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Quantifying sensorimotor experience: Body–object interaction ratings for more than 9,000 English words

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Abstract

Ratings of *body–object interaction* (BOI) measure the ease with which the human body can interact with a word's referent. Researchers have studied the effects of BOI in order to investigate the relationships between sensorimotor and cognitive processes. Such efforts could be improved, however, by the availability of more extensive BOI norms. In the present work, we collected BOI ratings for over 9,000 words. These new norms show good reliability and validity and have extensive overlap with the words used both in other lexical and semantic norms and in the available behavioral megastudies (e.g., the English Lexicon Project, Balota, Yap, Cortese, Hutchison, Kessler, & Loftis in Behavior Research Methods, 39, 445–459, 2007; and the Calgary Semantic Decision Project, Pexman, Heard, Lloyd, & Yap in Behavior Research Methods, 49, 407–417, 2017). In analyses using the new BOI norms, we found that high-BOI words tended to be more concrete, more graspable, and more strongly associated with sensory, haptic, and visual experience than are low-BOI words. When we used the new norms to predict response latencies and accuracy data from the behavioral megastudies, we found that BOI was a stronger predictor of responses in the semantic decision task than in the lexical decision task. These findings are consistent with a dynamic, multidimensional account of lexical semantics. The norms described here should be useful for future research examining the effects of sensorimotor experience on performance in tasks involving word stimuli.

Keywords Body-object interaction · Lexical decision task · Semantic decision task · Sensorimotor processes · Word ratings · Word recognition

In recent years, a great deal of research has explored the relationships between cognition and sensorimotor processing. This work has addressed important questions about how we learn, represent, and retrieve information about the world, and it has examined the extent to which cognition is grounded in our sensorimotor systems. Of particular relevance to the present work are studies that have investigated the role of sensorimotor information in language and cognitive processing by examining the effects of *body–object interaction* (BOI; Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008a). BOI is a variable that measures the ease with which the human body can interact with a word's referent. Words that refer to concrete objects can differ in their rated BOI; for example, the words *boot* and *map* are rated high in BOI, whereas the words *burr* and *moon* are rated low in BOI (Tillotson, Siakaluk, & Pexman, 2008).

Many studies have shown that BOI facilitates language processing, with a processing advantage for high- as compared to low-BOI words. This has been demonstrated in studies examining adults' lexical decisions (Siakaluk, Pexman, Aguilera, et al., 2008a; Tillotson et al., 2008; Van Havermaet & Wurm, 2014), semantic decisions (Bennett, Burnett, Siakaluk, & Pexman, 2011; Hansen, Siakaluk, & Pexman, 2012; Hargreaves et al., 2012; Siakaluk, Pexman, Sears, et al., 2008b; Tousignant & Pexman, 2012; Yap, Pexman, Wellsby, Hargreaves, & Huff, 2012), and sentence reading (Phillips, Sears, & Pexman, 2012; Xue, Marmolejo-Ramos, & Pei, 2015), as well as those examining children's printed word naming (Wellsby & Pexman, 2014) and auditory word naming (Inkster, Wellsby, Lloyd, & Pexman, 2016). In addition, the related dimension of "relative embodiment" has been shown to facilitate lexical–semantic processing for verb

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stimuli (Sidhu, Kwan, Pexman, & Siakaluk, 2014). The neural correlates of BOI effects have also been examined, and there is evidence that the processing of high-BOI words is associated with activation in the left inferior parietal lobule, an area involved in kinesthetic memory (Hargreaves et al., 2012).

BOI effects in lexical and semantic tasks have been interpreted as evidence that sensorimotor experience is an important aspect of semantic knowledge (Pexman, 2012). It is assumed that high-BOI words have richer semantic representations, by virtue of their relatively more extensive associated sensorimotor attributes, and that richer semantic representations facilitate lexical–semantic processing (Siakaluk, Pexman, Aguilera, et al., 2008a). These assumptions are tempered, however, by the results of other studies showing null BOI effects in lexical-/semantic-processing tasks (e.g., Hargreaves & Pexman, 2014; Taikh, Hargreaves, Yap, & Pexman, 2015). One limitation faced by researchers working on questions of sensorimotor effects in language and cognitive processing is that thus far BOI ratings have only been available for a limited set of words, and these words do not all appear in norms for related variables. To our knowledge, BOI ratings are available from just two sources: Tillotson et al. (2008) provided BOI ratings for 1,618 monosyllabic nouns, and Bennett et al. (2011) provided BOI ratings for 599 multisyllabic nouns. Thus, researchers have a limited set of words to draw from in designing studies of sensorimotor processing. The purpose of the present study was to remedy this by collecting BOI ratings for a much larger set of words.

Researchers could address many questions with a new, larger set of BOI norms. For instance, although there is some evidence that the effects of BOI are task-dependent, there is a need for more research on this issue. For example, BOI effects tend to be stronger in tasks that require relatively extensive semantic processing, such as the semantic decision task (e.g., a concrete–abstract decision), than in tasks such as lexical decision (word–nonword decision), which require less extensive semantic processing (e.g., Yap et al., 2012). Even within the semantic decision task, there is evidence that BOI effects vary as a function of the decision category (Newcombe, Campbell, Siakaluk, & Pexman, 2012). Tousignant and Pexman (2012) compared BOI effects across four versions of the semantic decision task. The word stimuli were the same in each case, and they included a set of words that referred to entities (including both high- and low-BOI words) and a set of filler words that referred to actions. When the decision was framed as "is it an entity or a nonentity?" a large BOI effect was observed; when the decision was framed as "is it an entity or an action?" or "is it an action or an entity?" modest BOI effects were observed; finally, when the decision was framed as "is it an action or a nonaction?," a null BOI effect was observed. Thus, BOI information seemed to be more useful when participants expected entity words to be presented, suggesting that the decision context influences lexical–semantic processing. The mechanisms underlying this kind of top-down control are not yet well understood.

The notion that BOI effects are modulated by task context is consistent with other evidence that sensorimotor effects are context-dependent (e.g., Hargreaves & Pexman, 2014; van Dam, Brazil, Bekkering, & Rueschemeyer, 2014; van Dam, Rueschemeyer, Lindemann, & Bekkering, 2010), tending to appear in contexts in which sensorimotor or action information is emphasized or task-relevant. Context-dependent sensorimotor effects are more difficult to reconcile with proposals that sensorimotor systems are accessed automatically in cognitive processing (e.g., Glenberg, 2015). Rather, such effects are more consistent with proposals that sensorimotor systems are flexibly and adaptively recruited when compatible with the context or task demands (e.g., Barsalou, Santos, Simmons, & Wilson, 2008; Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008). New BOI norms would allow researchers to investigate this issue further.

