A potential embodied influence in the semantic effects of Danger and Usefulness is investigated using Body-Object Interaction (BOI). Lexical decision times are influenced by ratings of Danger and Usefulness. In a frequently-found interaction, thought to be produced by activated approach-withdraw motor responses, increasing Danger ratings produce faster responses for items with lower Usefulness ratings while producing slower responses for items with higher Usefulness ratings. BOI is used to test the embodied explanation of this interaction. The same 102 words were presented in two lexical decision experiments. In both auditory and visual lexical decision, the effects of Danger and Usefulness were found to be diminished for items with higher BOI ratings. BOI moderates Danger and Usefulness effects in both auditory and visual lexical decision, in a way that suggests BOI is either the stronger or the temporally earlier effect.

Keywords: lexical access, visual lexical decision, auditory lexical decision, danger, usefulness, embodiment, body-object interaction, survival processing
recognition paradigm (usually auditory lexical decision). In each of the studies just mentioned, an interaction between Danger and Usefulness was found: For words rated relatively low on Usefulness, increasing Danger is associated with faster RTs; for words rated higher on Usefulness, increasing Danger is associated with slower RTs.

To explain this interaction Wurm (2007) proposed a framework in which meaning is extracted in two stages. The starting assumption of this framework is that the perceptual-motor system is predisposed to engage in approach behavior for things high on Usefulness and withdraw behavior for things high on Danger. A rapid, automatic first pass gives the perceptual system rough information about Danger and Usefulness. Sometimes information from this first stage alone will be enough for preparations to be made for an appropriate approach or withdraw response, even before a full semantic analysis (the second pass) has taken place. According to this account, increasing Danger in the context of low Usefulness is unambiguous and leads to faster RTs. Increasing Danger in the context of high Usefulness is associated with slower RTs because things high on both Danger and Usefulness activate both conflicting response patterns.

The foregoing account is embodied, in that it assumes that mental processes are grounded in sensory and motor experiences. Such accounts often emphasize the bidirectional relationship between bodily actions and cognition and/or simulation, the offline activation of all modalities (perceptual, motor, etc.) related to a concept or experience (Barsalou, 1999, 2008; Margaret Wilson, 2002). Influences of embodiment can be found in many aspects of cognition and behavior, including attitudes, judgments, emotion, distance perception, object preference, and even physical and moral purity (Jostmann, Lakens, & Schubert, 2009; Lee & Schwarz, 2010; Proffitt, Stefanucci, Banton, & Epstein, 2003; Strack, Martin, & Stepper, 1988; Tom, Pettersen, Lau, Burton, & Cook, 1991; Zhong & Leonardelli, 2008; Zhong & Liljenquist, 2006).

There is also evidence of embodiment in language, shown in studies of affective language processing, sentence comprehension, reading, priming, and recognition of single words (Myung, Blumstein, & Sedivy, 2006; Glenberg & Kaschak, 2002; Meier & Robinson, 2004; Havas, Glenberg, & Rinck, 2007; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005; Pulvermüller, Härlé, & Hummel, 2001; Hauk & Pulvermüller, 2004). In speeded visual and auditory lexical decision tasks, participants responded more quickly to words when primed by a word that shared action characteristics (e.g. target = typewriter; prime = piano) compared to a prime with few shared action characteristics (e.g. blanket) (Myung, Blumstein, & Sedivy, 2006).

Similarly, judging the sensibility of sentences is influenced by type of response required. Glenberg and Kaschak (2002) presented participants with sentences that
expressed a meaning with a specific direction (toward (put your finger under your nose) or away (close the drawer)) and asked them to decide as quickly as possible if the sentence made sense. Responses required either a reach forward or a move toward the body to press the response button. Response directions that were consistent with the sentence direction facilitated sentence comprehension.

Similar kinds of effects can also be observed with affective behaviors and language. In a study focusing on the metaphor concerning good/bad concepts and vertical position, evaluations of positive words are faster when they are presented higher in the visual field while evaluations of negative words are faster when presented lower. Conversely, after making a speeded evaluation, in an immediate discrimination task requiring a response of \( p \) or \( q \), responses were quicker when the correct answer was in the vertical position corresponding to the valence of the previous trial (e.g. correct answer in the up position after a positive word) (Meier & Robinson, 2004). When judging valence and sensibility of sentences, latencies of responses for both judgments are quicker when facial expressions match the valence of the sentence (Havas, Glenberg, & Rinck, 2007).

