Journal of Experimental Psychology: General
2014, Vol. 143, No. 2, 527–533

0096-3445/14/$12.00 DOI: 10.1037/a0034626

BRIEF REPORT

I See/Hear What You Mean: Semantic Activation in Visual Word Recognition Depends on Perceptual Attention

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How does the meaning of a word affect how quickly we can recognize it? Accounts of visual word recognition allow semantic information to facilitate performance but have neglected the role of modality-specific perceptual attention in activating meaning. We predicted that modality-specific semantic information would differentially facilitate lexical decision and reading aloud, depending on how perceptual attention is implicitly directed by each task. Large-scale regression analyses showed the perceptual modalities involved in representing a word's referent concept influence how easily that word is recognized. Both lexical decision and reading-aloud tasks direct attention toward vision, and are faster and more accurate for strongly visual words. Reading aloud additionally directs attention toward audition and is faster and more accurate for strongly auditory words. Furthermore, the overall semantic effects are as large for reading aloud as lexical decision and are separable from age-of-acquisition effects. These findings suggest that implicitly directing perceptual attention toward a particular modality facilitates representing modality-specific perceptual information in the meaning of a word, which in turn contributes to the lexical decision or reading-aloud response.

Keywords: visual word recognition, semantics, perceptual strength, perceptual attention

How do we read? Must we fully recognize a word form before we can access its meaning, or does the meaning of a word affect how quickly we can recognize it? Most current theories of visual word recognition favor the latter view that semantic information can mediate early word recognition processes (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Plaut, McClelland, Seidenberg, & Patterson, 1996). However, the extent and nature of such semantic effects remain controversial (Cortese & Balota, 2012; Graves, Binder, Seidenberg, & Desai, 2012) and largely unimplemented in computational models of word recognition (cf. Dilkina, McClelland, & Plaut, 2008, for impaired reading aloud in semantic dementia).

Much of the evidence for semantic effects in reading comes from two tasks: lexical decision (i.e., is *chair* a valid word?) and reading aloud (i.e., pronounce *chair* aloud; word naming). One consistent trend across studies is that semantic effects are stronger in lexical decision than in reading-aloud tasks. A range of variables that relate to word meaning have been found to affect lexical decision performance more strongly than reading-aloud performance, including concreteness, imageability, body–object interaction, number of meanings, number of semantic features, and density of semantic neighbors (e.g., Balota et al., 2004; Yap, Pexman, Wellsby, Hargreaves, & Huff, 2012). For example, people are faster to recognize high-imageability concepts like *chair* than low-imageability concepts like *truth* as being valid words, even when lexical variables such as length and frequency are controlled, but the equivalent effect is weaker when merely pronouncing the same words. Balota and colleagues (2004) suggested that distinguishing between words and nonwords is analogous to distinguishing between meaningful and nonmeaningful stimuli, and hence that lexical decision may cause participants to prioritize semantic information. Conversely, because there is no equivalent strategic advantage to focusing on semantic information when pronouncing a word aloud, where the task essentially involves translating from orthographic to phonological representation, any semantic effects on reading aloud are smaller.

However, the strength of semantic effects may depend on how one defines semantics. Grounded theories of cognition hold that the conceptual system has co-opted the perceptual and motor systems for the purpose of representation (Barsalou, 1999; Meteyard, Rodriguez Cuadrado, Bahrami, & Vigliocco, 2012). As such, semantics and perception are not necessarily separable, but rather share representational and attentional resources (Connell & Lynott, 2012b). The meaning of a word is processed using some of the

This article was published Online First October 7, 2013.

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This work was supported in part by UK Economic and Social Research Council Grant RES-000-22-3248. The order of authorship is arbitrary. Thanks to Anna Woollams for comments and Nick Shryane for statistical advice. Thanks also to Michael Cortese, Diane Pecher, and Max Coltheart for helpful reviews.

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same modality-specific neural structures as those involved in perceptual experience of its referent. Deciding whether a banana is *yellow*, for instance, recruits the same area of the left fusiform gyrus in the visual cortex as perceiving color stimuli (Simmons et al., 2007), whereas lexical decision on the word *telephone* activates the same auditory regions as perceiving sounds (Kiefer, Sim, Herrnberger, Grothe, & Hoenig, 2008).