In addition, new BOI norms would allow researchers to test more precisely the ways in which BOI is related to other variables. Some of these relationships have been tested in previous studies, but often with a limited number of stimuli. For instance, there is evidence that BOI is related to concreteness (with high-BOI words tending to have more concrete referents; see Newcombe et al., 2012, for a set of 200 words), age of acquisition (with high-BOI words tending to be acquired earlier; Thill & Twomey, 2016, 151 words), danger (with high-BOI words tending to be less dangerous; Heard, Madan, Protzner, & Pexman, 2018, 521 words), and graspability (with high-BOI words tending to have more graspable referents; Amsel, Urbach, & Kutas, 2012, 266 words; Heard et al., 2018, 521 words). To our knowledge, relationships with other sensorimotor dimensions, such as modality-specific dimensions, have not yet been tested. For instance, Lynott and Connell collected modality-specific ratings for experience through touch, hearing, sight, smell, and taste, for both adjectives (Lynott & Connell, 2009) and nouns (Lynott & Connell, 2013). A larger set of BOI ratings would allow researchers to test new relationships with these types of dimensions, to further understand the structure and effects of sensorimotor experience. Such ratings could also be used to establish whether the relationships that have already been reported are observed more broadly, since it is possible that BOI effects are limited to the particular word types or segments of lexical space for which BOI ratings were previously available.

Many studies have reported BOI effects in lexical–semantic tasks, over and above the effects of related semantic variables (e.g., Yap et al., 2012), but some studies have shown that BOI effects are not significant once other variables are taken into account (e.g., Juhasz, Yap, Dicke, Taylor, & Gullick, 2011). With more stimuli, researchers could more effectively compare the relative contributions of different semantic variables to performance in lexical and semantic tasks, and thus make inferences about the nature of semantic processing and the underlying semantic representations. Findings that multiple semantic variables contribute simultaneously to performance in lexical–semantic tasks have been taken as evidence that semantic representations are multidimensional (e.g., Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008; Pexman, Siakaluk, & Yap, 2013). For instance, the finding that there are simultaneous effects of language-based (e.g., number of semantic neighbors; Buchanan, Westbury, & Burgess, 2001; Siakaluk, Buchanan, & Westbury, 2003) and object-based (e.g., number of semantic features; Pexman, Lupker, & Hino, 2002) semantic dimensions in lexical processing suggests that both types of information are important to word meaning (Pexman et al., 2008). Indeed, according to pluralist or multimodal accounts, there are multiple dimensions of semantic information, including dimensions that capture linguistic, sensory, and motor experience (Dove, 2011; Reilly, Peelle, Garcia, & Crutch, 2016; Vigliocco, Meteyard, Andrews, & Kousta, 2009). Attempts to further investigate the simultaneous influences of these dimensions have, again, been limited by the availability of norms for the relevant dimensions. New BOI norms would help address that limitation.

Method

Participants

The participants were 1,258 Amazon Mechanical Turk (MTurk) workers (708 male, 550 female; M_{age} = 35.59, *SD* = 10.77). Participants were paid US $2. All participants were recruited via MTurk and randomly assigned to a stimulus list. All participants were over 18 years of age and were restricted from rating more than one stimulus list.

Stimuli

The total set of stimuli was composed of 9,351 words. Of these, 6,606 were nouns, 1,496 were verbs, 834 were adjectives, and 413 were some other part of speech (according to the dominant part-of-speech norms in Brysbaert, New, & Keuleers, 2012[1]). Of these, 4,998 were words from the Calgary Semantic Decision Project (Pexman, Heard, Lloyd, & Yap, 2017). In the Calgary semantic decision task (SDT), the semantic decision was whether a word represented a concrete–abstract item, and we chose only words rated "concrete" in that decision, since BOI is most relevant to words that describe concrete things. The remaining 4,353 words were selected because they were listed in one or more of the following sources: the sensory experience rating (SER) norms collected by Juhasz, Yap, Dicke, Taylor, and Gullick (2011) or the iconicity norms collected by Perry, Perlman, and Lupyan (2015) and Winter, Perlman, Perry, and Lupyan (2017). Concreteness values from Brysbaert, Warriner, and Kuperman (2014) were available for all of these words, and frequency values (log subtitle frequency; Brysbaert & New, 2009) were available for 8,986 of the words. Two of the selected words (*villain* and *stingray*) were spelled incorrectly in our stimulus list (as *villian* and *stringray*) and so were excluded from the analyses reported below. Another selected word (*countess*) was misspelled but as a different real word (*countless*), so we included it in the analyses (as *countless*).

We selected 30 of these words as a set of control words. Each of these had a previous BOI rating: 15 from the Bennett et al. (2011) ratings of multisyllabic words, and 15 from the Tillotson et al. (2008) ratings of monosyllabic words. We selected control words that had a range of BOI ratings (five words with ratings between 1.00 and 1.99, five words between 2.00 to 2.99, etc.) and that also varied in length, frequency, and concreteness.

In addition to these 9,351 items, we selected ten practice words. These included five words from the Bennett et al. (2011) ratings and five words from the Tillotson et al. (2008) ratings. Like the control words, the practice words had BOI ratings that spanned the rating scale.

To create the stimulus lists for presentation to participants, we divided the 9,321 words (i.e., excluding the control words, which appeared on each list) into 30 lists of either 310 or 311 words. The lists were created using the SOS! software (Armstrong, Watson, & Plaut, 2012) to equate the lists as much as possible for word frequency, concreteness, and length. Omnibus analyses of variance comparing the lists on these variables were nonsignificant ($p_{\text{Frequency}}$ = .64, $p_{\text{Concreteness}}$ = .56, p_{Length} = 1.00). To each list we then added the 30 control words and the ten practice words, for a total of either 350 or 351 words per list.

Procedure

The word stimuli were presented using Qualtrics and linked to MTurk's crowdsourcing website. The instructions given to participants are presented in the Appendix. Following the consent form and instructions page, participants rated the ten practice words, then proceeded to rate the full list of stimuli. The words were presented in the center of the page, with the rating scale presented horizontally below each word, as well as an "I don't know this word" option. There were 25 words per page, and a description of the rating scale was displayed at the top of each page. A demographic questionnaire was included after the stimulus list: Participants were asked to provide their age, gender, first language, subsequent languages (if applicable), and education level.