The idea that sensorimotor information plays a significant role in the processing of language is supported by functional links between motor and language areas of the brain, even showing activation of motor areas specific to word meaning. Transcranial magnetic stimulation (TMS) of arm motor areas in the left hemisphere resulted in enhanced processing of arm related action words but not leg related action words. Likewise TMS of leg motor areas resulted in enhanced processing of leg related action words but not arm related action words (Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). During a speeded lexical decision task, responses to verbs related to movement of the arms, legs and face (e.g. talk, pick, walk) produced strongest activation, measured using EEG recordings, in the motor areas related to the body parts responsible for carrying out the action in the verb (Pulvermüller, Härle, & Hummel, 2001). Similar results were found using a passive reading task measured with fMRI. Action words associated with movement of the arms, legs and face produced activation in body-part-specific motor areas (Hauk & Pulvermüller, 2004). These studies all point to an influence of sensorimotor information in language processing.

Body-Object Interaction (BOI) is a recently developed dimension that attempts to capture how sensorimotor knowledge affects semantic processing. BOI is defined as the ease or difficulty with which one can physically interact with a concept (Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008a; Siakaluk, Pexman, Sears, Wilson, Locheed, & Owen, 2008b), a definition with an obvious relationship to embodiment. In studies using a variety of speeded tasks (semantic categorization, semantic lexical decision, word and picture naming, lexical decision) items with high BOI ratings have been shown to produce faster and more accurate
responses compared to items with low BOI ratings (Siakaluk et al., 2008a, 2008b; Bennett, Burnett, Siakaluk, & Pexman, 2011; Wellsby, Siakaluk, Owen, & Pexman, 2011; Yap, Pexman, Wellsby, Hargreaves, & Huff, 2012).

The facilitative BOI effect has been interpreted as evidence of the role of sensorimotor information in semantic processing. It therefore provides an intriguing backdrop against which to evaluate whether the Danger and Usefulness effects in word recognition, described above, require the embodied explanation they have generally been given.

In the current study we test whether BOI interacts with Danger and/or Usefulness, in auditory and visual lexical decision. This combination of tasks provides maximum contact with the Danger and Usefulness literature, nearly all of which has used auditory lexical decision. It also allows for a linkage to studies of BOI processing, all of which have used visual processing.

Because Danger and Usefulness effects are presumed to reflect embodiment, BOI is expected to interact with them. The question is how, and there would seem to be two broad possibilities. On the one hand, Danger and Usefulness effects might be enhanced for items with higher BOI ratings, which could suggest a kind of synergy among the embodied variables. On the other hand, because embodiment need not necessarily reflect the kind of survival processing presumed to underlie Danger and Usefulness effects, the variables might not work together synergistically. Danger and Usefulness effects might be diminished for items with higher BOI ratings, which could suggest that the variables compete for processing resources.

**Preliminary Rating Study**

**Method**

**Stimuli**

102 common nouns that had Danger and Usefulness values available from other studies (Kryuchkova, Tucker, Wurm, & Baayen, 2012; Witherell et al., 2012; Wurm, 2007; Wurm & Vakoch, 2000) were selected. These are shown in the Appendix.

**Participants**

Participants were 113 native speakers of English with normal or corrected-to-normal vision, recruited from the Psychology participant pool at Wayne State University. They received extra credit in a psychology class in exchange for their participation.
**Procedure**
Participants viewed the stimuli one at a time on a computer screen and rated each one on the ease with which a person can physically interact with it (the full instructions from Tillotson et al. (2008) were used). Stimuli were presented in a different random order for each participant. Integers from 1 to 7 could be used. The following rating scale was displayed on-screen for the entire duration of the rating session:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Results and Discussion**

The mean BOI rating was calculated for each item, and used as that item's BOI value in subsequent analyses. Mean values ranged from 1.94 (*vampire*) to 6.24 (*food*), and their distribution was suitably normal without being transformed.

**Experiment 1: Auditory Lexical Decision**

**Method**

**Stimuli**

Real-word stimuli were described above. An equal number of nonwords were generated using the Wuggy pseudoword generator (Keuleers & Brysbaert, 2010). Wuggy generates orthographic stimuli, which we used in Experiment 2 below. These were matched to the real words on length and orthographic neighborhood. For purposes of the current experiment the pseudowords were phonetically transcribed and read by a male speaker unfamiliar with the purposes of the study. Stimuli were digitized at a sampling rate of 44.1 kHz, amplitude normalized, and stored in individual disk files. The spoken words and pseudowords were well-matched on duration (483 and 484 ms, respectively; $t(202) = -.0461, p = .963$).

