** $p < .01$.
*** $p < .001$.

The variables in the analysis were divided into two clusters: control variables and semantic variables. Control variables included lexical variables that have been shown to influence lexical decision performance (e.g., Colombo & Burani, 2002): log transformed HAL word frequency (Lund & Burgess, 1996), word length in letters, orthographic Levenshtein distance (OLD, Yarkoni, Balota, & Yap, 2008), number of morphemes, and AoA (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012). Semantic variables were imageability (Bird et al., 2001; Chiarello et al., 1999) and relative embodiment.

Correlations between these variables are presented in Table 2. As illustrated in Table 2, there was a positive relationship between imageability and relative embodiment. Thus, verbs rated as more imageable (in Bird et al. (2001) and Chiarello et al. (1999) studies) also tended to be rated as relatively more embodied (in the present study). This is not surprising, since bodily experience provides rich sensory information; for example, the visual experience of watching one's own or other bodies engaged in the actions, states, and relations described by the verb stimuli. In the analyses of the lexical decision latencies, presented next, we examine the unique contributions of imageability and relative embodiment.

Latencies were standardized as *z*-scores since these minimize the influence of a participant's processing speed and variability (Faust, Balota, Spieler, & Ferraro, 1999). A hierarchical regression analysis was conducted on the standardized lexical decision latencies. Control variables were entered in step 1 and semantic variables in step 2, and the regression results are presented in Table 3. Results for the control variables showed that word frequency and AoA were both significant predictors of lexical decision latencies for verbs, with faster latencies for more frequent verbs and verbs acquired earlier in life. As such, these findings replicate those of Colombo and Burani (2002) for Italian verbs, but in the present study with English verbs. Most importantly, once these control variables were entered into the equation, only relative embodiment (and not imageability) was a significant predictor of lexical decision latencies, such that lexical decision latencies were faster for verbs that were relatively more embodied.

The results of Experiment 1 show that the extent to which the human body is important to the meaning of a verb (as measured by the dimension we call *relative embodiment*) is related to lexical processing of that verb. We assume that this is because more embodied verbs generate stronger semantic activation, which provides stronger feedback to the orthographic units which are the primary basis of responding in lexical decision (Hino & Lupker, 1996). To confirm that the facilitatory effects of relative embodiment are, indeed, based in semantic processing (i.e., due to *semantic* richness) we examined relative embodiment effects in two other tasks that involve semantic processing: action picture naming in Experiment 2, and syntactic classification, where participants make decisions about the meanings of printed verbs, in Experiment 3.

3. Experiment 2

3.1. Method

The action picture naming data obtained for Experiment 2 were extracted from the International Picture Naming Project (IPNP; http://crl.ucsd.edu/experiments/ipnp/) action naming norms (Szekely et al., 2005). As such, they are best described as archival data, and were collected by the researchers involved in the IPNP from 50 adult English-speaking participants using, as stimuli, 275 black and white line drawings of actions. Full details for data collection procedures are available at the IPNP website and in Szekely et al. (2005). To be clear, we did not collect the data in Experiment 2, but rather analyzed extant data from the IPNP.

Table 2
Correlations between predictor variables and dependent measures in Experiment 1 (LDT).

Variable	1	2	3	4	5	6	7
1. Log frequency	–						
2. Length	−.31***						
3. OLD	−.33***	.87***	–				
4. Morphemes	−.24***	.47***	.45***				
5. Age of acquisition	−.55***	.47***	.50***	.41***			
6. Imageability	−.04	−.24***	−.24***	−.27***	−.52***		
7. Relative embodiment	.03	−.33***	−.35***	−.35***	−.54***	.70***	
8. LDT latencies	−.63***	.34***	.38***	.17**	.57***	−.20***	−.27***

Note. OLD = orthographic Levenshtein distance (Yarkoni et al., 2008); LDT = lexical decision task.
** $p < .01$.
*** $p < .001$.

3.1.1. Stimuli and procedure

Of the 275 action pictures for which there is behavioral data in the IPNP, 82 depicted verbs that were presented for ratings in Experiment 1. Thus, we selected these items for analysis. Descriptive characteristics for this subset of the IPNP actions are presented in Table 1.