Our target was 25 participants per list, and data collection was completed between March 12 and June 1, 2018. As is

[1] Note that part-of-speech information was not available for two words: *deerskin* and *glassblower*.

described below, our exclusion criteria led to the removal of some participants' data. Thus, some of the lists were reposted during this period in order to approach the desired target number of participants per list. Control words were rated by every participant, and each of the other words was rated by an average of 24.30 participants, with a range of 12 to 53 ratings per word. Overall, 98.86% of words were rated by at least 20 participants.

Results

We first cleaned the data by applying a series of criteria, modeled after those outlined in Brysbaert et al. (2014) and consistent with suggestions outlined by Dupuis, Meier, and Cuneo (2018) for screening for invalid data in online questionnaires. To begin with, we only included in our initial dataset participants who had completed more than 33% of the rating task. This resulted in a total of 391,042 observations from 1,258 participants. We then removed the data for 157 participants for whom English was not their first language. Next, we examined each participant's ratings of the 30 control words and generated correlations with the ratings of those words in existing BOI norms (Bennett et al., 2011; Tillotson et al., 2008). We removed 130 participants with a correlation coefficient between – .50 and .20, and reverse-scored the responses of four participants who had a correlation coefficient below – .50. Finally, we removed the data for 183 participants who responded with the same rating value 12 or more times in a row. Next, if more than 15% of the participants reported "not knowing" a particular word, we removed those words from the following data-cleaning step and from the analyses to be reported below. Ratings for 188 words were identified by this criterion and are highlighted in the BOI rating norms. After this process, we removed a further 44 participants whose ratings showed a correlation less than .10 with the average ratings of all participants. This left a total of 743 eligible participants with 252,362 observations, 3,875 of which were "I do not know this word" responses (1.54%). Demographic characteristics of the final group of 743 participants are provided in Table 1.

The resulting BOI ratings are provided here: https://osf.io/6syf3/ (see Table 2 for descriptive statistics) and as a supplementary file to this article. We examined the distribution of these BOI ratings and found a pattern that appeared to be nearly bimodal (Fig. 1). A kernel density plot of these ratings as a function of word type (Fig. 2) shows that this bimodality emerged from the different ratings of nouns as compared to ratings of the other word types. Nouns show a normal distribution across the range of possible BOI ratings, whereas adjectives, adverbs, and verbs received lower ratings and showed positively skewed distributions.

To examine the validity of these ratings, we computed the correlations between the ratings observed here and previous ratings, where available (*n* = 1,893 words; Bennett et al., 2011; Tillotson et al., 2008). We observed a strong positive correlation between these two sets of ratings ($r = .87$, $p < .001$), suggesting good validity. Next we computed the split-half reliability for each of the 30 word lists separately (using 100 random splits per list and taking the average correlation across all iterations). The average split-half reliability across all lists was .91 (*SD* = .03), suggesting good reliability.

Next, we examined the correlations between the new BOI ratings and various lexical and semantic properties of the words (Fig. 3). The lexical variables included letter length, orthographic Levenshtein distance (Yarkoni, Balota, & Yap, 2008), feedforward phonological consistency for first syllable onset and rime, feedback phonological consistency for first syllable onset and rime (Yap & Balota, 2009), and frequency (log subtitle frequency; Brysbaert & New, 2009). The semantic variables included concreteness (Brysbaert et al., 2014); age of acquisition (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012); imageability (Cortese & Fugett, 2004; Schock, Cortese, & Khanna, 2012); perceptual and motor attribute ratings on pain, smell, color, taste, sound, grasp, and motion (Amsel et al., 2012; grasp ratings are supplemented with those reported in Heard et al., 2018); perceptual strength ratings for the auditory, gustatory, haptic, olfactory, and visual modalities (Lynott & Connell, 2009, 2013); danger ratings (Witherell, Wurm, Seaman, Brugnone, & Fulford, 2012; Wurm, 2007; Wurm & Seaman, 2008; Wurm & Vakoch, 2000; Wurm, Whitman, Seaman, Hill, & Ulstad, 2007);

Table 1 Participant demographic characteristics

Characteristic	*n*	Mean (*SD*) [%]
Age	743	37.37 (*11.08*)
Gender female	366	49.13
Gender male	377	50.60
Years of education	686	15.35 (*3.14*)

Table 2 Descriptive statistics for the body–object interaction (BOI) ratings of 9,161 words

Descriptive Statistic	Value for BOI Ratings
Mean	3.55
Median	3.48
Standard deviation	1.37
Minimum	1.12
Maximum	6.88
1st quartile	2.32
3rd quartile	4.64
Skewness	0.25
Kurtosis	– 1.03

