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Experience with compound words influences their processing: An eye movement investigation with English compound words

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Abstract

Recording eye movements provides information on the time-course of word recognition during reading. Juhasz and Rayner [Juhasz, B. J., & Rayner, K. (2003). Investigating the effects of a set of intercorrelated variables on eye fixation durations in reading. *Journal of Experimental Psychology: Learning, Memory and Cognition, 29*, 1312–1318] examined the impact of five word recognition variables, including familiarity and age-of-acquisition (AoA), on fixation durations. All variables impacted fixation durations, but the time-course differed. However, the study focused on relatively short, morphologically simple words. Eye movements are also informative for examining the processing of morphologically complex words such as compound words. The present study further examined the time-course of lexical and semantic variables during morphological processing. A total of 120 English compound words that varied in familiarity, AoA, semantic transparency, lexeme meaning dominance, sensory experience rating (SER), and imageability were selected. The impact of these variables on fixation durations was examined when length, word frequency, and lexeme frequencies were controlled in a regression model. The most robust effects were found for familiarity and AoA, indicating that a reader's experience with compound words significantly impacts compound recognition. These results provide insight into semantic processing of morphologically complex words during reading.

Keywords

Age-of-acquisition; Compound words; Eye movements; Familiarity; Morphological processing

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As discussed by Rayner (2009), the decision of when to move the eyes during reading is influenced by properties of the currently fixated word. Eye movements provide a beneficial tool for exploring the influence of lexical variables on reading (for a review see Juhasz & Pollatsek, 2011). In terms of lexical variables, first-fixation duration (FFD: the duration of the first fixation on the word even if the word receives multiple fixations) and gaze duration (GD: the sum of all fixations on the word before the eyes move off of it) can be examined as an indication of initial processing (FFD) and word recognition time (GD). These are often supplemented by single-fixation duration (SFD: the duration of the first fixation on a word if it only receives one fixation) and total fixation duration (TFD: the summed duration of all fixations on the word, including re-reading).

In order to explore the time-course of lexical processing, Juhasz and Rayner (2003) examined five variables (word frequency; rated familiarity; word length; word concreteness; rated age-of-acquisition, AoA) for 72 target words embedded in sentences using a multiple regression approach. All five variables impacted reading, although the timing of the effects varied. Word frequency influenced all measures, with familiarity having significant effects on FFD, SFD, and GD. When adult frequency (Francis & Kučera, 1982) was included, AoA significantly predicted SFD and GD. Concreteness significantly influenced FFD, GD, and TFD. Word length was only significant for duration measures that took refixations into

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account. The Juhasz and Rayner (2003) study illustrates that eye movements can provide a window into the time-course of lexical and semantic variables that is not readily available from traditional word recognition tasks such as lexical decision (where words are discriminated from nonwords) and word naming.

While effects of frequency (e.g., Rayner & Duffy, 1986; Schilling, Rayner, & Chumbley, 1998), length (e.g., Rayner, Sereno, & Raney, 1996), and familiarity (e.g., Williams & Morris, 2004) on fixation durations had previously been reported, Juhasz and Rayner (2003) were the first to examine effects of AoA and concreteness on fixation durations. These findings suggested that words that are acquired earlier in life and refer to more concrete entities are read faster. The finding that words rated higher in concreteness receive shorter gaze durations has subsequently been reported by Sheikh and Titone (2013). The effect of AoA on fixation durations has been replicated in a college sample (Juhasz & Rayner, 2006) as well as with older adults and an individual with pure alexia (Cushman & Johnson, 2011). A recent study by Joseph, Wonnacott, Forbes, and Nation (2014) provided insight into the nature of AoA effects in reading. In their study, college students were presented with new vocabulary items to learn. Items were introduced over 5 days with "early" items being introduced on Day 1 and "late" items being introduced on Day 2. Number of repetitions of the items was kept constant. When read in neutral sentences at test, TFDs were significantly shorter for the "early" items, and more "early" items were correctly matched to their definitions. These results suggest that the AoA effects observed in reading may be related to the order in which the words were learned.