More importantly, the same attentional resources are shared between perceptual and conceptual processing (Connell & Lynott, 2010, 2012b; van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008). Selectively attending to a particular perceptual modality, even in the absence of a target, increases activation in the corresponding sensory cortex at the expense of other modalities (Foxe, Simpson, Ahlfors, & Saron, 2005; Langner et al., 2011) and facilitates subsequent processing of target stimuli in that modality (Spence, Nicholls, & Driver, 2001; Töllner, Gramann, Müller, & Eimer, 2009). That is, directing attention toward a particular perceptual modality facilitates conceptual processing of information in that modality by preactivating modality-specific perceptual systems (Connell & Lynott, 2012b; Connell, Lynott, & Dreyer, 2012; van Dantzig et al., 2008; see also Connell & Lynott, 2012b, in press, for discussion of facilitation vs. interference effects from perceptual attention). For example, Connell et al. (2012) found that directing people's attention to the tactile modality by stimulating the hands speeded up people's size judgments of manipulable objects like *wallet* (where object words were visually presented), but not nonmanipulable objects like *mansion*, because touch information forms a functional part of the representation of wallets. Similarly, people were faster to verify the phrase *broccoli is green*, presented onscreen, when attention was already directed toward the visual modality by a preceding light flash, compared with when the phrase was preceded by a perceptual stimulus from a mismatching modality, such as the auditory presentation of white noise (Van Dantzig et al., 2008).

In the present article, we take a novel approach to examining semantic effects in visual word recognition by introducing predictions from the grounded cognition literature regarding the effects of perceptual attention on conceptual access. Specifically, we tested whether modality-specific perceptual attention implicitly engaged during reading affects how quickly and accurately a word is processed. Word meanings almost all involve perceptual information to some extent (Lynott & Connell, 2009, 2013), and strongly perceptual words are recognized more easily than weakly perceptual words (Connell & Lynott, 2012a). Critically, taking account of the role of perceptual attention in activating meaning leads to some novel predictions regarding the role of semantics in lexical decision and reading-aloud tasks. First, lexical decision and reading aloud should show modality-specific differences in their semantic effects. Because both tasks direct visual attention to a display of written text, they should both facilitate representing visual content in word meaning. That is, we expected strongly visual words (e.g., *cloudy*) to be recognized more quickly and accurately in both tasks than weakly visual words (e.g., *salty*). However, because reading words aloud also directs auditory attention (i.e., it requires attending to sound in planning and monitoring of pronunciation), the reading-aloud task, but not lexical decision, should facilitate representing auditory content. That is, we expected strongly auditory words (e.g., *noisy*) to be faster and more accurate to name than weakly auditory words (e.g., *salty*). Second, the overall semantic effect should be as large in reading aloud as in lexical decision, contrary to previous reports that lexical decision is more susceptible to semantic facilitation. That is, because both tasks are subject to facilitation via implicit perceptual attention, we expected similar-size benefits to performance.

Study 1: Visual and Auditory Strength

In this and the following studies, we use large-scale regression analyses over hundreds of words to examine the effects of semantic variables on lexical decision and reading-aloud tasks, over and above lexical variables such as word frequency, length, and number of orthographic or phonological neighbors. This "megastudy" approach is preferable to factorial designs when testing for small or fragile effects because it has greater statistical power, better control of extraneous variables, and lower risk of experimenter bias (Balota, Yap, Hutchinson, & Cortese, 2012). As such, we used the Elexicon megastudy database (Balota et al., 2007) as a source of lexical decision and reading-aloud data for each word under examination. As semantic variables, we used visual and auditory strength ratings (Lynott & Connell, 2009, 2013), with which participants rated from 0 (*low strength*) to 5 (*high strength*) the extent to which they experienced a particular concept by seeing or hearing. These modality-specific perceptual strength norms have successfully predicted conceptual processing performance in a range of different tasks (Connell & Lynott, 2010, 2011; Louwerse & Connell, 2011; van Dantzig, Cowell, Zeelenberg, & Pecher, 2011). Most relevant to our present purposes, we have shown in recent work that perceptual strength in the dominant modality is a more powerful predictor of lexical decision and reading-aloud performance than traditional semantic ratings of concreteness or imageability (Connell & Lynott, 2012a). Examining modality-specific perceptual strength allows us to test, for the first time, whether semantic effects in visual word recognition emerge from modality-specific perceptual attention implicitly involved in each task.

Method

Materials. A total of 936 multisyllabic words had measures available on all predictor variables. Visual and auditory strength ratings were available for just over 1,000 words (see Lynott & Connell, 2009, 2013, and additional unpublished extensions), of which the Elexicon database (Balota et al., 2007) provided lexical variables for a subset of 936 words. See Table 1 for means and zero-order correlations.