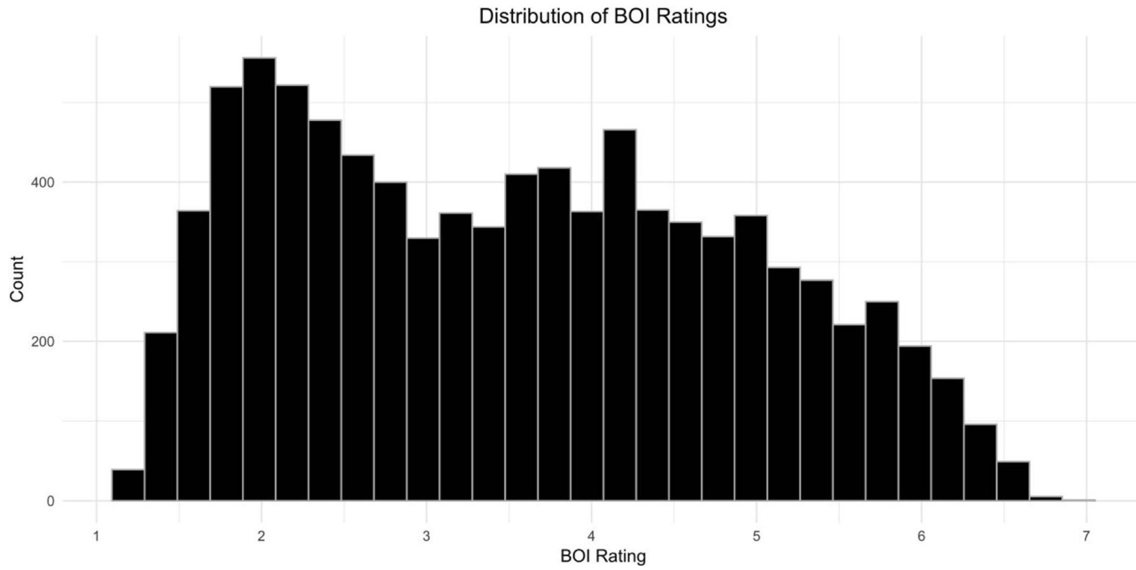

Fig. 1 Histogram of body–object interaction (BOI) ratings for 9,161 items

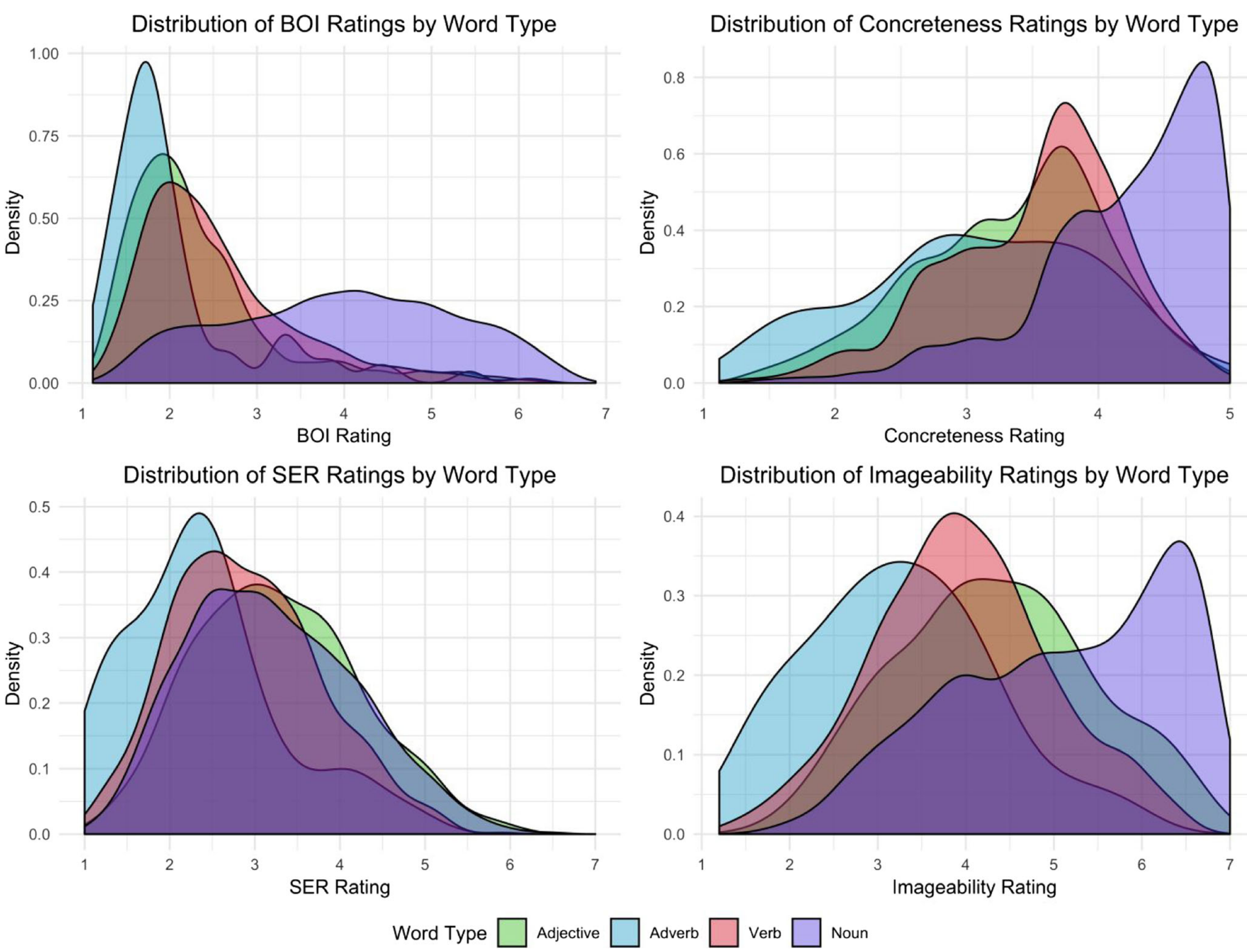

Fig. 2 Kernel density plot for the body–object interaction (BOI) ratings of adjectives, adverbs, verbs, and nouns (n = 8,828; top left). Also included are plots for the available concreteness (Brysbaert et al., 2014; n = 8,828; top right), imageability (Cortese & Fugett, 2004; Schock et al., 2012; n = 4,389; bottom right), and sensory experience (SER; Juhasz & Yap, 2013; n = 4,312; bottom left) ratings of these items

