**Quantifying children's sensorimotor experience:
Child body-object interaction ratings for 3,359 English words**

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Abstract

Body-object interaction (BOI) ratings measure how easily the human body can physically interact with a word's referent. Previous research has found that words higher in BOI tend to be processed more quickly and accurately in tasks such as lexical decision, semantic decision, and syntactic classification, suggesting that sensorimotor information is an important aspect of lexical knowledge. However, limited research has examined the importance of sensorimotor information from a developmental perspective. One barrier to addressing such theoretical questions has been a lack of semantic dimension ratings that take into account child sensorimotor experience. The goal of the current study was to collect Child BOI rating norms. Parents of children aged 5 – 9-years-old were asked to rate words according to how easily an average 6-year-old child can interact with each word's referent. The relationships of Child and Adult BOI ratings with other lexical semantic dimensions were assessed, as well as the relationships of Child and Adult BOI ratings with age of acquisition. Child BOI ratings were more strongly related to valence and sensory experience ratings than Adult BOI ratings and were a better predictor of three different measures of age of acquisition. The results suggest that child-centric ratings such as those reported here provide a more sensitive measure of children's experience that can be used to address theoretical questions in embodied cognition from a developmental perspective.

Keywords: embodied cognition, body-object interaction, word ratings, age of acquisition, language development

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In recent years, there has been considerable debate about the role of sensorimotor information in semantic processing (Meteyard, Rodriguez Cuadrado, Bahrami, & Vigliocco, 2012). Strong embodied theories propose that sensorimotor processes are essential for learning and retrieving the meanings of words (e.g., Glenberg & Gallese, 2012); in contrast, unembodied or traditional cognitive theories assume that sensorimotor processes are separable from the amodal, symbolic processes that enable semantic processing (e.g., Collins & Loftus, 1975). In between lie weakly embodied or secondary embodiment theories, by which semantic processing is assumed to draw on multiple systems, including those that process sensorimotor, emotion, interoceptive, and linguistic information (Andrews, Vigliocco, & Vinson, 2009; Borghi et al., 2019; Barsalou, Santos, Simmons, & Wilson, 2008), as well as, in some accounts, hubs or convergence zones (e.g., Patterson, Nestor, & Rogers, 2007).

One strategy that researchers have used to assess the role of sensorimotor information in semantic processing is to test for the body-object interaction (BOI) effect. BOI was first characterized by Siakaluk and colleagues as the relative ease with which the human body can interact with a word's referent (Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008). The BOI effect involves faster and/or more accurate responding for words rated high in BOI (e.g., *chair*, *map*, *mask*, *toothbrush*) than for words rated low in BOI (e.g., *comet*, *moon*, *ship*, *unicorn*), even when the high and low BOI words are equivalent in their other lexical-semantic characteristics, including concreteness, imageability, frequency, etc. (Pexman, Muraki, Sidhu, Siakaluk, & Yap, 2019). Studies have now shown BOI effects in numerous tasks with adult participants, including semantic decisions for word stimuli (Bennett, Burnett, Siakaluk, & Pexman, 2011; Hansen,

Siakaluk, & Pexman, 2012; Hargreaves et al., 2012; Muraki & Pexman, 2021; Tousignant & Pexman, 2012; Yap, Pexman, Wellsby, Hargreaves, & Huff, 2012), sentence reading (Phillips, Sears, & Pexman, 2012; Xue, Marmolejo-Ramos, & Pei, 2015), picture recognition (Winter, Stoeger, & Suggate, 2021), and mental rotation of objects (Suggate, Lehmann, Stoeger, & Jansen, 2019). Recent work has demonstrated that the main driver of BOI ratings is referent graspability (Heard, Madan, Protzner, & Pexman, 2019; Pexman et al., 2019): high BOI referents tend to be easy to grasp. In neuroimaging studies, semantic processing of high BOI (vs low BOI) words is associated with neural regions involved in grasping (Hargreaves et al., 2012) and praxis is associated with specific deficits in semantic processing for high BOI words (Riccardi, Yourganov, Rorden, Fridriksson, & Desai, 2019). Thus, BOI ratings do seem to correspond to variability in adults' physical experiences interacting with objects.

In a smaller number of studies, researchers have tested embodiment's developmental predictions by investigating BOI effects in children's word knowledge and lexical processing. These studies tested the embodied prediction that sensorimotor experience should facilitate children's vocabulary acquisition and have also investigated when BOI effects emerge in children's lexical processing. Using parent-report data of children's early word acquisition (MacArthur Communicative Development Inventory; MCDI, Fenson et al., 1993), Thill and Twomey (2016) examined the relationship between words' rated BOI and age of acquisition (AoA) for a set of 151 words for which both measures were available. They found that words rated high in BOI tended to be acquired earlier, even after differences in word frequency and rated imageability were controlled. This relationship was further explored by Pexman et al. (2019) using large-scale ratings norms for AoA (Kuperman, Stadthagen-Gonzalez, & Brysbaert,

2012) and BOI. Across the resulting set of 8,495 words, they found that words rated high in BOI also tended to be rated as early acquired.