3.2. Results and discussion

We extracted mean latencies for correct responses to 82 action pictures from the IPNP data (Szekely et al., 2005). We first examined correlations between these latencies and other dimensions relevant to action naming: frequency, AoA, objective visual complexity (a variable in the IPNP norms which quantifies the complexity of the presented visual images), and semantic richness (imageability, relative embodiment). These correlations are provided in Table 4. We then analyzed the action naming latencies using hierarchical regression analysis. Control variables (word frequency, AoA, and objective visual complexity) were entered in step 1 and semantic variables (imageability and relative embodiment) in step 2. As illustrated in Table 5, AoA was a significant predictor of action naming latencies (i.e., faster latencies for verbs acquired earlier in life). More importantly, once the control variables were entered in the equation, relative embodiment was again a significant predictor of response latencies. That is, action naming responses were faster for depicted verbs when their labels had been rated as relatively more embodied.

The results of Experiment 2 show that facilitatory effects of relative embodiment generalize beyond printed word stimuli to include action picture naming. In a picture naming task, it is assumed that participants must access meaning from the visual depiction, and then generate a verbal label for that concept (Alario et al., 2004). As such, picture naming depends largely on phonological activation, with feedback from the semantic units to the phonological units (e.g., Bennett et al., 2011). Relatively more embodied verbs generate stronger semantic activation, which provides stronger feedback to the phonological units and facilitates action picture naming.

4. Experiment 3

We have explained the results of Experiments 1 and 2 in terms of stronger semantic activation generated for relatively more embodied verbs, which provides stronger feedback to orthographic and phonological units, facilitating lexical decision and action picture naming, respectively. However, the tasks used in Experiments 1 and 2 are not direct measures of semantic processing; the effects of semantic activation in those tasks are assumed to be indirect, via feedback. To test the effect of relative embodiment on semantic processing in a more direct way we conducted a syntactic classification task in Experiment 3. To encourage a focus on meaning we presented a smaller number of items than in Experiment 1. In Experiment 1 we examined lexical processing for a large number of items and used a regression approach to control variance explained by other lexical and semantic variables. In Experiment 3 we examined semantic processing for carefully selected sets of high embodiment verbs and low embodiment verbs, using a between-items approach wherein we matched the high and low embodiment verb sets on other lexical and semantic dimensions. We focused only on the relative embodiment dimension in this case, and not imageability, because relative embodiment was the semantic richness variable that was significantly related to latencies in Experiments 1 and 2.

For the syntactic classification task we chose the verb/noun distinction as the decision category. As mentioned, however, there is evidence that meaning retrieval is easier for nouns than for verbs (e.g., Cordier et al., 2013; Szekely et al., 2005). As such, we devised the task to encourage participants to focus on verb meaning, and to discourage them from judging verb meaning as the absence of noun meaning. That is, the task used a go/no-go design in which participants judged whether each word presented was a verb or not; they responded with a button press if the word was a verb, and they did not respond if the word was not a verb.

Table 4
Correlations between predictor variables and dependent measures in Experiment 2 (action picture naming).

Variable	1	2	3	4	5
1. Log frequency					
2. Objective visual complexity	.11				
3. Age of acquisition	−.61***	.03			
4. Imageability	−.05	−.08	−.43***		
5. Relative embodiment	.04	−.18	−.46***	−.64***	
6. Picture naming latencies	.08	.18	.25*	−.32**	−.39***

Note. OLD = orthographic Levenshtein distance (Yarkoni et al., 2008); LDT = lexical decision task.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 5
Regression coefficients from item-level regression analyses for action picture naming latencies, Experiment 2.

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1					.12*	.12*
Control variables						
Log frequency	22.48	15.42	.17	.15		
Objective visual complexity	0.00	0.00	.15	.15		
Age of acquisition	46.74	17.37	.31	.29**		
Step 2					.22**	.10**
Semantic variables						
Imageability	−0.67	0.41	−.20	−.16		
Relative embodiment	−51.37	24.69	−.24	−.21*		

* $p < .05$.
** $p < .01$.

4.1. Method

4.1.1. Participants

Participants in Experiment 3 were 33 undergraduate students (22 female; mean age = 21.88, SD = 6.67) at the University of Calgary who participated in exchange for bonus credit in a psychology course, had normal or corrected-to-normal vision, and reported English proficiency. None of these individuals participated in Experiment 1.