The studies discussed above provide information on a range of lexical variables that influence fixation durations. However, the words examined in these studies have typically been relatively short, morphologically simple words. A large literature also exists using eye movements to examine morphological processing using stimuli such as compound words (for a review see Hyönä, 2012). Compound words consist of two free lexemes, which when presented together form a new word (e.g., *airport*, *campfire*). Many of the eye movement studies on compound word processing have examined whether compounds are decomposed during recognition, often by manipulating the frequencies of the constituent lexemes (e.g., Andrews, Miller, & Rayner, 2004; Bertram & Hyönä, 2003; Hyönä & Pollatsek, 1998; Inhoff, Starr, Solomon, & Placke, 2008; Juhasz, 2007, 2008; Juhasz, Starr, Inhoff, & Placke, 2003; Kuperman, Bertram, & Baayen, 2008; Marelli & Luzzatti, 2012; Pollatsek & Hyönä, 2005; Pollatsek, Hyönä, & Bertram, 2000). These investigations have provided insight into the representation of complex words in the mental lexicon.

Studies have also examined the role of semantic transparency on compound word processing using eye movements (e.g., Frisson, Niswander-Klement, & Pollatsek, 2008; Juhasz, 2007; Marelli & Luzzatti, 2012; Pollatsek & Hyönä, 2005; Underwood, Petley, & Clews, 1990). Semantic transparency refers to the degree to which the two lexemes contribute to the meaning of the compound word. It plays an important role in some theories of compound word processing (e.g., Libben, 1998). However, past research exploring this variable during reading has been mixed with some studies reporting a main effect of transparency or interactions with this variable (Juhasz, 2007; Marelli & Luzzatti, 2012; Underwood et al., 1990), while others report no effect of semantic transparency (Frisson et al., 2008; Pollatsek & Hyönä, 2005). Given the conflicting nature of the previous studies, further investigation is warranted.

Kuperman (2013) noted that semantic transparency is a *relational* semantic variable since it assesses how the meaning of the lexemes relate to the meaning of the entire compound word. While examining relational variables is important for theories of morphological processing, examining the influence of other semantic variables on compound word recognition can provide insight into the nature of semantic representations for morphologically complex words. Kuperman examined the influence of six semantic variables (valence; arousal; imageability; concreteness; sensory experience ratings (SER); and body–object interaction ratings, BOI) on lexical decision times (LDTs) for English compound words. Each variable was added separately to a by-item regression analysis on the LDTs from the English Lexicon Project (Balota et al., 2007), which contained compound word frequency, length, Lexeme 1 frequency, and Lexeme 2 frequency as control variables. Each model also included the relevant ratings for the compound lexemes. Compound word LDTs were significantly influenced by compound word valence, imageability, concreteness, and SER. In addition, with the exception of lexeme valence, none of the semantic properties of the lexemes influenced compound word LDTs.

Juhasz, Lai, and Woodcock (2015) recently extended this work by collecting ratings for over 600 English compound words. Two of the variables examined by Kuperman (2013) were included: imageability and SER. Ratings were also collected on familiarity and AoA. These variables assess the experience that a reader has with a particular compound word. Familiarity can be thought as an index of subjective frequency. Since many English compound words are quite low in frequency (see Libben, 2005, for a discussion), familiarity may be an important variable to take into consideration. AoA had not previously been examined for compound words. Finally, Juhasz et al. also included two relational semantic variables: semantic transparency and lexeme meaning dominance (LMD). LMD indexes whether the first or second lexeme contributes more to the meaning of the compound word (Inhoff et al., 2008). A "headed" compound is one where the first lexeme contributes most of the meaning of the word (e.g., staircase) while the second lexeme contributes more to the meaning for a "tailed" compound (e.g., drawbridge). Both LDTs and word naming times from the English Lexicon Project were explored following the approach of Kuperman (2013). Similar to Kuperman (2013), Juhasz et al. (2015) found effects of compound imageability and SER on LDTs and word naming times. Effects of compound familiarity and AoA were also observed. LMD did not significantly impact processing time. Semantic transparency was a significant predictor of LDTs but not word naming, suggesting that this variable may influence lexical decisions for compounds at a relatively late processing stage.