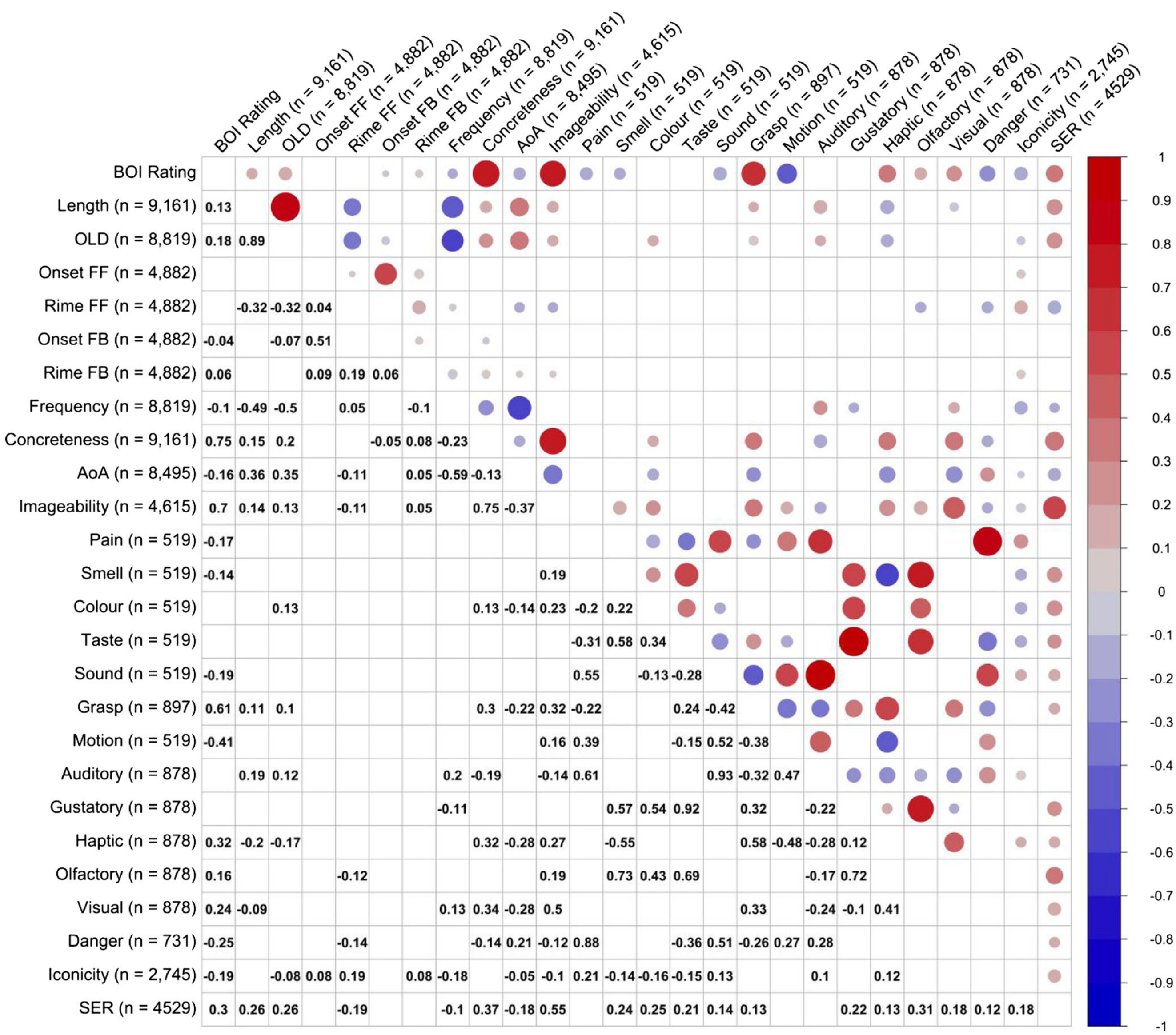

Fig. 3 Correlations between BOI and various lexical and semantic dimensions. The strength and direction of the coefficients are indicated by the size and color, respectively, of circles above the diagonal, and by numbers below the diagonal. Note that only correlations significant at $p < .01$ are shown. The values in parentheses are the numbers of items in common with our set of BOI ratings. BOI = body–object interaction; OLD = orthographic Levenshtein distance; AoA = age of acquisition; SER = sensory experience rating

iconicity ratings (Perry et al., 2015; Winter et al., 2017); and SERs (Juhasz & Yap, 2013).

These correlations revealed several interesting relationships that provide insight as to the nature of BOI. For instance, BOI ratings show positive correlations with concreteness ($r = .75$, $p < .001$), imageability ($r = .70$, $p < .001$), and SERs ($r = .30$, $p < .001$), reflecting the greater amount of embodied sensory information associated with these items. The correlations also allow us to explore this notion at a finer grain; for instance, items rated higher in BOI tend to be more graspable ($r = .61$, $p < .001$) and to have greater perceptual strength in the haptic ($r = .32$, $p < .001$) and visual ($r = .24$, $p < .001$) modalities. Interestingly, the correlations also reveal what kinds of words tend to have *low* BOI ratings: those that cause pain ($r = -.17$, $p < .001$), involve motion ($r = -.41$, $p < .001$), are dangerous ($r = -.25$, $p < .001$), and are iconic ($r = -.19$, $p < .001$).

Next, we examined the relationships of BOI ratings with performance in lexical–semantic tasks, using responses from the English Lexicon Project LDT (Balota et al., 2007) and the Calgary Semantic Decision Project SDT (Pexman et al., 2017). These correlations are presented across the full range of BOI ratings (Fig. 4). Note that these figures include all words for which LDT and SDT data are available in the megastudy datasets. As is illustrated in Fig.