4.1.2. Stimuli and procedure

The stimuli for Experiment 3 included 40 verbs with low relative embodiment ratings (<3.5) and 40 verbs with high relative embodiment ratings (>3.5). As illustrated in Table 6, these two sets of verbs were matched in terms of: log transformed HAL word frequency (Lund & Burgess, 1996), word length in letters, OLD (Yarkoni et al., 2008), number of morphemes, imageability (Bird et al., 2001; Chiarello et al., 1999),

Table 6
Mean descriptive statistics (standard deviations in parentheses) for verb stimuli in Experiment 3.

Variable	Low embodiment verbs	High embodiment verbs
Log frequency	8.70 (2.05)	8.83 (2.48)
Length	5.70 (1.32)	5.38 (1.63)
OLD	1.99 (0.46)	1.87 (0.45)
Morphemes	1.40 (0.55)	1.40 (0.55)
Age of acquisition	8.55 (2.41)	8.00 (2.47)
Imageability	3.90 (0.74)	4.05 (0.67)
Relative embodiment	2.77 (0.18)	4.43 (0.29)
Response latency	927.01 (265.33)	890.22 (222.18)
Response accuracy	0.91 (0.09)	0.94 (0.07)

Note. OLD = orthographic Levenshtein distance (Yarkoni et al., 2008).

and AoA (Kuperman et al., 2012). The two sets of words were only significantly different in terms of mean relative embodiment ($t(78) = 30.92$, $p < .001$). Additionally, we selected 80 nouns that were matched with the 80 verbs in terms of log transformed HAL word frequency, word length in letters, OLD, number of morphemes, length, and AoA.

Participants were tested in our laboratory, and were presented with a total of 160 experimental trials (80 verbs and 80 nouns). Verbs were presented in their non-inflected form. Stimulus presentation was as described for Experiment 1 except that each trial began with a fixation cross for 1000 ms and then a blank screen for 1000 ms and then the word was presented. Participants were instructed to decide whether each word was a verb. If they judged that the word was a verb, they were to press the response button. If they judged that the word was not a verb, they were to do nothing. If no response was made the next trial began automatically after 3000 ms. Each participant completed 14 practice trials with feedback before the experiment proper, including 7 verbs and 7 nouns. The experiment consisted of two blocks of 80 trials with a break in between. The blocks of trials were matched on all of the relevant variables and were counterbalanced across participants. Within blocks, trials were randomized separately for each participant.

4.2. Results and discussion

Incorrect verb trials (7.35%) and verb trials on which latencies were more than 2.5 *SD* from the participant's mean (3.20% of trials) were excluded from the analysis of response latencies. Mean latencies and accuracy for low and high relative embodiment verbs are presented in Table 6. *T*-tests were used to examine the effect of relative embodiment on latencies and accuracy, analyzed by subjects (t_1) and by items (t_2). Results showed that responses were, on average, 37 ms faster and 3% more accurate for high relative embodiment verbs than for low relative embodiment verbs (latencies: $t_1(32) = 2.37$, $p = .02$, Cohen's $d = 0.15$; $t_2(78) = 1.33$, $p = .18$; accuracy: $t_1(32) = 3.86$, $p = .001$, Cohen's $d = 0.42$; $t_2(78) = 1.96$, $p = .05$, Cohen's $d = 0.44$).

The results of Experiment 3 suggest that verbs judged to be relatively more embodied enjoy faster and more accurate syntactic classification responses. We assume that syntactic classification task performance is based primarily on activation in the semantic units (Bennett et al., 2011), and thus the observed facilitation is attributed to stronger semantic activation for relatively more embodied verbs.

5. General discussion

The aim of the present study was to investigate two dimensions of verb meaning using the semantic richness approach. We focused on the candidate dimensions of relative embodiment and imageability. We characterized relative embodiment for a large set of verb stimuli. Results showed that for some verbs knowledge gained through bodily experience was judged to be very important to their meaning; the highest relative embodiment ratings were for the verbs *dance*, *jog*, *breathe*, and *exhale*. Notably, these highest-rated verbs seem to be those that involve much of the body and rich sensorimotor experiences and not necessarily specific action patterns. For other verbs the human body was judged to be not at all important, with the lowest relative embodiment ratings for *forecast*, *expect*, *cancel*, and *evaporate*. Moderate ratings were provided for verbs that can be viewed as involving the body in less prescribed ways, for instance *retreat*, *excel*, *adjust*, and *demolish*. As such, these ratings seem to capture the bodily sense that Borghi and Cimatti (2010) described. This sense goes beyond specific and goal-directed actions that have been the focus of much verb representation and processing research in the literature (e.g., Hauk et al., 2004; Ruschemeyer et al., 2007), to include bodily experience involved in passive actions and internal sensorimotor states (e.g., proprioceptive states).