The present study

The primary purpose of the present study was to examine the impact of the six variables explored by Juhasz et al. (2015) on fixation durations. Therefore, neutral sentences were written for 120 compound words from the Juhasz et al. (2015) database, which varied continuously on these variables. In order to explore the time-course of compound processing, FFD, SFD, GD, and TFD were examined. Following the work of Kuperman (2013) and Juhasz et al. (2015), each variable was added separately to a baseline regression model that also included the compound words' frequency, length, and both lexeme frequencies. The design of the current study allows for several specific research questions to be explored.

With regards to familiarity, Juhasz (2008) reported significant effects of this variable on FFD and GD when familiarity was factorially manipulated along with word length. Familiarity was used by Juhasz (2008) as a proxy for word frequency, due to the restriction of range issue with English compound frequencies. Therefore, it is an open question whether familiarity will impact compound reading when included in the same model with a measure of word frequency. The current study utilized the subtitle frequency measure reported by Brysbaert and New (2009: SUBTLEX-US). Brysbaert and Cortese (2011) recently argued that subjective frequency measures are not necessary if optimal objective frequency counts, such as SUBTLEX-US, are used. The current investigation will determine whether familiarity is in fact an important variable to take into consideration for compound words. A similar criticism regarding the relationship of AoA and frequency has also been made, although the results of Brysbaert and Cortese (2011) support the position that subjective AoA still reliably influences word recognition time with optimal objective word frequency measures. However, there are only a small number of published studies that have examined AoA effects in the eye movement record (Cushman & Johnson, 2011; Juhasz & Rayner, 2003, 2006). The current study allows an exploration of the role of this variable for compound words.

SER is a recently developed word recognition variable (Juhasz & Yap, 2013; Juhasz, Yap, Dicke, Taylor, & Gullick, 2011) based on the grounded cognition framework (Barsalou, 2008). The ratings assess the degree to which a word evokes a sensory experience in the mind of the reader. Past research has found this variable to reliably predict lexical decision and word naming times for thousands of mono- and bi-syllabic English words (e.g., Juhasz & Yap, 2013; Juhasz et al., 2011). SERs have also been found to predict LDTs in French (Bonin, Méot, Ferrand, & Bugaïska, 2015) and to predict semantic categorization performance (Zdrazilova & Pexman, 2013). There are no reports in the literature investigating the influence of this variable on eye movements during reading.

Imageability is a well-established semantic variable that has been reported to affect lexical decision and word naming (e.g., Cortese & Khanna, 2007; Cortese & Schock, 2013). It is surprising that this variable has not received more attention in the eye movement literature. Concreteness, which is often highly correlated with imageability (see Paivio, Yuille, & Madigan, 1968) has been found to influence gaze durations during reading (Juhasz & Rayner, 2003; Sheikh & Titone, 2013). However, the two variables are tapping different constructs; concreteness gauges whether the referent of a word is abstract or concrete, while imageability assesses how easy it is to create a mental image for a word. Behrmann, Shomstein, Black, and Barton (2001) examined the number of fixations of two individuals with pure alexia while reading passages. There was a significant effect of imageability on fixation number such that the readers with pure alexia made significantly more fixations on words with lower imageability. A corresponding effect was not observed for the control group of typical readers. However, imageability was likely confounded with other variables. A systematic study of the role of imageability on eye movements is necessary to establish its effect during reading.

Experimental study

Method

Participants. Forty-five Wesleyan undergraduates participated in exchange for partial course credit for their Introductory Psychology course. All participants had normal or corrected-to-normal vision and reported their primary language to be English.[1]

Apparatus. Eye movements were recorded via an Eyelink 1000 (SR Research, Ltd.) eye-tracker. This system records eye movements every millisecond. Participants, who were seated 83 cm from the screen, viewed the sentences binocularly. Eye movements were only recorded from the right eye. All sentences were displayed in black Courier New 14-point font on a white background. The sentence

Table 1. Descriptive statistics for the 120 compound words in the experiment.