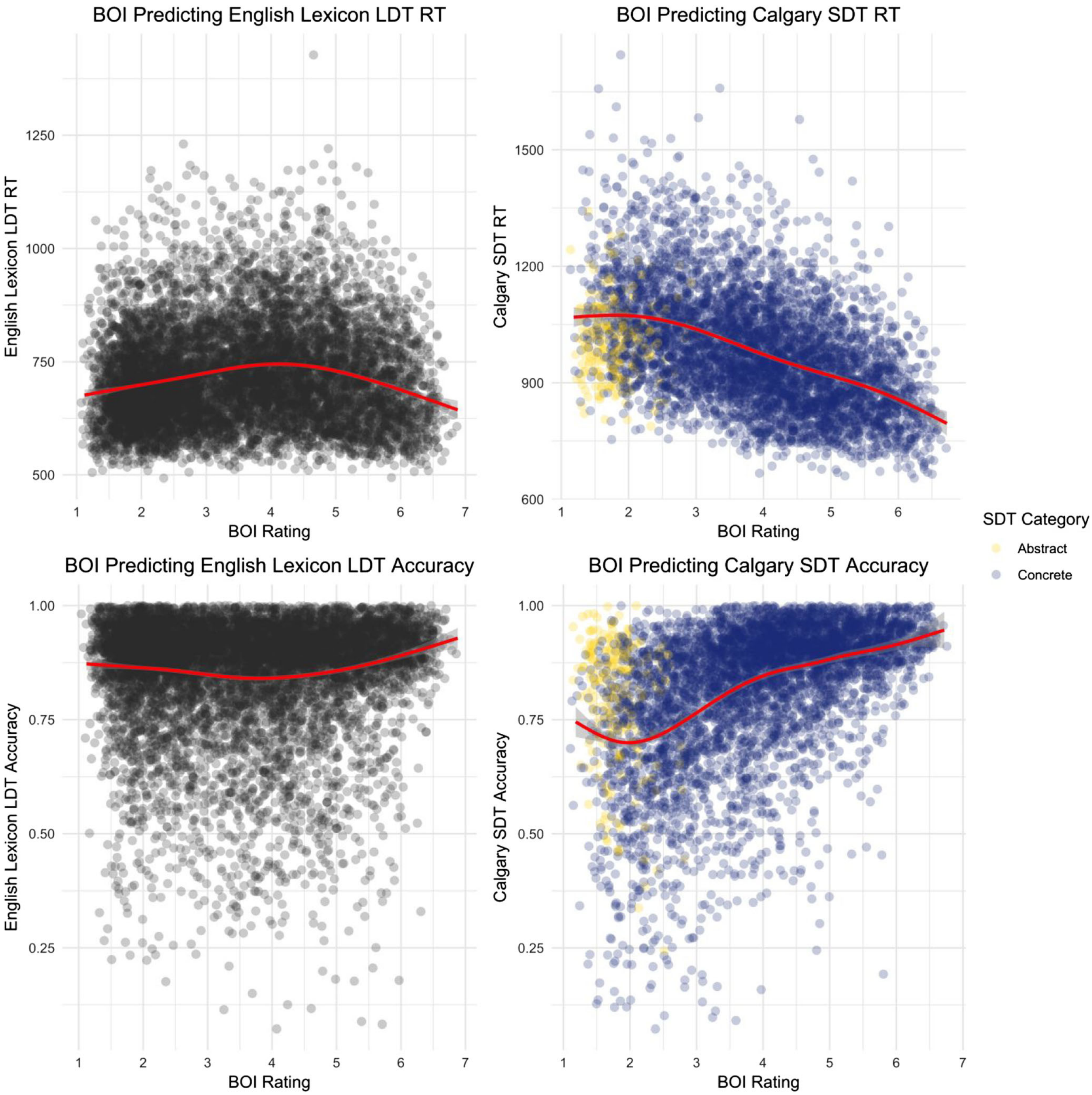

Fig. 4 Relationships between body–object interaction (BOI) ratings and, clockwise from the top left: English Lexicon Project lexical decision task (LDT) response latencies ($n = 8{,}819$), Calgary Semantic Decision Project semantic decision task (SDT) response latencies ($n = 5{,}087$), Calgary Semantic Decision Project SDT response accuracy, and English Lexicon Project LDT response accuracy. Relationships were visualized using a loess function. *SDT Category* refers to whether the correct response for an item was "Abstract" or "Concrete" in the Calgary Semantic Decision Project

4, the relationship between BOI and the LDT measures changes over the range of BOI and appears to be quadratic rather than linear. That is, BOI appears to facilitate responses on the LDT only past the midpoint of BOI. This nonlinearity is also apparent for the SDT. Although BOI generally shows a strong facilitatory effect for SDT responses, this is not true for the lowest quartile of the BOI ratings. Notably, these are words with low concreteness values for which participants responded "Abstract" on the SDT. Indeed, Newcombe et al. (2012) reported that when participants made semantic decisions to abstract nouns (is it abstract?), BOI was associated with slower and less accurate responses. This pattern further speaks to the possibility that BOI effects are moderated by decision category (see also Tousignant & Pexman, 2012). On a larger scale, these patterns suggest that researchers are most likely to see BOI effects in the LDT for words with BOI ratings above the midpoint, and in the SDT for words with "concrete" responses.

We next conducted a series of regression analyses to further examine the relationships of BOI to lexical and semantic processing. These analyses included other lexical and semantic predictors in order to isolate the unique relationships of BOI to processing. For these analyses, we included only those words for which *both* LDT (Balota et al., 2007) and SDT (Pexman et al., 2017) data were available in the existing megastudy datasets. The SDT megastudy dataset includes responses for words that were classified as "concrete" and responses for words that were classified as "abstract," and there is evidence that participants have different criteria for these two responses (Newcombe et al., 2012; Pexman & Yap, 2018). To simplify the inferences in the present analyses, in both the LDT and SDT analyses we included only those words that were given "concrete" responses in the SDT. Furthermore, given the different natures of BOI for nouns and for other word types (Fig. 2), we conducted two versions of each of these regression analyses: In the first versions of these analyses, we included all word types (n = 4,106 words), and in the second versions of the analyses we included only nouns (n = 3,591 words).

We examined the relationship of BOI to English Lexicon Project LDT latencies using hierarchical regression. LDT latencies were standardized as z-scores (these minimize the influence of a participant's overall processing speed and variability; Faust, Balota, Spieler, & Ferraro, 1999), and all predictor variables were mean-centered. The lexical variables letter length and letter length squared (length^2; New, Ferrand, Pallier, & Brysbaert, 2006), word frequency, word prevalence (Brysbaert, Mandera, McCormick, & Keuleers, 2018), and OLD were entered in Step 1, and the semantic variables were entered in Step 2. These semantic variables included age of acquisition, concreteness, BOI and, in light of the nonlinear BOI relationships depicted in Fig. 4, BOI^2. The results for all word types are presented in Table 3. In this analysis, the lexical variables were all significant predictors of LDT latencies. LDT latencies were faster for words that are shorter, more frequent, more prevalent, and less orthographically distinct. Of the semantic variables, age of acquisition was a significant predictor of LDT latencies, with faster LDT latencies for words acquired early in life. BOI^2 was also a significant predictor, indicating a quadratic trend between BOI and LDT latency, with faster responses for both very low and high BOI (past the midpoint of the scale) values. The results for nouns only are presented in Table 4. In this analysis, the same lexical variables remained significant predictors for LDT latencies, and both age of acquisition and BOI^2 were significant predictors, though the effect of BOI^2 was reduced relative to the full word analysis. Concreteness was also a significant predictor of LDT latencies for noun stimuli, with faster LDT latencies for more concrete nouns.

We repeated the same regression analyses for English Lexicon Project LDT accuracy. The results for all word types are presented in Table 5. In this analysis, the lexical variables were all significant predictors of LDT accuracy. LDT accuracy was higher for longer, more frequent, more prevalent, and less orthographically distinct words. As in the latency analysis, age of

Table 3 Regression coefficients from item-level regression analyses for English Lexicon Project LDT latencies (n = 4,106)

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					$.60^{***}$	$.60^{***}$
Length	.04	.004	.21	$.10^{***}$		
Length^2	.01	.001	.13	$.13^{***}$		
Frequency	– .12	.01	– .24	$-.18^{***}$		
Prevalence	– .40	.01	.13	$-.34^{***}$		
OLD	.06	.01	.15	$.07^{***}$		
Step 2 (Semantic variables)					$.63^{***}$	$.03^{***}$
AoA	.03	.002	.21	$.17^{***}$		
Concreteness	.02	.01	.02	.01		
BOI	– .01	.004	– .03	$-.02^{*}$		
BOI^2	.01	.002	.04	$.04^{***}$		

LDT = lexical decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

Table 4 Regression coefficients from item-level regression analyses of nouns only (n = 3,591) for English Lexicon Project LDT latencies