A handful of studies have examined effects of BOI on children's lexical processing. First, Suggate and Stoeger (2017; also Winter et al., 2021) measured the time it took 3- to 6-year-old children to point to pictures of high and low BOI objects on hearing the names of those objects. They found that children were faster to point to pictures of high BOI referents than low BOI referents. Further, Suggate and Stoeger found that children's fine motor skills were uniquely related to their pointing latencies for high BOI objects, which the authors took as evidence for the role of sensorimotor experience in vocabulary development. Second, Wellsby and Pexman (2014) tested for BOI effects in children's word naming, with children aged 6-9 years alongside a group of adults. They found that only the older children (aged 8-9 years) and adults showed facilitatory BOI effects in naming responses. Wellsby and Pexman concluded that BOI effects in lexical processing emerge around 8 years of age, when children have sufficient reading efficiency and sensorimotor experience to enjoy processing benefits of richer semantic representations for high BOI words.

Third, Inkster and colleagues (Inkster, Wellsby, Lloyd, & Pexman, 2016) investigated whether children showed BOI effects at a younger age when the response task did not depend on their reading skills. Inkster et al. used an auditory naming task where 6- to 7-year-old children heard high- and low-BOI words and simply repeated those words aloud. In a departure from the previous studies, Inkster et al. also measured BOI by asking a group of parents to rate BOI for the word stimuli from an average 6-year-old's perspective (a dimension they called *Child BOI*). The results showed that children had faster naming latencies for words that parents had rated as high BOI from a child's perspective than for words that parents had rated as low BOI

from a child's perspective. They took this Child BOI effect as evidence that children as young as 6 years of age have richer semantic representations for words that afford easy physical interaction, consistent with developmental predictions of an embodied account of word meaning.

The BOI ratings used in most studies conducted thus far have been provided by adult participants making reference to adult bodies. This is true even in developmental studies, and indeed most studies of children's vocabulary acquisition and lexical-semantic processing rely on adult ratings when examining effects of different semantic dimensions. See, for instance, studies examining effects of adult-rated imageability on children's vocabulary acquisition (e.g., Hansen, 2017; Ma, Golinkoff, Hirsh-Pasek, McDonough, & Tardif, 2009) and lexical processing (e.g., Coltheart, Laxon, & Keating, 1988; Schwanenflugel & Akin, 1994). It seems likely that sensitivity is lost when using ratings of adult experience to predict children's behaviour. This practice is particularly problematic for BOI because the BOI variable is meant to capture relative differences in experiences physically interacting with objects, and child bodies allow different sensorimotor experiences than do adult bodies. Indeed, Thill and Twomey (2016) suggested there was a need for child-centric lexical and semantic predictors, in particular for BOI. As mentioned, this issue was addressed in the Inkster et al. (2016) study by collecting Child BOI ratings from parents, but on a very small scale; in that study 16 parents provided Child BOI ratings for just 60 words.

The goal of the present study was to collect ratings of Child BOI for a large set of words. We compared these new ratings to the existing Adult BOI ratings, as well as to lexical and semantic dimensions to characterize the unique aspects of child vs adult experience captured in BOI ratings. We included lexical dimensions in our analysis in acknowledgement that linguistic

information is not independent of semantic information (e.g., semantic dimensions such as concreteness have been associated with lexical dimensions; Lievers, Bolognesi, & Winter, 2021). We included semantic dimensions that index sensorimotor experience in our analysis to provide a more nuanced understanding of the type of sensorimotor experience uniquely captured by the Child BOI ratings. We also tested the utility of these ratings to account for variability in AoA measures, to determine if child-centric dimensions are a useful tool for future research on sensorimotor effects in language and cognitive development.

Method

Participants

Participants were recruited from a participant database managed by the Child and Infant Learning and Development (Ch.I.L.D.) research group at the University of Calgary. We were interested in ratings that reflected the experience of a 6-year-old, because this is the age at which BOI effects seem to emerge in lexical-semantic processing (Inkster et al., 2016). We included parents who had children between 5 and 9 years of age in order to include as large a sample as possible of individuals who would soon or had recently had a child who was 6 years old. Parents were contacted via email and asked to complete a survey on the online platform, Qualtrics. All participants were given a \$10 gift card as a token of appreciation for their contribution to the project. Participants were twice reminded of the opportunity to participate in the study. After the second reminder was sent, a technical error occurred in the survey platform, resulting in 57 participant responses which had to be discarded due to the survey error. Only the data for participants who completed the survey before the error occurred are reported here.

Participants were 345 parents: 332 mothers, 12 fathers, one grandfather. Of all participants who completed the survey, 263 reported speaking no languages other than English at home and 82 reported speaking languages other than English at home. Participants reported that they were parents of between one and six children, with a median of two children. All parents had children who fell within our specified age range for recruitment (5 - 9 years old), 118 participants reported having a 5-year-old, 111 reported having a 6-year-old, 113 reported having a 7-year-old, 84 reported having an 8-year-old, and 42 reported having a 9-year-old.