**Participants**

Participants were 111 native speakers of English with normal hearing and normal or corrected-to-normal vision, recruited from the Psychology participant pool at Wayne State University. They received extra credit in a psychology class in exchange for their participation.
Procedure
Participants were tested one at a time in a sound-attenuating chamber. Stimuli were presented over headphones at a comfortable intensity chosen by each participant. Participants were directed to decide as quickly and accurately as possible whether each stimulus was a real word in English. They pressed one button for real words and a different button for pseudowords. Reaction times (RTs) were measured from the onset of each stimulus. Stimuli were presented in a different random order for each participant.

Data Analysis
In both experiments, a multilevel linear mixed-effects analyses of covariance with participants and items as crossed random factors was used to analyze the RTs (Baayen, 2008a).1 Main effects were entered in a first step. Two-way interactions between BOI, Danger, and Usefulness were entered in a second step. The three-way interaction was entered in a final step. The significance of a given effect was assessed at the step at which it was entered. In addition to the BOI values collected in the Preliminary Rating Study above, regressor values included each word’s Danger and Usefulness values (from the studies listed above), spoken duration, uniqueness point (UP — the point at which the word becomes uniquely identifiable in English; Marslen-Wilson & Welsh, 1978), word frequency (from the English Lexicon Project Database (Balota et al., 2007)), neighborhood density (defined as the number of words still consistent with the acoustic input one phoneme prior to the UP; Wurm, 2007; Wurm & Ross, 2001; Wurm et al., 2007), and concreteness (from the MRC Psycholinguistic Database (M. Wilson, 1988)).

Several variables had moderate positive skew and were log transformed to reduce the effects of atypical outliers: duration, UP, frequency, neighborhood density, Danger, and Usefulness. Concreteness values had mild negative skew. These values were reflect-and-square-root transformed (Tabachnik & Fidell, 2007), and then multiplied by –1 so the direction of the regression coefficient can be interpreted normally. BOI values were suitably normal without any transformation. Means and standard deviations for all variables used in the statistical analyses are shown in Table 1.

Results and Discussion
Data from two participants with low accuracies (both < .67) were discarded. Data from four of the 102 items (noose, jet, bean, and jail) were also discarded, as performance was not significantly better than chance for these items.
Overall accuracy was .95. RTs on the correct trials were retained for analysis, except for RTs faster than 500 ms from acoustic onset (0.4% of the data) or more than 2.5 standard deviations slower than the grand mean (2.3% of the data). Results of the analysis are shown in Table 2.

Words with longer durations, later UPs, or denser neighborhoods had slower RTs. Words with higher frequencies or concreteness values had faster RTs. BOI and Danger also had significant facilitative main effects. This is the first demonstration of a BOI effect in auditory lexical decision. However, interpretation of this effect, and of the Danger effect, must be qualified by their involvement in significant interactions.

Figure 1 shows the Danger x Usefulness interaction. This figure was plotted using the regression equation from the second step of the analysis, with all regressors set equal to their means except Danger and Usefulness. Danger was defined as a vector running from the lowest value in the stimulus set to the highest value in the stimulus set. High and low Usefulness were defined as one standard deviation above and below the mean Usefulness value in the stimulus set, respectively. Other figures in this paper were created by the same method.

As the figure shows, the relationship between Danger and RT depends on Usefulness, becoming inhibitory for higher values of Usefulness. This is precisely the nature of the interaction described in the Introduction, which has been observed several times in previous studies.

Table 1. Mean Stimulus Values on the Predictor Variables (Standard Deviations in Parentheses).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>9.37 (1.43)</td>
</tr>
<tr>
<td>Duration(a)</td>
<td>6.16 (0.20)</td>
</tr>
<tr>
<td>Uniqueness Point (UP)(a)</td>
<td>5.96 (0.26)</td>
</tr>
<tr>
<td>Length(b)</td>
<td>1.52 (0.26)</td>
</tr>
<tr>
<td>Number of auditory competitors(a)</td>
<td>2.14 (1.35)</td>
</tr>
<tr>
<td>Concreteness</td>
<td>-9.72 (5.27)</td>
</tr>
<tr>
<td>BOI</td>
<td>4.41 (0.90)</td>
</tr>
<tr>
<td>Danger</td>
<td>0.91 (0.51)</td>
</tr>
<tr>
<td>Usefulness</td>
<td>1.45 (0.32)</td>
</tr>
</tbody>
</table>

Note. Frequency, Duration, Uniqueness Point, Length, Number of auditory competitors, Danger, and Usefulness were log transformed. Concreteness was reflect-and-square-root transformed, and then multiplied by -1 so that the direction of the regression coefficient could be interpreted normally.