We observed a strong relationship between relative embodiment ratings and imageability ratings and, as mentioned, this is likely because there is imagery associated with many of the high-embodiment verbs. Certainly, imageability and relative embodiment could both be considered modal dimensions. Importantly, however, the relative embodiment ratings seem to capture something incremental to imagery (as there were significant effects of relative embodiment but not imageability in Experiments 1 and 2), and we propose it is knowledge gained through sensorimotor and proprioceptive experience afforded by having a human body, as Borghi and Cimatti (2010) have described.

It is worth clarifying that the relative embodiment dimension captured in the present ratings for verb stimuli is not the same as the BOI dimension captured in previous studies with noun stimuli (e.g., Bennett et al., 2011). The relative embodiment dimension for verbs asks participants to judge the importance of having a body to understanding verb meaning (i.e., understanding the actions, states, and relationships implicated by verbs), whereas the BOI dimension asks participants to judge the ease with which the human body can interact with the word's referent, which, in all cases, is an object (i.e., a noun).

The lexical decision results of Experiment 1 showed that the dimension of relative embodiment for verb meaning is relevant to visual word recognition for verb stimuli; we observed faster latencies for relatively more embodied verbs. The fact that verbs associated with relatively more bodily knowledge were recognized faster implies that participants activated sensorimotor information derived through bodily experience in the process of recognizing verbs presented in isolation. As such, the present findings provide support for the idea derived from the embodied cognition framework, that knowledge gained through bodily experience may be an important dimension of verb meaning.

The results of Experiments 2 and 3 show that the effects of relative embodiment generalize to situations where participants do not see the printed verbs (action picture naming) and where they focus more directly on the meaning conveyed by the printed word (syntactic classification). The tasks used in Experiments 1, 2, and 3 all involve somewhat different demands, but a core process in each is activation of meaning. The fact that relative embodiment effects were observed in all three experiments suggests that these effects should be attributed to that core process of meaning activation. Thus, these results help to confirm that higher relative embodiment generates greater semantic activation for verb stimuli. This stronger semantic activation leads to facilitated lexical decisions (through semantics–orthography connections), action picture naming (through semantics–phonology connections), and syntactic classification decisions (through stronger semantic activation).

Importantly, the present results demonstrate that semantic richness effects extend to word classes beyond concrete nouns, which have been the focus of previous studies. Despite the fact that they are less imageable (Allport & Funnell, 1981), the present study demonstrates that verbs can generate other semantic richness effects. We have established that relative embodiment is one such semantic richness effect. Further, we suggest that it is important that other candidate dimensions of verb meaning be evaluated in future research. For instance, Gennari and Poeppel (2003) showed that lexical decisions were slower to verbs that evoke an event structure than to verbs that denote facts without causal structure. This aspect of verb conceptual complexity could be extended to a larger number of verb stimuli and then compared to effects of relative embodiment. While many aspects of verb meaning are likely to be distinct from those of noun meaning, others (such as those derived from an embodiment framework) may overlap. For instance, several researchers have now shown that dimensions that capture survival information, or death avoidance (e.g., Amsel, Urbach, & Kutas, 2013; Wurm, Vakoch, & Seaman, 2004) are related to lexical processing of nouns, and it seems possible that this dimension could also extend to verb meaning.