Variables	*M*	*SD*	Range
Length	8.66	1.29	6.00–13.00
Frequency	1.84	4.17	0.04–38.04
L1 frequency	92.35	265.49	0.35–2009.16
L2 frequency	208.03	478.51	0.41–2990.65
Fam.	6.23	0.88	2.57–7.00
AoA	4.20	1.11	2.07–6.47
Tran.	4.92	1.20	1.67–6.71
LMD	5.41	1.34	1.93–8.33
SER	3.38	1.01	1.20–5.93
Image.	5.34	1.12	2.62–6.95

Note: All frequencies were taken from the Subtlex-US corpus (Brysbaert & New, 2009) from the English Lexicon Project (Balota et al., 2007). L1 = Lexeme 1; L2 = Lexeme 2; Fam. = familiarity; AoA = age-of-acquisition; Tran. = transparency; LMD = lexeme meaning dominance; SER = sensory experience rating; Image. = imageability. All ratings were taken from the Juhasz et al. (2015) database.

Table 2. Sample sentences from the experiment.

Compound	Sentence
airport	During the holidays, our local airport plays festive music in the terminals.
bodyguard	Surrounded by an angry mob, the large bodyguard kept the politician from danger.
coffeepot	Jason was upset that his new coffeepot cracked when he dropped it yesterday.
songbird	Lina's mood was brightened when the pretty songbird chirped a cheerful tune.
sunlamp	In the terrarium, the powerful sunlamp kept a variety of reptiles alive.
textbook	She knew that the required textbook would be useless, so she did not buy it.

display was controlled by the EyeTrack software (http://www.psych.umass.edu/eyelab/software/).

Materials. Bilexemic English compound words were selected from the Juhasz et al. (2015) database. Ratings of the six variables of interest were taken from this database. Sentences were written for 209 compound words with the constraint that the compound could not be the first two or last two words and that the pre-target and post-target words were at least three characters in length. Ratings were then collected on how well the compound word fitted into the sentence (1–7 scale) and how predictable the compound word was from the beginning sentence context (modified cloze procedure). Sentences were split into two lists for ratings. Ten Wesleyan University students completed each questionnaire (for a total of 40 raters).

A final set of 120 sentences was then selected. The cloze probability was 0% for each of the compounds and lexemes within the compounds. Average goodness-of-fit was 6.43 (SD = 0.49, range = 5.1–7.0). All compounds were used as nouns. Stimuli characteristics are reported in Table 1. Example sentences are reported in Table 2.

Procedure. After eye-tracker adjustment, a single-line calibration and validation process was conducted. The experiment began if the average error of the calibration was 0.4 degrees of visual angle or less, and the maximum error was less than 0.5°. Recalibrations were conducted when deemed necessary by the experimenter, or whenever the participant took a break. Sentence display was triggered by a gaze-contingent box on the left side of the screen. When participants were done reading each sentence silently for comprehension, they were instructed to look to the right of the sentence and to press a button on a gamepad. Eighty filler sentences were also included in the session, for a total of 200 sentences. The experiment began with five practice sentences. Comprehension was checked via yes–no comprehension questions on 24% of the sentences. Average accuracy was 94.20%.

Results

Analyses were conducted within the R environment for statistical computing (Version 3.2.1 R Core Team, 2015) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015). A baseline linear mixed effects regression (LMER) model was created containing whole compound word frequency, compound word length, Lexeme 1 frequency, and Lexeme 2 frequency. These four variables are the control variables used by Kuperman (2013) and Juhasz et al. (2015) to examine compound processing in lexical decision and word naming. The log of the word frequency count from the SUBTLEX-US corpus was used in the models (Brysbaert & New, 2009). Each variable of interest was added separately to the model for the four log-transformed dependent measures (FFD, SFD, GD, TFD). All predictor variables were centred on their means. A random effects structure that included by-participant and by-item random intercepts as well as by-participant random slopes for the predictor variables was used.[2] T-values were computed for each variable of interest. Variables were considered to be statistically significant at the alpha = .05 level if the absolute t-value was greater than 2.00. Correlations between the variables are presented in Table 3. By-item averages were 259 (SD = 22) for FFD, 271 (SD = 32) for SFD, 326 (SD = 43) for GD, and 391 (SD = 73) for TFD. Table 4 displays the coefficients, standard errors, and t-values for each variable of interest when added to the baseline model.