\(a\) Used only in the auditory experiment

\(b\) Used only in the visual experiment

Overall accuracy was .95. RTs on the correct trials were retained for analysis, except for RTs faster than 500 ms from acoustic onset (0.4% of the data) or more than 2.5 standard deviations slower than the grand mean (2.3% of the data). Results of the analysis are shown in Table 2.

Words with longer durations, later UPs, or denser neighborhoods had slower RTs. Words with higher frequencies or concreteness values had faster RTs. BOI and Danger also had significant facilitative main effects. This is the first demonstration of a BOI effect in auditory lexical decision. However, interpretation of this effect, and of the Danger effect, must be qualified by their involvement in significant interactions.

Figure 1 shows the Danger x Usefulness interaction. This figure was plotted using the regression equation from the second step of the analysis, with all regressors set equal to their means except Danger and Usefulness. Danger was defined as a vector running from the lowest value in the stimulus set to the highest value in the stimulus set. High and low Usefulness were defined as one standard deviation above and below the mean Usefulness value in the stimulus set, respectively. Other figures in this paper were created by the same method.

As the figure shows, the relationship between Danger and RT depends on Usefulness, becoming inhibitory for higher values of Usefulness. This is precisely the nature of the interaction described in the Introduction, which has been observed several times in previous studies.
Table 2. Summary of Analysis for Variables Predicting Response Time in Auditory Lexical Decision Task.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient ((B))</th>
<th>Standard error of (B)</th>
<th>(t)</th>
<th>(p_{MCMC})</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>−0.017</td>
<td>0.001</td>
<td>−12.85</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>Duration</td>
<td>0.259</td>
<td>0.009</td>
<td>28.31</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>UP</td>
<td>0.075</td>
<td>0.008</td>
<td>9.75</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>NComp</td>
<td>0.007</td>
<td>0.001</td>
<td>5.53</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>Concrete</td>
<td>−0.002</td>
<td>0.000</td>
<td>−6.62</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>BOI</td>
<td>−0.018</td>
<td>0.002</td>
<td>−8.61</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>Danger</td>
<td>−0.012</td>
<td>0.003</td>
<td>−3.65</td>
<td>0.0006</td>
<td>0.0003</td>
</tr>
<tr>
<td>Usefulness</td>
<td>−0.010</td>
<td>0.006</td>
<td>−1.61</td>
<td>0.1008</td>
<td>0.1070</td>
</tr>
<tr>
<td><strong>Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D \times BOI)</td>
<td>0.017</td>
<td>0.004</td>
<td>4.17</td>
<td>0.0002</td>
<td>0.0000</td>
</tr>
<tr>
<td>(U \times BOI)</td>
<td>0.012</td>
<td>0.005</td>
<td>2.32</td>
<td>0.0216</td>
<td>0.0206</td>
</tr>
<tr>
<td>(D \times U)</td>
<td>0.016</td>
<td>0.013</td>
<td>2.08</td>
<td>0.0342</td>
<td>0.0376</td>
</tr>
<tr>
<td>(D \times U \times BOI)</td>
<td>0.015</td>
<td>0.012</td>
<td>1.28</td>
<td>0.1878</td>
<td>0.1992</td>
</tr>
</tbody>
</table>

Note. \(p_{MCMC}\) is the probability from the Markov chain Monte Carlo simulation and \(p\) is the traditional probability (see Note 1).

Figure 1. Log RT for Experiment 1 as a function of Danger and Usefulness, in ms. U stands for Usefulness.
Figure 2 shows the BOI x Danger (left panel) and BOI x Usefulness (right panel) interactions. The two horizontal axes do not show the same ranges, because they have been drawn to include only values that actually occurred in our stimulus set. Readers are reminded that this study did not have stimulus groups defined by high or low values on any dimension, and that all predictor variables of interest were continuous. Thus, certain kinds of questions are not answered by the analysis we performed (e.g. whether the vertical distance between an L and an H on Figure 2 is significant).²

Figure 2. The two-way interactions between Body-Object Interaction (BOI) and Danger (left panel) and between BOI and Usefulness (right panel).
The significant interactions in our multi-level model indicate that the slope relating BOI to log RT varies significantly as a linear function of an additional predictor (Danger in the left panel; Usefulness in the right panel). What we can say about both panels of Figure 2 is that as BOI values increase, the relationships of Danger (left panel) and Usefulness (right panel) to log RT become diminished. Put another way, at higher values of BOI, responses are generally fast and the other variables have little effect. This pattern supports the competition hypothesis outlined in the Introduction and suggests that BOI is the strongest of these effects.