Stimuli

The word list was generated by first selecting words that had AoA below Grade 6 in Brysbaert and Biemiller (2017) and that occurred in books that were part of Grades 1 and 2 curricula, as indexed in the Zeno (1995) word frequency norms. This ensured that our words would be familiar to most 6-year-olds. The words from the MacArthur Bates Communicative Development Inventory (MCDI; Fenson et al., 1993) were also included in the word list. The word list was then pruned by excluding any words that were inappropriate for children, had repeated plural forms, differing verb forms, plurals, or contractions, with a few exceptions. The final list included 3,359 words.

An additional 20 words with known Child BOI ratings spanning a range of low, medium, and high ratings were selected from data collected during a pilot study. These were included as control words, such that in the main study the ratings collected for these 20 words were compared to the pilot study Child BOI ratings to ensure high-quality data were included in the norms. In the pilot study, we recruited 39 parents whose child was participating in an unrelated study to provide BOI ratings from the perspective of an average 6-year-old for a set of 221 words that had been selected for separate child studies conducted in our laboratory (Inkster et

al., 2016; Kim et al., 2020). The pilot study parents also provided verbal feedback about the ratings instructions to help us finalize the wording of instructions for the main study.

Procedure

Participants in the main study were contacted via email and were provided a link to the online survey on Qualtrics, which took approximately 30 minutes to complete. After providing consent and demographic information (i.e., their relationship to the 6-year-old such as mother or father, their occupation, highest level of education completed, and proportion of languages besides English spoken, if any), the participants were given instructions to rate a list of words according to how easily the average 6-year-old can physically interact (using the body: hands, mouth, etc.) with what each word represents. Ratings were provided using a 7-point Likert scale, with 1 being 'things that a typical child does not easily physically interact with' and 7 being 'things a typical child would easily physically interact with'. The full instructions are presented in Appendix A. Participants provided ratings for five practice words, selected from the pilot study stimuli, before being presented with 340 words to rate. The set of words for each participant was randomly selected from the full word list. In addition, each participant was presented with the 20 control words, which were randomly distributed throughout their list.

Results

The data were cleaned following methods used in Pexman et al. (2019) to screen for invalid responses (e.g., inattentive participants, bot responses) in the online questionnaire. First, we excluded one participant who did not report any children between 5 and 9 years of age and 11 participants who indicated hearing less than 50% English at home. We then excluded four participants who completed less than 33% of the questionnaire and 43 participants who

provided the same rating for more than 12 words in a row. Then ratings for the 20 control words were compared to ratings already acquired for those words from the pilot study. Any participant whose ratings correlated with the pilot data between -0.5 and 0.2 were to be excluded, which resulted in the exclusion of one participant. Finally, we calculated the correlation between each remaining participants' ratings and the average rating of all participants on the same words. Any participant with a correlation less than 0.10 was to be excluded, however no additional participants were removed due to this criterion. A total of 61 participants were removed via these data cleaning steps, leaving responses from 284 participants. A minimum of 20 valid ratings per word were collected, with a maximum of 51 ratings observed for some words. Table 1 provides the demographic information for the total and, separately, retained samples. Demographics did not vary substantially between the full and retained samples. The resulting Child BOI ratings and raw data are available at:

<https://osf.io/xcezv/>.

Table 1*Demographic Information for Full (n = 345) and Retained (n = 284) Parent Sample*

	Full sample	% of full sample	Retained sample	% of retained sample
No. of mothers	332	96.23	276	97.18
No. of fathers	12	3.48	8	2.82
More than one language spoken	82	23.77	58	20.42
Median no. of children	2		2	
Education level				
Some high school, no diploma	1	0.29	1	0.35
High school graduate	12	3.48	10	3.52
Associate degree	10	2.90	9	3.17
Trade/technical/vocational training	42	12.17	36	12.68
Some Bachelor's, no degree	26	7.54	23	8.10
Bachelor's degree	156	45.22	127	44.72
Master's degree	57	16.52	49	17.25
Professional degree	23	6.67	16	5.63
Doctorate degree	18	5.22	13	4.58

We examined the reliability of the ratings by computing two intraclass correlation coefficients (ICC) based on the control word ratings from all participants (Brysbaert et al., 2019; Fletcher, 2015). The first ICC corresponds to the average correlation of the control item ratings

between participants and was 0.569. The second ICC corresponds to the anticipated correlation between the mean ratings of the existing participants and the mean ratings that would be anticipated if we collected an equivalent group of participants and was 0.997. We then examined the validity of the ratings by comparing the new Child BOI ratings to Child BOI ratings collected in the pilot study ($n = 211$ words). The current Child BOI ratings were strongly correlated with the ratings collected for the same words in the pilot study ($r = 0.93$).