Rated familiarity was a robust predictor of compound word processing. It was significant for all duration measures when added to the baseline model including compound word length, frequency, and lexeme frequencies (all $|t|$s > 2.00). Rated AoA significantly influenced measures

Table 3. Correlations between the predictor variables.

Variables	Len.	Freq.	L1 Freq.	L2 Freq.	Fam.	AoA	Tran.	LMD	SER	Image.
Len.	1.00	.05	.08	.01	.06	.02	−.04	−.06	−.04	−.08
Freq.		1.00	.29**	.22**	.54**	−.38**	.03	−.18*	.26**	.29**
L1 Freq.			1.00	.06	.21*	−.16	.14	−.12	.17	−.05
L2 Freq.				1.00	.05	.14	.13	−.25**	−.11	−.04
Fam.					1.00	−.70**	.20*	−.06	.52**	.56**
AoA						1.00	−.24**	−.01	−.51**	−.65**
Tran.							1.00	−.18*	.21*	.30*
LMD								1.00	.09	.09
SER									1.00	.55**
Image.										1.00

Note: Len. = length; Freq. = log frequency from the Subtlex-US corpus (Brysbaert & New, 2009) extracted from the English Lexicon Project (Balota et al., 2007); L1 = Lexeme 1; L2 = Lexeme 2; Fam. = familiarity; AoA = age-of-acquisition; Tran. = transparency; LMD = lexeme meaning dominance; SER = sensory experience ratings; Image. = imageability. All ratings were taken from the Juhasz et al. (2015) database.
**p* < .05. ***p* < .01.

Table 4. Linear mixed effects regression results for the six variables of interest.

Measures	Values	Fam.	AoA	Tran.	LMD	SER	Image
FFD	Coefficient	−0.010	0.005	−0.003	−0.001	−0.007	−0.001
	SE	0.004	0.003	0.003	0.002	0.003	0.003
	t	−2.51*	1.77	−1.03	−0.34	−2.15*	−0.39
SFD	Coefficient	−0.013	0.008	−0.002	−0.001	−0.005	−0.001
	SE	0.006	0.004	0.004	0.003	0.004	0.004
	t	−2.21*	1.92	−0.56	−0.30	−1.18	−0.13
GD	Coefficient	−0.018	0.010	−0.0001	0.001	−0.008	−0.002
	SE	0.006	0.004	0.004	0.003	0.005	0.004
	t	−2.99*	2.26*	−0.04	0.17	−1.62	−0.37
TFD	Coefficient	−0.026	0.014	−0.003	0.003	−0.012	−0.009
	SE	0.008	0.006	0.005	0.004	0.006	0.006
	t	−3.44*	2.45*	−0.68	0.70	−1.89	−1.68

Note: Coefficients and standard errors are presented for each variable when added separately to the baseline model containing compound word length, frequency, Lexeme 1 frequency, and Lexeme 2 frequency. *SE* = standard error; Fam. = familiarity; AoA = age-of-acquisition; Tran. = transparency; LMD = lexeme meaning dominance; SER = sensory experience rating; Image. = imageability; FFD = first-fixation duration; SFD = single-fixation duration; GD = gaze duration; TFD = total fixation duration.
*Significant at the $\alpha = .05$ level.

that took refixations on the compound into account, GD and TFD (both $|t|s > 2.00$) and approached significance in SFD ($t = 1.92$). The effect of SER was time-locked. It had a significant influence only on FFDs ($t = -2.15$), although it approached significance in TFD ($t = -1.89$). Imageability, transparency, and LMD did not significantly influence reading times in the present study.[3,4]