To assess this possibility, we constructed Figure 3, which shows the three key main effects on the same y-axis scale. This will allow us to determine whether the
BOI effect is stronger than the other two. As the figure shows, the BOI effect is more than three times as large as the others.

Another implication of the competition hypothesis is that the BOI effect might emerge earlier in processing. One indirect way to assess this possibility is to examine performance on the fastest trials of the experiment. We re-ran Step 1 of the hierarchical analysis shown in Table 1, but restricted the data to those trials that were faster than the median RT. For this half of the data, there was a robust facilitative effect of BOI ($B = -.010$, $SE_B = .002$, $t = -5.18$, $p < .001$), and no effect of either Danger or Usefulness ($B = -.002$, $SE_B = .003$, $t = -0.56$, $p = .574$ and $B = -.007$, $SE_B = .006$, $t = 1.19$, $p = .234$, respectively). This outcome also supports the competition hypothesis: On the trials that produced the fastest lexical decisions, and for which there were no traces of Danger or Usefulness effects, BOI was already significantly facilitating processing. This is consistent with the possibility that BOI gets temporal priority in processing. We will explore this issue further in Experiment 2.

Experiment 2: Visual Lexical Decision

All previous work on the BOI construct has used visual stimulus presentation. Experiment 1 demonstrated that the BOI effect can be observed with auditory presentation as well, but we decided to replicate Experiment 1 with visual stimulus presentation in order to make maximum contact with the existing BOI literature.

Method

Stimuli
The stimuli from Experiment 1 were used, in printed rather than spoken form.

Participants
Participants were 97 native speakers of English with normal or corrected-to-normal vision, recruited from the Psychology participant pool at Wayne State University. They received extra credit in a psychology class in exchange for their participation.

Procedure
Participants were tested one at a time in a sound-attenuating chamber. Stimuli were presented in capital letters in the center of a computer screen. Participants
were directed to decide as quickly and accurately as possible whether each stim-
ulus was a real word in English. They pressed one button for real words and a
different button for pseudowords. Reaction times (RTs) were measured from the
onset of each stimulus. Stimuli were presented in a different random order for
each participant.

Data Analysis
Data were analyzed as in Experiment 1, but auditory regressors were changed to
visual ones where appropriate. Length in letters was substituted for duration in
ms, neighbors were defined orthographically rather than in terms of a spoken
cohort (values were taken from the English Lexicon Project (Balota et al., 2007)),
and UP was dropped as it has no visual counterpart. Length in letters was log
transformed because of skew. No transformation of neighborhood density result-
ed in adequate normality so it was converted to a two-level factor. More than four
neighbors was considered many \( (n = 52) \) and four or fewer was considered few
\( (n = 50 \) stimuli).

Results and Discussion
Data from one participant with low accuracy (.47) were discarded. Data from two
of the 102 items (noose and syringe) were also discarded, as performance was not
significantly better than chance for these items.

Overall accuracy was .95. RTs on the correct trials were retained for analysis,
except for RTs faster than 300 ms from visual onset (0.7% of the data) or more
than 2.5 standard deviations slower than the grand mean (1.7% of the data). Re-
results of the analysis are shown in Table 3.

Longer words had slower RTs. Words with higher frequencies or concreteness
values had faster RTs. BOI and Usefulness had significant facilitative main effects,
and Danger had a significant inhibitory main effect. BOI interacted once again
with both Danger and with Usefulness. As in Experiment 1 any interpretation of
lower-level effects must be qualified by the highest-level interaction, which in this
case was a significant three-way interaction.

In an analysis with continuous predictors, a significant three-way interaction
means that the effect of a two-way interaction varies significantly as a linear func-
tion of some third predictor. There are three different ways to decompose such an
interaction so that it can be interpreted. In this case, because the expected nature
of the Danger x Usefulness interaction is known from previous research, we di-
vided the data set into a low-BOI half (items at or below the median on BOI) and
We then assessed the Danger x Usefulness interaction for each half of the data separately.