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					$.60^{***}$	$.60^{***}$
Length	.04	.004	.20	$.10^{***}$		
Length^2	.01	.001	.14	$.13^{***}$		
Frequency	– .11	.01	– .22	$-.17^{***}$		
Prevalence	– .40	.01	– .44	$-.34^{***}$		
OLD	.06	.01	.16	$.08^{***}$		
Step 2 (Semantic variables)					$.63^{***}$	$.03^{***}$
AoA	.03	.002	.21	$.16^{***}$		
Concreteness	.03	.01	.03	$.02^{*}$		
BOI	– .01	.01	– .02	– .01		
BOI^2	.01	.003	.02	$.02^{*}$		

LDT = lexical decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

Table 5 Regression coefficients from item-level regression analyses for English Lexicon Project LDT accuracy (n = 4,106)

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					.42***	.42***
Length	.02	.002	.24	.12***		
Length²	– .001	.000	– .05	– .05***		
Frequency	.07	.003	.41	.07***		
Prevalence	.20	.01	.58	.46***		
OLD	– .02	.003	– .11	– .05***		
Step 2 (Semantic variables)					.46***	.04***
AoA	– .01	– .001	– .24	– .19***		
Concreteness	.003	.01	.01	.01		
BOI	– .002	.002	– .02	– .01		
BOI²	– .004	.001	– .04	– .04***		

LDT = lexical decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. * $p < .05$; ** $p < .01$; *** $p < .001$

acquisition and BOI² were also significant predictors of LDT accuracy. The results for nouns are presented in Table 6. In this analysis, the lexical variables were again significant predictors of LDT accuracy, as were age of acquisition and BOI².

We next repeated the regression analyses for Calgary Semantic Decision Project SDT latencies, using SDT latencies standardized as z-scores. The results for all word types are presented in Table 7. In this analysis, the lexical variables were all significant predictors of SDT latencies. SDT latencies were faster for shorter, more frequent, and more prevalent words; however, in a different pattern from that observed for the LDT latencies, SDT latencies were faster for more orthographically distinct words. Age of acquisition, concreteness, and BOI were significant predictors of SDT latencies, with faster latencies for words that are acquired earlier in life and are more concrete. BOI² was also a significant predictor for SDT latency, indicating a nonlinear trend for BOI. The results for nouns are presented in Table 8. In this analysis, all lexical and semantic variables were again significant predictors.

Finally, we repeated the regression analyses for Calgary Semantic Decision Project SDT accuracy. The results for all word types are presented in Table 9. In this analysis, the lexical variables were significant predictors of SDT accuracy. Responses were more accurate for shorter, more frequent, more prevalent, and more orthographically distinct words. Age of acquisition, concreteness, and BOI² were also significant predictors of response accuracy, with greater accuracy for words that are acquired earlier or more concrete. Once again, a nonlinear trend was observed for BOI. The results for nouns are presented in Table 10. In this analysis, the lexical variables were significant predictors of SDT accuracy, with the exception of frequency, as were age of acquisition, concreteness, and BOI².

Table 6 Regression coefficients from item-level regression analyses of nouns only (n = 3,591) for English Lexicon Project LDT accuracy

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					.42***	.42***
Length	.02	.002	.24	.12***		
Length²	– .001	.000	– .06	– .06***		
Frequency	.01	.003	.07	.05***		
Prevalence	.19	.01	.59	.46***		
OLD	– .01	.004	– .11	– .05***		
Step 2 (Semantic variables)					.46***	.04***
AoA	– .01	.001	– .23	– .18***		
Concreteness	.003	.01	.01	.01		
BOI	– .002	.002	– .02	– .01		
BOI²	– .003	.001	– .03	– .03***		

LDT = lexical decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. * $p < .05$; ** $p < .01$; *** $p < .001$

Table 7 Regression coefficients from item-level regression analyses for Calgary Semantic Decision Project SDT latencies (n = 4,106)

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					.20***	.20***
Length	.12	.01	.52	.25***		
Length^2	.01	.001	.10	.09***		
Frequency	– .10	.01	– .16	– .12***		
Prevalence	– .31	.02	– .28	– .22***		
OLD	– .21	.01	– .47	– .23***		
Step 2 (Semantic variables)					.49***	.29***
AoA	.05	.003	.27	.21***		
Concreteness	– .25	.02	– .23	– .16***		
BOI	– .09	.01	– .25	– .18***		
BOI^2	.03	.003	.10	.09***		

SDT = semantic decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. * $p < .05$; ** $p < .01$; *** $p < .001$

Discussion

In the present work, we collected new BOI rating norms for a large set of words. The resulting norms have good validity, as evidenced by a strong correlation between the new ratings and those collected in previous norming studies (Bennett et al., 2011; Tillotson et al., 2008). This consistency was observed despite the fact that the previous BOI ratings were collected in laboratories from undergraduate students (at the University of Northern British Columbia and the University of Calgary) and the new BOI ratings were collected online from MTurk workers. Thus, it seems likely that the norms described in the present work will be generalizable to a broad range of participants in future studies.

Importantly, the correlational analyses of the new BOI norms provide insights as to the nature of the BOI dimension. High-BOI words refer to entities that tend to be graspable and associated with haptic and visual perceptual experience. Furthermore, BOI ratings tended to be lower for words that evoke pain, motion, and danger. Many of these items are living things that, although very concrete, do not afford easy bodily interaction. These findings are consistent with the inferences made by Heard et al. (2018) about the importance of grasping to BOI effects. The present findings also go beyond some of the previous work; the large number of words included in the new norms has allowed new inferences. For instance, across 8,495 words we found that the relationship between BOI and AoA was modest but significant (r = – .16, $p < .001$). That is, high-BOI words tend to be acquired at a younger age than low-BOI words, perhaps reflecting the role of sensorimotor experience in grounding children's early concepts (Thill & Twomey, 2016). Across 4,529 words we found that the relationship between BOI and SER was positive (r = .30, $p < .001$), suggesting that the two dimensions have some similarity but are also capturing distinct aspects of sensorimotor experience. In addition, the plots presented in Fig. 2 show that BOI distinguishes lexical categories (in particular, nouns from the other types) more effectively than does SER. This points to an additional distinction between SER and BOI and also suggests that BOI may be an effective dimension for exploring the semantic basis of lexical categories. Those distinctions could be explored in future research.