In order to further examine the contribution of each variable of interest to the baseline regression model, by-items regression analyses were conducted, as in Juhasz et al. (2015). The proportion of variability accounted for in each dependent measure was assessed for the baseline model. Adjusted R^2 values are reported in Table 5. The significance of the increase in R^2 was assessed when each predictor was added separately to the model. The findings complemented the LMER analyses in showing a significant increase in the proportion of variability explained when familiarity was added to the model for all fixation duration measures [FFD: $F(1, 114) = 7.84$, $p = .006$; SFD: $F(1, 114) = 5.57$, $p = .02$; GD: $F(1, 114) = 14.45$, $p < .001$; TFD: $F(1, 114) = 16.42$, $p < .001$]. The increase in the proportion of variance explained when AoA was added to the model was marginally significant in FFD, $F(1, 114) = 3.16$, $p = .078$, and SFD, $F(1, 114) = 3.59$, $p = .061$, and reached significance in both GD, $F(1, 114) = 6.06$, $p = .015$, and TFD, $F(1, 114) = 6.48$, $p = .012$. The addition of SER to the baseline model significantly increased the proportion of variance accounted for in FFD, $F(1, 114) = 4.48$, $p = .037$, and was marginally significant in GD, $F(1, 114) = 3.48$, $p = .065$, and TFD, $F(1, 114) = 3.57$, $p = .061$. The proportion of variability increase was also marginally significant when imageability was added to the

Table 5. Adjusted R^2 values for the by-items regression analyses.

Model	FFD	SFD	GD	TFD
Baseline	.122	.150	.211	.214
Fam.	.171**	.183*	.293***	.307***
AoA	.138†	.169†	.244*	.249*
Tran.	.125	.146	.204	.211
LMD	.115	.143	.205	.209
SER	.148*	.150	.227†	.231†
Image	.116	.143	.207	.232†

Note: Adjusted R^2 are presented for the baseline model containing compound word length, frequency, Lexeme 1 frequency, and Lexeme 2 frequency as well as when each predictor variable is added separately to the model. Fam. = familiarity; AoA = age-of-acquisition; Tran. = transparency; LMD = lexeme meaning dominance; SER = sensory experience rating; Image. = imageability; FFD = first-fixation duration; SFD = single-fixation duration; GD = gaze duration; TFD = total fixation duration. Significance of the R^2-change analyses is presented as follows: †$p < .100$. *$p < .05$. **$p < .01$. ***$p < .001$.

baseline model for TFD, $F(1, 114) = 3.75$, $p = .055$. None of the other models tested produced significant increases in the R^2 values relative to the baseline model.

General discussion

This study examined the time-course of six variables on English compound word recognition during reading. The most robust predictor of compound word recognition was rated familiarity, which had an early and long-lasting effect on compound word reading. Compounds that are more familiar are read more quickly in context. Adding familiarity to the by-item baseline regression model that included frequency significantly increased the proportion of variance accounted for in all fixation duration models. This runs counter to the suggestion of Brysbaert and Cortese (2011) that subjective measures of frequency are no longer necessary when optimal measures of word frequency are available. It should be noted that compound word frequency was also a significant predictor when familiarity was included in the LMER models for SF, GD, and TFD (all $|t|$s > 2.00), but did not reach significance in FFD ($t = -1.66$). This suggests that both word frequency and rated familiarity significantly impact compound word processing. The finding that familiarity is a robust predictor of compound word recognition may be related to the fact that many English compounds are relatively low in frequency. In the present study, while word frequencies ranged from 0.04 per million to 38.04 per million, only four of the compounds (*roommate* = 11.39, *railroad* = 12.43, *background* = 17.63, *airport* = 38.04) had frequencies above 10 per million. While, as expected, the correlation between familiarity and frequency is significant for these 120 items ($r = .54$, $p < .01$), there were many very-low-frequency English compounds that are highly familiar to readers (e.g., *pillowcase*: frequency = 0.65, familiarity = 6.93; *weekday*: frequency = 0.43, familiarity = 7.00; *cobweb*: frequency = 0.20, familiarity = 6.71). Rated familiarity provides a useful index of a reader's experience with the compound words, which is not captured by more objective frequency counts and is therefore important to consider when examining English compound word recognition.