For items low on BOI (left panel of Figure 4), the Danger x Usefulness interaction was significant ($B = .085$, $SE_B = .025$, $t = 3.37$, $p < .001$). This is the same slope relationship observed in previous research, as well as in Experiment 1 of the current study (notice the similarity between the left panel of Figure 4 and Figure 1). The relationship between Danger and RT depends on Usefulness, becoming more inhibitory as values of Usefulness increase.

The right panel of Figure 4 shows the analogous plot for items high on BOI. For these items, the Danger x Usefulness interaction was not significant ($B = -.026$, $SE_B = .029$, $t = -0.92$, $p = .357$). Comparison of the two halves of Figure 4 reveals the nature of the three-way interaction: The two-way interaction between Danger and Usefulness weakens, and in fact becomes non-significant, as BOI increases. As in Experiment 1, then, the conclusion is that high BOI attenuates Danger and Usefulness effects (in this case their joint effect).

As in Experiment 1, we assessed whether the BOI main effect was stronger and/or temporally prior to these other effects. Figure 5 shows the three key main effects on the same y-axis scale. In contrast to Experiment 1, the BOI effect was not the largest of the three.

### Table 3. Summary of Analysis for Variables Predicting Response Time in Visual Lexical Decision Task.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient $(B)$</th>
<th>Standard error of $B$</th>
<th>$t$</th>
<th>$pMCMC$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>–0.026</td>
<td>0.002</td>
<td>–16.71</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>Length</td>
<td>0.024</td>
<td>0.009</td>
<td>2.59</td>
<td>0.0104</td>
<td>0.0095</td>
</tr>
<tr>
<td>OrthoN</td>
<td>–0.006</td>
<td>0.005</td>
<td>1.32</td>
<td>0.1920</td>
<td>0.1884</td>
</tr>
<tr>
<td>Concrete</td>
<td>–0.001</td>
<td>0.000</td>
<td>–2.56</td>
<td>0.0120</td>
<td>0.0106</td>
</tr>
<tr>
<td>BOI</td>
<td>–0.008</td>
<td>0.002</td>
<td>–3.49</td>
<td>0.0004</td>
<td>0.0005</td>
</tr>
<tr>
<td>Danger</td>
<td>0.016</td>
<td>0.004</td>
<td>4.17</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>Usefulness</td>
<td>–0.054</td>
<td>0.007</td>
<td>–7.29</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td><strong>Interactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D x BOI</td>
<td>0.027</td>
<td>0.005</td>
<td>5.59</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>U x BOI</td>
<td>0.024</td>
<td>0.006</td>
<td>4.05</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>D x U</td>
<td>–0.000</td>
<td>0.017</td>
<td>–0.01</td>
<td>0.9996</td>
<td>0.9896</td>
</tr>
<tr>
<td>D x U x BOI</td>
<td>–0.049</td>
<td>0.014</td>
<td>–3.47</td>
<td>0.0002</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

Note. $pMCMC$ is the probability from the Markov chain Monte Carlo simulation and $p$ is the traditional probability (see Note 1).
Also as in Experiment 1, we re-ran Step 1 of our main analysis, but restricted the data to those trials that were faster than the median RT. For this half of the data, there was no effect of BOI ($B = -0.001, \text{SE} B = 0.002, t = -0.6, p = 0.561$), but both Danger and Usefulness were significant ($B = 0.007, \text{SE} B = 0.003, t = 2.2, p < 0.05$ and $B = -0.027, \text{SE} B = 0.006, t = -4.7, p < 0.001$, respectively). This outcome patterns exactly the opposite of that seen in Experiment 1. Our best guess about why has to do with differences in the time-course of information uptake in the two modalities, a point we will return to below.

**Figure 4.** The three-way interaction between Danger, Usefulness, and BOI, in Experiment 2. U stands for Usefulness. The left panel shows log RT as a function of Danger and Usefulness, in ms, for items at or below the median on Body-Object Interaction (BOI). For these items, the Danger x Usefulness interaction was significant. The right panel shows the same thing for items above the median on BOI. For these items, the Danger x Usefulness interaction was not significant.
General Discussion

The current study provides the first demonstration of a facilitative BOI effect in auditory lexical decision. All previous work had relied on visual paradigms. In addition, the current study is one of only three (Benette et al., 2011; Yap et al., 2012) to statistically treat BOI as the continuous construct that it is. All other studies have used BOI ratings to divide stimuli into groups of high- and low-BOI items, a strategy that imposes artificial structure on the construct and reduces statistical power (e.g. Baayen, 2004).