Descriptive statistics for Child BOI ratings of 3,359 words are presented in Table 2 and the distribution of the Child BOI ratings is shown in Figure 1. The Child BOI ratings showed a slight bimodal distribution. We further assessed the distribution of the Child BOI ratings by syntactic class, as compared to the distribution of Adult BOI ratings for the same items ($n = 2,421$; Figure 2). When comparing across all syntactic classes, the Adult BOI ratings appear to show a more bimodal distribution relative to the Child BOI ratings. For nouns, Adult BOI shows a greater concentration of items rated between ~ 4.25 and 6.5, whereas Child BOI shows a somewhat more even distribution of items rated between ~ 3 and 6.5, with more items rated above 6.5 than in the Adult BOI ratings. However, for all other syntactic classes, Child BOI ratings showed a greater concentration of ratings above 3 compared to the Adult BOI ratings. This may reflect a belief on the part of our raters that children have more extensive sensorimotor experiences with the world and therefore parent raters provided higher BOI ratings even for syntactic classes which are typically associated with less body-object interaction information by adult standards.

Table 2*Descriptive Statistics for Child Body-Object Interaction Ratings for 3,359 Words*

Descriptive Statistic	Value
Mean	3.74
Median	3.52
Standard Deviation	1.41
Minimum	1.00
Maximum	7.00
1st quartile	2.63
3rd quartile	4.72
Skewness	0.48
Kurtosis	-0.69

Figure 1*Distribution of Child Body-Object Interaction Ratings for 3,359 Words* *Note.* BOI = body-object interaction**Figure 2***Distribution of Child and Adult Body-Object Interaction Ratings by Syntactic Class*

Note. BOI = body-object interaction

We then examined relationships between the BOI ratings (Child and Adult) and linguistic ratings datasets. We inspected how each of the BOI ratings correlated with the lexical dimensions length (number of letters), word frequency (log subtitle frequency; Brysbaert & New, 2009), orthographic and phonological Levenshtein distance (OLD and PLD; Yarkoni, Balota, & Yap, 2008), AoA derived from the MacArthur Bates Communicative Development Inventory (MCDI; Fenson et al., 1993), a test-based measure of AoA derived from Dale and O'Rourke (1981) and updated by Brysbaert and Biemiller (2017), and a ratings-based measure of AoA (Kuperman et al., 2012). In addition, a frequency measure derived from child-directed speech was obtained from the CHILDES database (MacWhinney, 2000). Raw frequency counts from all North American English conversations excluding utterances by the target child were extracted from the database and log-transformed using the method described by Brysbaert and New (2009). The correlations are presented in Figure 3.

Child BOI was strongly related to frequency in child-directed speech (Child BOI $r = 0.34$, Adult BOI $r = -0.03$), whereas Adult BOI was more strongly related to subtitle frequency (Child BOI $r = -0.05$, Adult BOI $r = -0.30$). Child BOI was more related to all three measures of AoA than was Adult BOI: AoA ratings-based (Child BOI $r = -0.60$, Adult BOI $r = -0.12$), AoA MCDI (Child BOI $r = -0.40$, Adult BOI $r = -0.31$), and AoA test-based (Child BOI $r = -0.35$, Adult BOI $r = -0.12$).

Figure 3*Correlations Between Child and Adult Body-Object Interaction Ratings and Lexical Dimensions*

Note. BOI = body-object interaction; AoA = age-of-acquisition; MCDI = MacArthur Bates

Communicative Development Inventory; LgSUBTLWF = log subtitle frequency; LgChildesWF = log word frequency derived from child-directed speech; OLD = orthographic Levenshtein distance; PLD = phonological Levenshtein distance. Pairwise correlations were calculated using all

available word items for the dimensions in each correlation. Sample sizes indicate the number of items for each dimension that had corresponding items within the Child BOI ratings.

We next examined relationships between the new Child and existing Adult BOI ratings to semantic dimensions related to sensorimotor, perceptual and emotional experience, including concreteness (Brysbaert et al., 2014), imageability (Cortese & Fuggett, 2004; Schock, Cortese, & Khanna, 2012), sensory experience ratings (SER; Juhasz & Yap, 2013), arousal and valence (Warriner, Kuperman, & Brysbaert, 2013), danger (Witherell, Wurm, Seaman, Brugnone, & Fulford, 2012) perceptual and action strength ratings from the Lancaster Sensorimotor Norms (auditory, interoceptive, gustatory, haptic, olfactory, visual, foot/leg actions, hand/arm actions, head actions, mouth actions, torso actions, and the Minkowski 3 composite measures of overall perceptual and action strength; Lynott, Connell, Brysbaert, Brand, & Carney, 2020), and perceptual and motor attribute ratings on color, grasp, motion, and pain (Amsel, Urbach, & Kutas, 2012). The resulting correlations are presented in Figure 4.