The idea that a reader's experience with compound words influences compound recognition is also supported by the finding that AoA significantly predicted both GD and TFD on compounds when frequency, length, and lexeme frequencies were controlled. Compound words that are learned earlier in life are processed faster when read in sentences. This extends past research on AoA effects (Juhasz & Rayner, 2003, 2006) to longer morphologically complex words. For compound words the effect of AoA appears to be most robust in the measures that take refixations into account. There is debate about the locus of AoA effects (see Johnston & Barry, 2006; Juhasz, 2005, for reviews). The semantic locus hypothesis suggests that AoA effects arise at the level of semantic representations of words. Modelling work by Steyvers and Tenenbaum (2005) suggested that concepts that are acquired earlier have more interconnections to other concepts in a semantic network. Due to this rich pattern of semantic interconnections, they receive a processing advantage compared to concepts that are acquired later. This model has recently been extended to explain the growth of derived and compound morphological families in English (Henry & Kuperman, 2013). A semantic locus of AoA fits with the time-course of processing observed. In most English compound words, the second lexeme is the semantic head of the compound word. First lexemes were on average 4.46 letters ($SD = 1.10$) while the average initial landing position for all items was 3.35 ($SD = 0.49$). Thus, first fixations tended to land on the first lexeme. AoA effects for the compound may therefore be most apparent once the second lexeme was identified during refixations, and the semantic representation of the compound was accessed.

It should be noted that many of the variables of interest were significantly correlated in the present study (see Table 3), as was the case for the entire database of 629 compounds reported in Juhasz et al. (2015, their Table 2). In order to reduce potential multicollinearity in both studies, each predictor variable was added separately to the baseline model to assess its own predictive power. The fact that the variables are correlated should therefore be taken into consideration when interpreting the pattern of results. When participants are asked to rate words for familiarity, they are most likely also taking into consideration how long they have known a word. Similarly, when participants are asked to rate AoA, the subjective familiarity that they have with a word is also most likely assessed. This issue is not unique to the present study. Rated AoA has previously been criticized in the literature due to its correlations with other lexical variables (see e.g., Baayen, Milin, & Ramscar, 2016, for a recent discussion, and Juhasz, 2005, for a review). Brysbaert (2016) recently addressed this criticism of AoA ratings by demonstrating that rated AoA had better criterion validity in predicting measures of objective AoA than a measure of rated AoA that was statistically corrected for word frequency, word length, and semantic variables.

In the current study, there was no indication that two relational semantic variables, semantic transparency and LMD, influenced compound recognition. As stated in the introduction, the evidence for semantic transparency effects has been mixed in the eye movement literature. Past studies have suggested that the influence of transparency is dependent on the nature of the spatial layout of the compound words in both sentence reading (Frisson et al., 2008) and lexical decision (Ji, Gagné, & Spalding, 2011). In addition, for the larger set of items included in Juhasz et al. (2015), transparency was only found to significantly impact lexical decision performance, not naming times. The impact of semantic transparency appears to be sensitive to task demands and individual difference factors (Schmidtke, Van Dyke, & Kuperman, 2015). The Juhasz (2007) study, which found a main effect of transparency on gaze durations during reading, employed a factorial design where 40 items that were highly transparent and 40 items that were very opaque were included in the same experimental list. It is possible that this design drew attention to compound transparency. In the current study, compounds ranged quite a bit in their semantic transparency (1.67–6.71), which should have allowed for a strong test of the influence of this variable. However, the fact that transparency varied continuously may have made it less noticeable to participants. This highlights the importance of examining word recognition variables as continuous measures in addition to factorial designs where variables are dichotomized into extreme groups (for a discussion of these issues in word recognition research, see Balota, Yap, Hutchinson, & Cortese, 2012).

Finally, two nonrelational semantic variables, SER and imageability, were also explored in the current study. Imageability was not found to significantly affect any fixation duration measure on the compound words, although the increase in the proportion of variance accounted for when imageability was added to the by-item baseline regression model for TFD was marginally significant. This is surprising as it was found to influence lexical decision times and word naming for English compounds (Juhasz et al., 2015; Kuperman, 2013) and has a long history in the word recognition literature. Future research should be devoted to examining whether imageability effects can generalize to natural reading or whether these effects are limited to word-in-isolation tasks such as lexical decision and word naming.