Our results demonstrate that sensorimotor information is important to the processing of verb meaning, and are compatible with an embodied cognition framework like that proposed by Barsalou (1999, 2008) in which meaning is grounded, not just through specific, goal-oriented action, but in multiple ways (e.g., bodily experience involved in passive actions and internal sensorimotor states; see also Borghi & Cimatti, 2010; Glenberg & Gallese, 2012). We have traced these effects of relative embodiment to the semantic processing component of the visual word recognition system, and propose that, in keeping with proposals made by Siakaluk et al. (2008a), Siakaluk et al. (2008b) and Juhasz, Yap, Dicke, Taylor, and Gullick (2011), sensorimotor information is an important dimension of lexical meaning. Certainly, these results do not conclusively demonstrate that sensorimotor processing is *necessary* for verb comprehension (Mahon & Caramazza, 2008). Further, the proposed explanation of the present study is not the only possible explanation. It is also possible that more embodied verbs are processed faster because they benefit from automatic motor system activation (Jeannerod, 2001). Reading more embodied verbs could involve internal simulation of the action described, via resonance in the mirror neuron system (Grafton, 2009; Rizzolatti, Fogassi, & Gallese, 2001; Van Overwalle & Baetens, 2009). Our results do not obviously adjudicate between these possibilities.

The novel contribution of our work is the demonstration that relative embodiment is a dimension of verb meaning, one that skilled readers access when making lexical, syntactic or semantic decisions, and when naming pictured actions. Admittedly, we have much to learn about other aspects of verb meaning, but we suggest that the semantic richness approach holds promise as a strategy for investigating how the meanings of verbs are represented in the mind.

Acknowledgments

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) in the form of a Canada Graduate Scholarship to DMS and Discovery Grants to PMP and PDS. We thank Gemma Leonard for help with programming and data collection.

Appendix A. Instructions for embodiment ratings

Verbs are words that typically express an action, state, or relation between two things. The meanings of many verbs refer to actions, states, or relations that easily involve the human body, whereas the meanings of other verbs refer to actions, states, or relations that do not easily involve the human body. For example, the meanings of verbs such as “to leap” and “to sleep” easily involve the human body, whereas the meanings of verbs such as “to appreciate” and “to dissolve” do not easily involve the human body. Any verb (e.g., “to leap”) that in your estimation refers to an action, state, or relation that easily involves the human body should be given a high rating (at the upper end of the numerical scale). Any verb (e.g., “to appreciate”) that in your estimation refers to an action, state, or relation that does not easily involve the human body should be given a low rating (at the lower end of the numerical scale). It is important that you base these ratings on how easily an action, state, or relation involves a human body and not on how easily it can be experienced by human senses (e.g., vision, taste, etc.). Also, because words tend to make you think of other words as associates, it is important that your ratings not be based on this and that you judge only how easily an action, state, or relation involves a human body.

The purpose of this experiment is to rate verbs regarding how easily an action, state, or relation involves a human body. In other words, how important is having a body to understanding the meaning of each verb?

Your ratings will be made on a 1 to 7 scale. A value of 1 will indicate actions, states, or relations that do not easily involve the human body, and a value of 7 will indicate actions, states, or relations that do easily involve the human body. Values of 2 to 6 will indicate intermediate ratings. Please feel free to use the whole range of values to make your ratings. When making your ratings, try to be as accurate as possible, but do not spend too much time on any one word.

References

Alario, F. -X., Ferrand, L., Laganaro, M., New, B., Frauenfelder, U. H., & Segui, J. (2004). Predictors of picture naming speed. *Behavior Research Methods, Instruments, & Computers*, *36*, 140–155.

Allport, D. A., & Funnell, E. (1981). Components of the mental lexicon. *Philosophical Transactions of the Royal Society of London. Series B Biological Sciences*, *29*, 397–410.

Amsel, B.D., Urbach, T. P., & Kutas, M. (2013). Perceptual and motor attribute ratings for 559 object concepts. *Behavior Research Methods*, *44*, 1028–1041.

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

Balota, D. A., Ferraro, F. R., & Connor, L. T. (1991). On the early influence of meaning in word recognition: A review of the literature. In P. J. Schwanenflugel (Ed.), *The psychology of word meanings* (pp. 187–222). Hillsdale, NJ: Erlbaum.

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

Barsalou, L. W. (2008). Cognitive and neural contributions to understanding the conceptual system. *Current Directions in Psychological Science*, *17*, 91–95.

Barsalou, L. W., Santos, A., Simmons, W. K., & Wilson, C. D. (2008). Language and simulation in conceptual processing. In M. De Vega, A.M. Glenberg, & A. Graesser (Eds.), *Symbols, embodiment, and meaning*. Oxford, UK: Oxford University Press.

Bennett, S. D. R., Burnett, A. N., Siakaluk, P. D., & Pexman, P.M. (2011). Imageability and body–object interaction ratings for 599 multisyllabic nouns. *Behavior Research Methods*, *43*, 1100–1109.