Figure 5. Comparison of the sizes of the main effects for Body-Object Interaction (BOI), Danger, and Usefulness in Experiment 2. The BOI main effect translates to about 22 ms. The Danger main effect translates to about 17 ms. The Usefulness main effect translates to about 45 ms.
The current study sheds important new light on the interaction between Danger and Usefulness observed in several previous studies of word recognition (Witherell et al., 2012; Wurm, 2007, 2012; Wurm & Seaman, 2008; Wurm & Vakoch, 2000; Wurm et al., 2004, 2007). Previous studies have offered an embodied interpretation of the interaction, and it is for this reason that BOI (a construct explicitly created to index embodiment) was expected to interact with Danger and Usefulness. The current study was the first attempt to tie Danger and Usefulness effects directly to an explicitly embodied processing variable. In addition, because nearly all of the existing literature on Danger and Usefulness used auditory stimulus presentation, the current study is important for showing that Danger and Usefulness interact in visual word recognition, at least for items lower on BOI. That BOI interacted in the way it did suggests competition with Danger and Usefulness rather than synergy, which might be due to the fact that the information captured by BOI is of a more general type than that indexed by Danger and Usefulness. BOI simply indexes the possibility of physical interaction with something, while Danger and Usefulness are defined to have specific relevance to survival processing.

The three-way interaction between Danger, Usefulness, and BOI was only significant in one of the two experiments. We do not take this to mean, though, that embodied effects on lexical processing work in one way for printed words and another way for spoken words. Instead, we think the cross-experiment differences are probably due to the differing time-courses of information uptake in the two modalities. Information uptake is virtually instantaneous for a single printed word, whereas the average auditory stimulus required nearly 500 ms to unfold. It is thus not surprising that the results of the two experiments did not match perfectly. After all, even fast, automatic processes cannot be completed before the necessary stimulus information has been presented.

Nevertheless, there were many similarities in the results of the two lexical decision experiments, and we can characterize the moderating effect of BOI in the same way for both of them: Higher BOI values attenuate the effects of Danger and Usefulness. Thus BOI seems to compete with these other constructs for processing resources.

Experiment 1 provided additional evidence in support of this account. The BOI effect was larger than the Danger and Usefulness effects, and the BOI effect was significant in the faster half of the auditory lexical decision times while the Danger and Usefulness effects were not. Follow-up analyses in the visual experiment, though, did not support that same conclusion. As we discuss below, other kinds of methodologies would allow a more direct assessment of this explanatory mechanism, and thus additional research should help explain these cross-experiment differences.
The current study reinforces the conclusion of the earlier work on BOI, that sensorimotor information is available during semantic processing and influences the speed with which words are accessed. Words referring to objects that are more easily manipulated have more sensorimotor information associated which leads to faster processing (Siakaluk et al., 2008a, 2008b). The current study thus adds to the literature suggesting that sensorimotor information may be incorporated into the semantic representation. Furthermore, most previous work in this area used some variant of semantic categorization, and the current study shows that the effects of BOI are observable even in tasks thought to tap into earlier stages of processing.

Related to this, it is interesting that even though lexical decision does not explicitly require engagement of the semantic system, effects of variables like BOI, Danger, and Usefulness emerge in the RTs. This, too, lends support to the idea that language is represented in an embodied fashion.

The current study adds to the literature showing that the act of accessing a word in the mental lexicon is influenced by low-level, behaviorally-relevant semantic variables. Effects like these have never been included in any formal model of word recognition, and some models can accommodate the effects more easily than others. The flexibility of connectionist models means that there would be multiple possibilities for how to model semantic effects. Danger, Usefulness, and BOI might affect resting activation levels, or connection weights, or they might even be used at later, decision stages. Models that do not allow for top-down exchange of information would seem to be at more of a disadvantage, but here, too, it would be possible to model semantic effects. Theorists would need to tie the semantic information in question to the stored lexical information, and to make that information available in a cascaded fashion (i.e. information would need to be available for use before recognition is complete; e.g. Boot & Pecher, 2008; Forster, 2006; Forster & Hector, 2002).