The correlation between BOI and concreteness could be computed for all 9,161 words in the new norms, and it was strong and positive (r = .75, $p < .001$). Although strongly related, both variables had significant unique relationships with processing measures in the SDT and with latencies for nouns in the LDT. This suggests that both dimensions capture important information about semantic representation and processing. As such, the findings are consistent with a multidimensional account of lexical semantics (e.g., Reilly et al., 2016). Further insight as to semantic representation could be gleaned in future studies by examining whether the effects of other meaning dimensions, particularly those derived from linguistic or episodic sources, co-occur with BOI effects.

The regression analyses reported here provide support for the task-dependent nature of BOI effects. The semantic variables (BOI and concreteness) explained considerably more variance in the SDT than in the LDT. With lexical and other semantic variables in the

Table 8 Regression coefficients from item-level regression analyses of nouns only (n = 3,591) for Calgary Semantic Decision Project SDT latencies

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					.22***	.22***
Length	.12	.01	.54	.27***		
Length^2	.01	.001	.09	.09***		
Frequency	– .08	.01	– .13	– .10***		
Prevalence	– .33	.02	– .31	– .25***		
OLD	– .20	.01	– .44	– .22***		
Step 2 (Semantic variables)					.48***	.26***
AoA	.05	.003	.27	.21***		
Concreteness	– .24	.02	– .22	– .16***		
BOI	– .09	.01	– .22	– .17***		
BOI^2	.02	.004	.08	.08***		

SDT = semantic decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. * $p < .05$; ** $p < .01$; *** $p < .001$

Table 9 Regression coefficients from item-level regression analyses for Calgary Semantic Decision Project SDT accuracy (n = 4,106)

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					$.08^{***}$	$.08^{***}$
Length	– .03	.002	– .38	$-.19^{***}$		
Length^2	– .002	.000	– .08	$-.07^{***}$		
Frequency	.01	.004	.073	$.06^{***}$		
Prevalence	.05	.007	.15	$.12^{***}$		
OLD	.08	.01	.51	$.25^{***}$		
Step 2 (Semantic variables)					$.37^{***}$	$.29^{***}$
AoA	– .01	.001	– .21	$-.17^{***}$		
Concreteness	.09	.01	.26	$.18^{***}$		
BOI	.03	.002	.24	$.18^{***}$		
BOI^2	– .02	.001	– .18	$-.17^{***}$		

SDT = semantic decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

analyses, BOI effects were more evident in the SDT than in the LDT. These differences are, presumably, attributable to the different processing demands in the two tasks and the dynamic nature of semantic processing. Task context influences the ways that BOI information is recruited in the two tasks. In the LDT, the focus is largely on orthographic processing, and semantic activation is involved only indirectly, in terms of feedback from the semantic units to the orthographic units. Effects of BOI are observed in the LDT because BOI can provide evidence that a letter string is a real word. In the SDT, the focus is on semantic processing per se, and semantic variables such as BOI that influence semantic activation will thus have stronger effects on response measures (see also Yap et al., 2012).

Thus, the present work builds on the previous literature, showing that semantic information is multimodal and that semantic processing is both dynamic and modulated by task demands. In future research it will be important to begin to group (and dissociate) some of the many semantic dimensions that have been described in recent years, to better understand the factor structure of semantic representation. In addition, in the present work we have shown that there is nonlinearity in the relationship between BOI and lexical–semantic processing. This is likely true of other semantic dimensions, but to our knowledge, this possibility has not yet been examined. We also think that there will be utility to future studies that investigate the effects of semantic dimensions on the time course of semantic processing. Such studies may involve electroencephalography, reaction time distributional analyses, and other

Table 10 Regression coefficients from item-level regression analyses of nouns only (n = 3,591) for Calgary Semantic Decision Project SDT accuracy

Variable	B	SEB	β	sr	R^2	ΔR^2
Step 1 (Lexical variables)					$.08^{***}$	$.08^{***}$
Length	– .03	.002	– .42	$-.21^{***}$		
Length^2	– .002	.000	– .07	$-.21^{***}$		
Frequency	.002	.004	.01	.01		
Prevalence	.06	.01	.18	$.14^{***}$		
OLD	.07	.004	.51	$.25^{***}$		
Step 2 (Semantic variables)					$.32^{***}$	$.24^{***}$
AoA	– .01	.001	– .21	$-.16^{***}$		
Concreteness	.08	.01	.25	$.18^{***}$		
BOI	.03	.002	.22	$.16^{***}$		
BOI^2	– .01	.001	– .14	$-.13^{***}$		

SDT = semantic decision task; OLD = orthographic Levenshtein distance; AoA = age of acquisition; BOI = body–object interaction. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

methods that provide insight about the timing of semantic effects.

Conclusion

These new norms of BOI ratings should be useful for researchers studying the effects of sensorimotor experience in language processing as well as in other cognitive tasks that involve word stimuli (e.g., recall, recognition, paired associate learning). As such, these ratings should facilitate future research and help answer outstanding questions about the relationships between cognition and sensorimotor processes.

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Appendix: BOI ratings instructions

Words differ in the extent to which they refer to objects or things that a human body can physically interact with. Some words refer to objects or things that a human body can easily physically interact with, whereas other words refer to objects or things that a human body cannot easily physically interact with. The purpose of this experiment is to rate words as to the ease with which a human body can physically interact with what they represent. For example, the word "chair" refers to an object or thing that a human body can easily physically interact with (e.g., a human body can sit on a chair, or stand on a chair, or move a chair from one part of a room to another), whereas the word "ceiling" refers to an object or thing that a human body cannot easily physically interact with (e.g., a human body could jump up and touch a ceiling). Any word (e.g., "chair") that in your estimation refers to an object or thing that a human body can easily physically interact with should be given a high body-object interaction rating (at the upper end of the numerical scale). Any word (e.g., "ceiling") that in your estimation refers to an object or thing that a human body cannot easily physically interact with should be given a low body–object interaction rating (at the lower end of the scale).

It is important that you base these ratings on how easily a human body can physically interact with what a word represents, 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 the ease with which a human body can physically interact with what a word represents.

Your body–object interaction ratings will be made on a 1 to 7 scale. A value of 1 will indicate a low body–object interaction rating, and a value of 7 will indicate a high body–object interaction rating. Values of 2 to 6 will indicate intermediate ratings. Please feel free to use the whole range of values provided when making your ratings. Choose the rating that is most appropriate for each word. When making your ratings, try to be as accurate as possible, but do not spend too much time on any one word.

1 2 3 4 5 6 7

Low Medium High

If you would like to withdraw from the survey at any point, hit the "next" button at the bottom of each page until you reach the end.

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