Bird, H., Franklin, S., & Howard, D. (2001). Age of acquisition and imageability ratings for a large set of words, including verbs and function words. *Behavior Research Methods, Instruments, & Computers*, *33*, 73–79.

Borghi, A.M., & Cimatti, F. (2010). Embodied cognition and beyond: Acting and sensing the body. *Neuropsychologia*, *48*, 763–773.

Boulenger, V., Décoppet, N., Roy, A.C., Paulignan, Y., & Nazir, T. A. (2007). Differential effects of age-of-acquisition for concrete nouns and action verbs: Evidence for partly distinct representations? *Cognition*, *103*, 131–146.

Buchanan, L., Westbury, C., & Burgess, C. (2001). Characterizing semantic space: Neighborhood effects in word recognition. *Psychonomic Bulletin & Review*, *8*, 531–544.

Burgess, C., & Lund, K. (1997). Modeling parsing constraints with high-dimensional context space. *Language & Cognitive Processes*, *12*, 177–210.

Chiarello, C., Shears, C., & Lund, K. (1999). Imageability and distributional typicality measures of nouns and verbs in contemporary English. *Behavior Research Methods, Instruments, & Computers*, *31*, 603–637.

Colombo, L., & Burani, C. (2002). The influence of age of acquisition, root frequency, and context availability in processing nouns and verbs. *Brain and Language*, *81*, 398–411.

Cordier, F., Croizet, J. -C., & Rigalleau, F. (2013). Comparing nouns and verbs in a lexical task. *Journal of Psycholinguistic Research*, *42*, 21–35.

Dove, G. (2009). Beyond perceptual symbols: A call for representational pluralism. *Cognition*, *110*, 412–431.

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin*, *125*, 777–7999.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, *22*, 455–479.

Gennari, S., & Poeppel, D. (2003). Processing correlates of lexical semantic complexity. *Cognition*, *89*, B27–B41.

Glenberg, A.M., & Gallese, V. (2012). Action-based language: A theory of language acquisition, comprehension, and production. *Cortex*, *48*, 905–922.

Grafton, S. T. (2009). Embodied cognition and the simulation of action to understand others. *The Year in Cognitive Neuroscience*, *1156*, 97–117.

Grondin, R., Lupker, S. J., & McRae, K. (2009). Shared features dominate semantic richness effects for concrete concepts. *Journal of Memory and Language*, *60*, 1–19.

Hargreaves, I. S., & Pexman, P. M. (2014). Get rich quick: The signal to respond procedure reveals the time course of semantic richness effects during visual word recognition. *Cognition*, *131*, 216–242.

Hargreaves, I. S., Leonard, G., Pexman, P.M., Pittman, D., Siakaluk, P. D., & Goodyear, B. G. (2012). The neural correlates of the body–object interaction effect in semantic processing. *Frontiers in Human Neuroscience*, http://dx.doi.org/10.3389/fnhum.2012.00022.

Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review*, *111*, 662–720.

Hauk, O., Johnsrude, I., & Pulvermuller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, *41*, 301–307.

Hino, Y., & Lupker, S. J. (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., Lupker, S. J., & Pexman, P.M. (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.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, *14*, S103–S109.

Juhasz, B. J., Yap, M. J., Dicke, J., Taylor, S.C., & Gullick, M. M. (2011). Tangible words are recognized faster: The grounding of meaning in sensory and perceptual systems. *The Quarterly Journal of Experimental Psychology*, *64*, 1683–1691.

Kauschke, C., & Stenneken, P. (2008). Differences in noun and verb processing in lexical decision cannot be attributed to word form and morphological complexity alone. *Journal of Psycholinguistic Research*, *37*, 443–452.