Child BOI was more related than Adult BOI to SER (Child BOI $r = 0.41$, Adult BOI $r = 0.35$) and valence (Child BOI $r = 0.25$, Adult BOI $r = 0.14$). Adult BOI was more related to concreteness (Child BOI $r = 0.62$, Adult BOI $r = 0.79$), imageability (Child BOI $r = 0.62$, Adult BOI $r = 0.76$), and arousal (Child BOI $r = -0.15$, Adult BOI $r = -0.20$). In terms of the Lancaster perceptual strength ratings, Child and Adult BOI relationships were similar on most dimensions, although Child BOI was less related than Adult BOI to interoceptive strength (Child BOI $r = -0.17$, Adult BOI $r = -0.33$). On the Lancaster action strength ratings, Child BOI was more related than Adult BOI to

foot/leg action strength ratings (Child BOI $r = 0.11$, Adult BOI $r = -0.01$), mouth action strength ratings (Child BOI $r = 0.05$, Adult BOI $r = -0.04$) and torso action strength ratings (Child BOI $r = 0.11$, Adult BOI $r = 0.01$), and also to the composite measure of action strength (Child BOI $r = 0.36$, Adult BOI $r = 0.16$). In addition, Child BOI was more positively related than Adult BOI to color attributes (Child BOI $r = 0.13$, Adult BOI $r = 0.03$), and more negatively related to pain attributes (Child BOI $r = -0.33$, Adult BOI $r = -0.20$) and to danger (Child BOI $r = -0.38$, Adult BOI $r = -0.25$). Adult BOI was more positively related to grasp attributes (Child BOI $r = 0.43$, Adult BOI $r = 0.53$) and negatively related to motion attributes (Child BOI $r = -0.30$, Adult BOI $r = -0.41$).

Figure 4*Correlations Between Child and Adult Body-Object Interaction Ratings and Semantic Dimensions*

Note. BOI = body-object interaction; SER = sensory experience rating. Pairwise correlations were calculated using all available word items for the dimensions in each correlation. Sample sizes indicate the number of items for each dimension that had corresponding items within the Child BOI ratings.

Finally, we examined the difference scores between the two sets of BOI ratings (Child BOI minus Adult BOI) and how those difference scores were related to the lexical and semantic dimensions. In this measure positive BOI difference scores reflect items that have higher BOI ratings for child compared to adult experience and negative BOI differences scores reflect items that have higher BOI ratings for adult compared to child experience. We fit a regression line with BOI difference scores on the x axis and the lexical semantic dimension rating on the y axis. These relationships are depicted in Figure 5.

We observed negative relationships between BOI differences and both ratings- and test-based AoA ($r = -0.51$ and $r = -0.21$ respectively). This pattern indicates that, as one might expect, items for which Child BOI was rated higher than Adult BOI are acquired earlier than items for which Adult BOI was rated higher than Child BOI. Relationships observed for concreteness ($r = -0.37$), imageability ($r = -0.33$), and visual perceptual strength ($r = -0.20$) indicate that items with higher Adult than Child BOI ratings are associated with more concrete and visual information. Similar patterns for the danger ($r = -0.18$) and pain ($r = -0.24$) dimensions indicate that items with higher Adult than Child BOI ratings are also considered more dangerous and more associated with pain.

We observed positive relationships between BOI difference scores and both measures of word frequency (LgChildeSWF $r = 0.44$ and LgSUBTLWF $r = 0.34$), suggesting that more frequent items also tend to receive higher Child BOI than Adult BOI ratings. Furthermore, more positive valence ($r = 0.15$) and higher interoceptive strength ratings ($r = 0.30$) are associated with items that had higher Child BOI than Adult BOI ratings. More modest positive relationships were observed between most action strength dimensions (excluding hand/arm) and differences in Child and Adult BOI.

Figure 5*Correlations Between BOI Difference Scores and Lexical Semantic Dimensions*

Note. BOI = body-object interaction; AoA = age-of-acquisition; MCDI = MacArthur Bates

Communicative Development Inventory; LgSUBTLWF = log subtitle frequency; LgChildesWF = log

word frequency derived from child-direct speech; OLD = orthographic Levenshtein distance; PLD = phonological Levenshtein distance; SER = sensory experience rating.

Relationships to Age-of-Acquisition

The relationships of Child and Adult BOI ratings, as well as BOI difference scores, to the three different AoA measures were tested using regression models. For each AoA measure we began with a base model that included word frequency in child-directed speech, length, and imageability. Thill and Twomey (2016) found that word frequency and imageability were both associated with AoA, presumably because acquisition is related to frequency in the child language environment and with visual experience with word referents. As such we included those variables here to control for these relationships, and so that any variance explained by BOI could be interpreted based on motor-related experience. Within each AoA dataset, if any word had multiple meanings, or multiple reported AoA ratings for the same word, the earliest AoA rating was used. For each measure of AoA, only words that had ratings for both Child and Adult BOI were included in the analyses to provide a fair comparison between the two predictors.

The first AoA measure was parent estimates of child word production from the MacArthur Bates Communicative Development Inventory (MCDI: Fenson et al., 1993). This inventory consists mainly of words typically acquired before 30 months, where AoA is measured as the month when 50% or more of the sample of infants were estimated to have the ability to produce a certain word. This model was included to test whether Child BOI is a better predictor

than Adult BOI for words acquired in the first few years of childhood, with the implication being that the experience of a 6-year-old is likely closer to the experience of a younger child than the experience of an adult.