From the realm of spoken word recognition, the distributed cohort model (DCM; Gaskell & Marslen-Wilson, 1997) would seem most amenable to accommodating effects such as those found in the current study. In this model, the speech signal is mapped directly onto a distributed representation for a word (i.e. there are no discrete units that correspond to individual words). This representation carries all information associated with that word, including semantics. As soon as a lexical match has occurred, all information is extracted. The model thus seems to readily predict semantic effects in word recognition, although it is almost completely unspecified as to the nature of the semantic information associated with a word. The model’s architecture makes it straightforward to accommodate semantic effects in word recognition; one would simply add the required information to each word’s semantic node.
Wurm (2007; Wurm et al., 2007) described a two-pass model of meaning extraction in spoken word recognition. A very fast, rough, automatic analysis (cf. Kryuchkova et al., 2012; Robinson, 1998) provides an assessment of stimuli on a small number of adaptively and behaviorally relevant dimensions such as Danger, Usefulness, and BOI. A second, less fast analysis would provide full access to the meaning of the word. Information from the incomplete first pass is hypothesized to be enough for initial behavioral preparations to be made. Theoretical approaches that define meaning in terms of features (e.g. Harm & Seidenberg, 2004; McRae, de Sa, & Seidenberg, 1997; McRae, Cree, Seidenberg, & McNorgan, 2005) might be meshed with the DCM, providing the front end of this kind of a model.

As noted above, one promising avenue for future work is to employ other research methodologies. ERPs offer a more continuous view of lexical processing than discrete button presses from a lexical decision task. Kryuchkova et al. (2012) found Danger effects very early in auditory lexical processing, while Usefulness effects emerged later. BOI has never been examined in an ERP study. Doing so would allow a very direct test of our conjecture above that BOI is a temporally earlier effect than Danger and Usefulness.

It would also be informative to employ methods more closely tied to embodiment. In a classic study, Chen and Bargh (1999) found that participants were faster to pull a lever toward themselves for positively-valenced words and to push a lever away for negatively-valenced words. Dozens of variants and many control conditions have been run since that original study, but to our knowledge none of the studies has looked at Danger, Usefulness, or BOI.

Including BOI in research studies employing varied methodologies would clarify its role among more well-established (and thus better understood) processing variables, and provide valuable information about how it would need to be modeled. It would also allow for more wide-reaching conclusions about the embodied nature of lexical knowledge.

Authors’ Note

We thank Patricia Siple, Lara Jones, and Jean Andruski for helpful comments during the planning of this project.
Notes

1. There is no agreed-upon method for calculating degrees of freedom for this analysis, and the procedure for calculating effect sizes is thus unclear. For the same reason, there are multiple ways to compute $p$-values. The value printed by most software can be anticonservative (Baayen, 2008a; Baayen, Davison, & Bates, 2008). Baayen (2008b; Baayen et al., 2008) recommends a Monte-Carlo based solution using 10,000 generated samples. In the current study effects will only be reported and discussed as significant if they are significant by both the traditional and the Monte Carlo methods.

2. Similarly, one reviewer wondered whether the apparent facilitation shown for the H line in the right panel of Figure 2 was significant. The effect being illustrated by that line translates to roughly 12 ms, but as we have just noted, this kind of question cannot be answered by our analysis because that line does not represent a discrete group of items. A separate analysis focusing only on items at least one standard deviation above the mean on BOI revealed no significant effect of Usefulness ($p > .32$). Thus, if one wants to, it is not inappropriate to think of that line as being statistically flat.

References


**Appendix**

**Stimuli**

angel, apple, arm, army, axe, bag, ball, barn, basket, bean, bear, bench, board, bomb, boot, bottle, bull, bus, cannon, cheese, choir, circle, cliff, cotton, crab, crow, devil, diamond, doll, drum, earth, fish, fist, flag, flower, food, fork, gift, girl, globe, guard, hair, hammer, hand, heart, hill, hook, horn, hospital, house, jail, jet, key, knife, lake, lamp, lightning, lock, magazine, man, money, nail, napkin, neck, noose, nun, ocean, owl, paint, pea, pencil, pie, pin, priest, race, rat, razor, rock, school, shell, skunk, smoke, spring, stove, string, sun, swan, sword, syringe, tarantula, tiger, torch, trap, trunk, vampire, vest, volcano, water, week, window, woman, wood

**Corresponding Address**

Lisa R. Van Havermaet
Clarke University
Department of Psychology
1550 Clarke Drive
Dubuque, IA 52001
USA
lisavhav@gmail.com