Kuperman, V., Stadthagen-Gonzalez, H., & Brysbaert, M. (2012). Age-of-acquisition ratings for 30,000 English words. *Behavior Research Methods*, *44*, 978–990.
Lund, K., & Burgess, C. (1996). Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior Research Methods, Instruments, & Computers*, *28*, 203–208.
Mahon, B. Z., & Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology — Paris*, *102*, 59–70.
McRae, K., de Sa, V. R., & Seidenberg, M. S. (1997). On the nature and scope of featural representations of word meaning. *Journal of Experimental Psychology: General*, *126*, 99–130.
Nazir, T. A., Boulenger, V., Roy, A., Silber, B., Jeannerod, M., & Paulignan, Y. (2008). Language-induced motor perturbations during the execution of a reaching movement. *The Quarterly Journal of Experimental Psychology*, *61*, 933–943.
Van Overwalle, F., & Baetens, K. (2009). Understanding others' actions and goals by mirror and mentalizing systems: A meta-analysis. *NeuroImage*, *48*, 564–584.
Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology*, *45*, 255–287.
Pexman, P.M. (2012). Meaning based influences on visual word recognition. In J. S. Adelman (Ed.), *Visual word recognition*. : Psychology Press.
Pexman, P.M., Hargreaves, I. S., Edwards, J.D., Henry, L. C., & Goodyear, B. G. (2007). The neural consequences of semantic richness: When more comes to mind, less activation is observed. *Psychological Science*, *18*, 401–406.
Pexman, P.M., Hargreaves, I. S., Siakaluk, P. D., Bodner, G. E., & Pope, J. (2008). There are many ways to be rich: Effects of three measures of semantic richness on visual word recognition. *Psychonomic Bulletin & Review*, *15*, 161–167.
Pexman, P.M., Holyk, G. G., & Monfils, M. -H. (2003). Number of features effects and semantic processing. *Memory & Cognition*, *31*, 842–855.
Pexman, P.M., Lupker, S. J., & Hino, Y. (2002). The impact of feedback semantics in visual word recognition: Number of features effects in lexical decision and naming tasks. *Psychonomic Bulletin & Review*, *9*, 542–549.
Plaut, D. C., & Shallice, T. (1993). Deep dyslexia: A case study of connectionist neuropsychology. *Cognitive Neuropsychology*, *10*, 377–500.
Repetto, C., Colombo, B., Cipresso, P., & Riva, G. (2013). The effects of rTMS over the primary motor cortex: The link between action and language. *Neuropsychologia*, *51*, 8–13.
Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, *2*, 661–670.
Rösler, F., Streb, J., & Haan, H. (2001). Event-related brain potentials evoked by verbs and nouns in a primed lexical decision task. *Psychophysiology*, *38*, 694–703.
Ruschemeyer, S. A., Brass, M., & Friederici, A.D. (2007). Comprehending prehending: Neural correlates of processing verbs with motor stems. *Journal of Cognitive Neuroscience*, *19*, 855–865.
Siakaluk, P. D., Pexman, P.M., Aguilera, L., Owen, W. J., & Sears, C. R. (2008). Evidence for the activation of sensorimotor information during visual word recognition: The body–object interaction effect. *Cognition*, *106*, 433–443.
Siakaluk, P. D., Pexman, P.M., Sears, C. R., Wilson, K., Locheed, K., & Owen, W. J. (2008). The benefits of sensorimotor knowledge: Body–object interaction facilitates semantic processing. *Cognitive Science*, *32*, 591–605.
Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., et al. (2005). Timed action and object naming. *Cortex*, *41*, 7–26.
Tousignant, C., & Pexman, P.M. (2012). Flexible recruitment of semantic richness: context modulates body–object interaction effects in lexical–semantic processing. *Frontiers in Human Neuroscience*, 53, http://dx.doi.org/10.3389/fnhum.2012.00053.
Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*, 625–636.
Wurm, L. H., Vakoch, D. A., & Seaman, S. R. (2004). Recognition of spoken words: Semantic effects in lexical access. *Language and Speech*, *47*, 175–204.
Yap, M. J., Pexman, P.M., Wellsby, M., Hargreaves, I. S., & Huff, M. (2012). An abundance of riches: Cross-task comparisons of semantic richness effects in visual word recognition. *Frontiers in Human Neuroscience*, http://dx.doi.org/10.3389/fnhum.2012.00053.
Yap, M. J., Tan, S. E., Pexman, P.M., & Hargreaves, I. S. (2011). Is more always better? Effects of semantic richness on lexical decision, speeded pronunciation, and semantic classification. *Psychonomic Bulletin & Review*, *18*, 742–750.
Yarkoni, T., Balota, D. A., & Yap, M. J. (2008). Moving beyond Coltheart's N: A new measure of orthographic similarity. *Psychonomic Bulletin & Review*, *15*, 971–979.