The second measure was test-based AoA obtained from the updated version of Dale and O'Rourke (1981) as reported in Brysbaert and Biemiller (2017). This measure was derived by testing thousands of children in different grades for their knowledge of the meanings of thousands of words. In this dataset, each word's AoA is taken as the earliest grade level at which an estimated 50 - 70% of students chose the correct meaning from a set of three response options. The original Dale and O'Rourke dataset spanned Grades 2 through 12 and the Brysbaert and Biemiller updated dataset included grades 13 and 16 (representing university years one and four respectively). However, given the manner in which we derived our word list for this study, our data only included words known by grades 2, 4, and 6 in the Brysbaert and Biemiller norms. As such, we used an ordinal logistic regression to test different models predicting this measure of test-based AoA. Finally, we extracted rating-based AoA from Kuperman et al. (2012). This measure was derived from adults' ratings of the age (in years) at which they believe they acquired a word.

MCDI

A base model with only the predictors log CHILDES frequency, length, and imageability accounted for 31.50% of variance in MCDI AoA. The addition of Adult BOI ratings to the model accounted for an additional 0.52% of variance, whereas the addition of Child BOI ratings to the model accounted for an additional 6.43% and the addition of BOI difference to the model

accounted for an additional 1.96%. For every unit increase in BOI rating, MCDI AoA decreases for Child BOI, $\beta = -0.39$, Adult BOI, $\beta = -0.13$, and BOI differences scores, $\beta = -0.16$. See Table 2 for estimates of all model parameters.

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Table 3*Regression Coefficients from Item-Level Analyses Predicting MCDI Age of Acquisition (N = 407)*

Predictor	Child BOI Model					Adult BOI Model					BOI Difference Model				
	β	<i>SE</i>	<i>t</i>	R^2	ΔR^2	β	<i>SE</i>	<i>t</i>	R^2	ΔR^2	β	<i>SE</i>	<i>t</i>	R^2	ΔR^2
Intercept	0.00	0.04	0.00			0.00	0.04	0.00			0.00	0.04	0.00		
Frequency	-0.53	0.06	-9.45***			-0.58	0.06	-9.91***			-0.60	0.06	-10.40***		
Length	0.15	0.04	3.30***			0.14	0.05	3.05**			0.15	0.05	3.13**		
Imageability	-0.44	0.08	-5.91***			-0.66	0.08	-8.09***			-0.85	0.06	-14.03***		
BOI	-0.39	0.06	-6.54***	0.38	0.07***	-0.13	0.07	-2.02*	0.32	0.01*	-0.16	0.05	-3.59***	0.33	0.02***

Note. BOI = body-object interaction; Frequency = log CHILDES frequency; BOI difference = Child BOI minus Adult BOI. Adjusted R^2 reported.

Delta R^2 is calculated by comparing each model to the base model with no BOI predictor.

* $p < .05$, ** $p < .01$, *** $p < .001$

Test-based AoA

A base model with only the predictors log CHILDES frequency, length, and imageability was used to predict test-based AoA at grades 2, 4, and 6. A Likelihood Ratio Test (LRT) was used to assess improvement in model fit with the addition of each BOI measure of interest to the base model. The addition of Child BOI ratings significantly improved the model fit, $\chi^2(1) = 11.95$, $p = .001$, as did the addition of BOI difference, $\chi^2(1) = 22.54$, $p < .001$. The addition of Adult BOI ratings did not result in a significant improvement in model fit, $\chi^2(1) = 3.43$, $p = .064$. For every unit increase in BOI rating, the odds of a word being acquired at an older grade (i.e., grades 4 or 6) decreased for both Child BOI and BOI difference scores (OR = 0.81 and OR = 0.77 respectively), whereas the odds of a word being acquired at an older grade increased for Adult BOI (OR = 1.12). See Table 3 for estimates of all model parameters.

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Table 4*Regression Odds Ratios from Item-Level Analyses Predicting Test-based Age of Acquisition (N = 1,966)*

Predictor	Child BOI Model				Adult BOI Model				BOI Difference Model			
	OR	95% CI	<i>t</i>	χ^2	OR	95% CI	<i>t</i>	χ^2	OR	95% CI	<i>t</i>	χ^2
Intercept (2 4)			7.75***				-7.82***				-8.16***	
Intercept (4 6)			-1.13				-1.20				-1.51	
Frequency	0.29	0.25, 0.35	-14.79***		0.25	0.22, 0.29	-18.38***		0.29	0.25, 0.34	-15.75***	
Length	1.11	1.02, 1.21	2.32*		1.14	1.04, 1.24	2.84**		1.15	1.05, 1.25	3.00*	
Imageability	0.79	0.71, 0.88	-4.37***		0.63	0.55, 0.73	-6.43***		0.64	0.58, 0.70	-9.18***	
BOI	0.81	0.72, 0.91	3.44***	11.95***	1.12	0.99, 1.26	1.84	3.43	0.77	0.70, 0.86	-4.73***	22.54***

Note. BOI = body-object interaction; Frequency = log CHILDES frequency; BOI difference = Child BOI minus Adult BOI; OR = Odds Ratio. The χ^2 likelihood ratio test was calculated by comparing each model to the base model with no BOI predictor.