Past studies have also reported that SER affects lexical decision and word naming for monomorphemic English words (Juhasz & Yap, 2013) as well as for English compound words (Juhasz et al., 2015; Kuperman, 2013). This is the first study in the literature to observe an effect of SER on eye movements. Somewhat unexpectedly, SER was found to have an early, time-locked effect in that it only significantly influenced first fixations on the compound word. SER has been interpreted within the language as simulated sensation model (LASS: Barsalou, Santos, Simmons, & Wilson, 2008), which suggests that words evoke a linguistic representation as well as a situated simulation of sensory and perceptual processes. SERs can therefore be linked to a measure of the strength of the situated simulations. However, according to this model, situated simulations peak after the linguistic form is activated, and therefore the time-course should be later than that observed in the present study. In addition, von der Malsburg and Angele (2016) have recently suggested that corrections should be applied to *p*-values when several fixation-duration-dependent measures are examined to reduce the potential for false positives and note that this has not been the standard practice in the field. They endorse the conservative Bonferroni correction across dependent measures. This amounts to correcting the alpha level for the number of dependent measures that are examined in the eye movement record. For the present study, since four dependent measures were examined, this would mean adopting an alpha value of .0125. For the SER measure, the change in R^2 for FFD was significant with a $p = .037$, which would not be considered significant using this strict correction. Given this, and the fact that this is the first study to observe an effect of SERs on eye fixation durations, future studies are needed to see whether the impact of SER generalizes from tasks such as lexical decision. There is a growing number of word recognition variables related to sensory or perceptual processing such as body–object interaction ratings (Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008) as well as ratings for words on individual sensory dimensions (e.g., smell intensity; Amsel, Urbach, & Kutas, 2012). Exploring the time-course of these semantic variables using the eye movement record could be beneficial for developing and refining theories of the activation of sensory/perceptual characteristics of words.

In conclusion, out of the six variables examined in the present study, familiarity and AoA had the clearest impact on English compound word recognition when included in a regression with “traditional” compound word predictors. These variables both gauge aspects of a reader’s experience with the compound words, with AoA indexing the age (or order) with which the word is acquired and familiarity indexing how often the word is experienced. Therefore, compound word recognition, even in skilled adult readers, appears to be affected by experience with the words. Future research could examine this prospectively either using a word learning experiment similar to Joseph et al. (2014) or by examining compound word recognition during literacy development in children.

Notes

1. Data were collected from 13 additional participants. Due to excessive track losses (20% or greater), inaccurate calibrations, self-reported reading disabilities, or technical difficulties saving the files, their data were not included in the analyses. Additional participants began the experiment but could not complete it due to difficulty tracking.
2. The model including semantic transparency did not converge in FFD and GD. The model including imageability did not converge in SFD and GD. For these analyses, a by-subject random slope was only included for the variable of interest.
3. Kuperman (2013) and Juhasz et al. (2015) also explored the impact of the semantic characteristics for compound lexemes. Neither study reported reliable effects of lexeme SER or imageability on compound lexical decision times. Juhasz et al. (2015) also did not report a significant effect of lexeme AoA on lexical decision times. It was therefore not predicted that lexeme AoA, SER, or imageability would influence fixation durations. Additional analyses including lexeme AoAs (from Cortese & Khanna, 2008; Schock, Cortese, Khanna, & Toppi, 2012), imageability (from Cortese & Fugett, 2004; Schock, Cortese, & Khanna, 2012), and SER (for 94 compounds from Juhasz & Yap, 2013) were conducted. These variables, which were centred on their means, were added to the relevant model for each of the log-transformed dependent measures. The random effects structure included by-participant and by-item random intercepts. Lexeme ratings did not significantly predict any dependent measure ($|t|$s <2).
4. Goodness-of-fit (GOF) values were added to the models when one of the predictor variables was significant to assess the robustness of effects. Due to a lack of convergence, only random intercepts for subjects and items were included. The pattern of significance was the same as that reported above except for single-fixation duration where the influence of familiarity was no longer significant when GOF was included in the model, $\beta=-0.010$, $SE=0.006$, $t=-1.77$.

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