* $p < .05$, ** $p < .01$, *** $p < .001$

Rating-based AoA

A model with only the predictors log CHILDES frequency, length, and imageability accounted for 57.42% of variance in rating-based AoA. The addition of Adult BOI ratings to the model accounted for an additional 0.47% of variance, whereas the addition of Child BOI ratings to the model accounted for an additional 5.62% and the addition of BOI difference to the model accounted for an additional 8.14%. For every unit increase in BOI rating, rating-based AoA decreased for Child BOI, $\beta = -0.35$, and BOI differences scores, $\beta = -0.33$, whereas rating-based AoA increased for Adult BOI, $\beta = 0.11$. The significant positive relationship between Adult BOI and rating-based AoA seems to be due to the high correlation between imageability and Adult BOI ($r = 0.75$ for the 1,900 items in this regression), although this does not meet the threshold for multicollinearity (imageability VIF = 2.58, Adult BOI VIF = 2.42). Indeed, when imageability is removed from this model, the relationship between Adult BOI and rating-based AoA reverses ($\beta = -0.14$). See Table 4 for estimates of all model parameters.

Table 5*Regression Coefficients from Item-Level Analyses Predicting Rating-based Age of Acquisition (N = 1,900)*

Predictor	Child BOI Model					Adult BOI Model					BOI Difference Model				
	β	<i>SE</i>	<i>t</i>	R^2	ΔR^2	β	<i>SE</i>	<i>t</i>	R^2	ΔR^2	β	<i>SE</i>	<i>t</i>	R^2	ΔR^2
Intercept	0.00	0.01	0.00			0.00	0.01	0.00			0.00	0.01	0.00		
Frequency	-0.58	0.02	-33.56***			-0.75	0.02	-48.19***			-0.60	0.02	-38.54***		
Length	0.06	0.01	3.85***			0.09	0.02	5.38***			0.10	0.01	7.19***		
Imageability	-0.02	0.02	-1.13			-0.34	0.02	-14.20***			-0.35	0.01	-23.75***		
BOI	-0.35	0.02	-17.00***	0.63	0.06***	0.11	0.02	4.72***	0.58	0.00***	-0.33	0.02	-21.20***	0.66	0.08***

Note. BOI = body-object interaction; Frequency = log CHILDES frequency; BOI difference = Child BOI minus Adult BOI. Adjusted R^2 reported.

Delta R^2 is calculated by comparing each model to the base model with no BOI predictor.

* $p < .05$, ** $p < .01$, *** $p < .001$

Discussion

The purpose of the present study was to collect Child BOI ratings for a set of early-acquired words. These new ratings estimate the sensorimotor experience of a child, whereas the existing BOI ratings are based on adult experience (Pexman et al., 2019). The resulting norms have good validity, strongly correlating with Child BOI ratings from a pilot study conducted prior to this study and moderately correlating with existing Adult BOI rating norms (Pexman et al.). This moderate correlation to Adult BOI rating norms indicates that judgements of children's physical interaction experience do not map directly onto judgements of adult experience.

Our analyses suggest that the Child BOI rating norms have moderate reliability, which may indicate a greater degree of variability in sensorimotor experience across 6-year-olds. The moderate reliability may also reflect the fact that ratings were provided by parents taking the perspective of a 6-year-old when making the ratings. This perspective-taking places additional cognitive load on the rater and is different from the requirements for other lexical and semantic rating dimensions, which access one's memory for one's own experiences (e.g., Adult BOI or AoA ratings). The reliability ratings were only calculated on 20 items because participants each received a randomly generated list of words to rate, and this limited sample may also influence the estimate of reliability.

The correlations between Child BOI and other lexical semantic variables indicate that Child BOI was more strongly related to frequency in child-directed speech and Adult BOI was more strongly related to log subtitle frequency. Furthermore, Child BOI was more strongly

related to all three measures of AoA than was Adult BOI. When examining the relationships between lexical variables and BOI difference scores, we observed that items with higher Child than Adult BOI ratings were associated with earlier AoA, whereas items that had higher Adult BOI ratings than Child BOI ratings were associated with later AoA. This is not surprising; if a word's referent is encountered at an older age, it stands to reason that this would be reflected in both higher Adult BOI ratings and later acquisition.

The relationships to sensorimotor dimensions provide further insight into the differences between Child and Adult BOI ratings. Child BOI is more strongly related than Adult BOI ratings to word valence. In addition, although Adult BOI ratings were more strongly related to interoceptive strength, BOI difference scores indicate that items with more positive valence and higher interoceptive strength ratings tended to have higher Child BOI ratings than Adult BOI ratings. These relationships are consistent with the findings of Ponari et al. (2016) and Reggin et al. (2021), who reported that more positively valenced words tended to be acquired at an earlier age than neutral or negatively valenced words. Furthermore, interoceptive perceptual strength has been strongly associated with emotional concepts (Connell, Lynott, & Banks, 2018). The current findings provide further support for the proposal that children ground the meanings of words through positive emotional experiences, associated with an interoceptive perceptual modality (see Lund et al., 2019, for further discussion of this mechanism).

Adult BOI was more strongly related to imageability and concreteness than was Child BOI; both imageability and concreteness are ratings dimensions based on adult experience.

These relationships suggest that the most sensitive measure of embodied word meaning, be it BOI, imageability, or concreteness, will likely be one that is appropriate to the age of the participants tested. Adult BOI was also more strongly related to grasp ratings and negatively related to motion ratings. In contrast, Child BOI ratings were more strongly related to action strength for other effectors, including foot/leg actions, mouth actions, and torso actions. This indicates that Child BOI ratings reflect interactions that occur with more of the whole body, whereas Adult BOI has been shown to largely reflect hand-related interactions such as graspability (Heard et al., 2019). These differences may be influenced by the fact that adults have more developed fine motor skills than young children.

Another key difference between Child and Adult BOI ratings was observed in their relationships to danger and pain ratings. Child BOI ratings were more negatively related to both danger and pain ratings than Adult BOI ratings, and the relationships between BOI difference scores and these dimensions indicate that words that received higher BOI ratings from an adult perspective were rated as more dangerous and associated with more pain. This suggests that children have less bodily experience with words associated with danger or pain. In sum, these relationships provide further confirmation that Child BOI estimates children's sensorimotor experiences with objects whereas Adult BOI estimates adults' sensorimotor experiences with objects.

Child BOI was a better predictor of AoA than was Adult BOI in each of the AoA datasets we tested, accounting for a larger percent of variance than Adult BOI in all three measures. In addition, BOI difference scores were also a significant predictor of AoA in each of the AoA

datasets tested. This would suggest that this a sensitive measure to test differences in embodied experience between children and adults. The present findings support Thill and Twomey's (2016) assertion that child-centric lexical and semantic predictors should be derived and used to investigate embodied theories of language through a developmental lens.

The limitations to the present study include the fact that the sample had higher levels of education than that typically found in the population and were mostly mothers. This may limit the generalizability of these ratings to a broader population. For instance, fathers may have fundamentally different experiences with their children depending on the nature of caregiving roles within the home. Furthermore, the task instructions asked respondents to provide ratings based on the experience of a *typical* 6-year-old, however, what is considered *typical* may vary depending on several factors, including demographic characteristics such as parent's educational attainment. A typical 6-year-old representing a highly homogenous sample such as the one reported here may not share the same experiences as a typical 6-year-old of a more heterogenous sample.

In addition, ratings were based on adults assuming the perspective of a 6-year-old. While the participants were all parents and thus likely to be highly engaged in their children's activities, it is possible that these ratings may not be the ideal estimation of the physical interactions a 6-year-old has with their environment. However, collecting ratings from children themselves would present several challenges. For example, in order to follow task instructions children would need to be able to understand the abstract notion of *ease* of interaction, as opposed to providing ratings that reflect *frequency* of interaction. In addition, there would be

constraints on the methodology if ratings were collected from children, such as needing to use substantially shorter word lists for participants to rate and shifting to an in-person administration of the task to better support child participants.

The present findings suggest that Child BOI rating norms provide a more sensitive measure than adult norms to investigate sensorimotor effects in language development. In future research it will be necessary to explore how effectively these rating norms predict variability in child language processing, however at present there are few behavioural datasets available which provide enough items to undertake large-scale analysis of embodied predictions in child language processing. These new Child BOI rating norms should provide a useful resource for researchers to better test embodied theories of language from a developmental perspective and to further elucidate the role of sensorimotor experience in language, memory, and other aspects of cognitive development.

Open Practices Statement

The data and analysis scripts are available at <https://osf.io/xcezv/> and the experiment was not preregistered.

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Appendix A

Child-Object Interaction Ratings Instructions

Words differ in the extent to which they refer to objects or things that a child has experience physically interacting with. Some words refer to objects or things that a child easily interacts with physically, whereas other words refer to objects or things that a child does not easily physically interact with. We need your help to judge the words listed on the following pages for **how easily the average 6-year-old can physically interact (using the body: hands, mouth, etc.) with what each word represents.**

For example, the words “ball”, “pillow”, and “banana” refer to objects or things that a 6-year-old child physically interacts with easily, using their hands, face, mouth, etc. Things like this should get high ratings.

In contrast the words, “unicorn”, “fire”, and “cloud” refer to objects or things that a 6-year-old child does not physically interact with easily and so should get low ratings; a “unicorn” is imaginary, so although children may be familiar with unicorn they cannot easily physically interact with them; “fire” is dangerous and so not easy for children to interact with, and a “cloud” is too large, distant, and vaporous for children to easily interact with.

Please rate the child’s experiences with the real object or thing, not a toy version of an object. 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 child could physically interact with what the given word represents.

Your child-object interaction ratings will be made on a 1 to 7 scale. A value of 1 will indicate a low child-object interaction rating, and a value of 7 will indicate a high child-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. If you are unsure of what the word means, please skip the rating.