Procedure. We conducted two-step hierarchical regression analyses on three different dependent variables per lexical decision and reading aloud task from Elexicon (Balota et al., 2007): response times ([RTs] ms: $M_{LD} = 661$, $SD_{LD} = 81$; $M_{RA} = 639$, $SD_{RA} = 61$), standardized RT to partial out participant variation (*z*-scores: $M_{LD} = -0.441$, $SD_{LD} = 0.279$; $M_{RA} = -0.401$, $SD_{RA} = 0.257$), and accuracy rate (%: $M_{LD} = 93.9$, $SD_{LD} = 10.6$; $M_{RA} = 98.1$, $SD_{RA} = 4.8$). Standard lexical variables for each word (log word frequency, log-squared word frequency to overcome floor effects for very high-frequency items, length in letters, number of syllables, orthographic neighborhood size, and phonological neighborhood size) were entered in Step 1, and semantic variables (visual and auditory strength ratings) were entered in Step 2.

Table 1
Zero-Order Correlations, With Means and Standard Deviations, for Independent Predictor Variables in Study 1 (N = 936)

Variable	1	2	3	4	5	6	7	8
1. Auditory strength	—							
2. Visual strength	−.243	—						
3. Log frequency	.199	−.081	—					
4. Log^2 frequency	−.083	.040	−.629	—				
5. Length in letters	−.101	.031	−.613	.764	—			
6. Number of syllables	.193	.143	−.301	.300	.310	—		
7. Orthographic neighbors	.177	.129	−.314	.308	.322	.977	—	
8. Phonological neighbors	.148	−.052	.813	−.536	−.579	−.295	−.299	—
M	1.79	3.57	5.92	4.70	11.46	2.64	7.80	1.76
SD	1.36	0.94	1.91	5.66	13.16	0.91	4.87	0.84

Results

Table 2 presents standardized coefficients and adjusted R^2 for each regression model. As predicted, visual strength of the referent concept facilitated both lexical decision and reading-aloud performance, whereas auditory strength facilitated reading-aloud performance alone. Moreover, comparing the ΔR^2 values between tasks showed that the size of the overall semantic effect was similar for both reading aloud and lexical decision, $t(2) = 1.81$, $p = .422$, Cohen's $d = .569$.

Study 2a: Including Age of Acquisition

Early acquired words are processed more quickly and accurately than late acquired words in both lexical decision and reading aloud (e.g., Brown & Watson, 1987; Cortese & Khanna, 2008). Indeed, previous work has revealed that age of acquisition (AoA) eliminates semantic effects in reading aloud, at least when imageability is used as a semantic variable (Cortese & Khanna, 2008; cf. Cortese & Schock, 2013). We did not include AoA as a predictor variable in Study 1 because its conceptualization as a predictor (rather than an outcome) variable in word processing has been controversial (Zevin & Seidenberg, 2004). Nonetheless, we did not expect AoA to eliminate the semantic effect on reading aloud for two reasons. First, because imageability ratings are visually biased and tend to neglect or misinterpret other perceptual modalities (Connell & Lynott, 2012a), we predicted that AoA was likely to weaken the effects of visual strength (following Cortese & Khanna's, 2008, findings for imageability) but have little impact on auditory strength. Second, humans live in a visually rich environment, and our use of language appears to make more fine-grained distinctions between visual experience than auditory experience (or indeed experience in any other modality): For instance, in a random selection of 400 noun concepts, Lynott and Connell (2013; see also Lynott & Connell, 2009) found that visually dominant concepts outnumbered auditorily dominant concepts 8:1. Children may therefore acquire labels for strongly visual concepts (of which there are many) before they acquire labels for weakly visual concepts (of which there are relatively few) where another perceptual modality such as audition is likely to be dominant. We thus expected AoA to correlate with visual strength and subsume its effect in lexical decision and reading aloud, but to be uncorrelated with auditory strength and leave its effect on reading aloud intact.

Method

AoA ratings from Kuperman, Stadthagen-Gonzalez, and Brysbaert (2012) were available for a subset of 863 words from Study 1, and so we replicated the analysis except for entering AoA in Step 2 as a lexical semantic variable, and then semantic predictors in Step 3 (see Table 3 for means and correlations).

Table 2
Standardized Coefficients for Semantic Predictors, and R^2 Values per Hierarchical Step of Regression Models With Accompanying F Tests, for Response Times (in Milleseconds), Standardized Response Times (Z-Scores), and Accuracy Rates (%) in Study 1

Predictor	Lexical decision			Reading aloud		
	RT	zRT	Accuracy	RT	zRT	Accuracy
Step 1 (lexical)						
Adjusted R^2	.521	.594	.385	.373	.388	.161
$F(6, 929)$	170.49^{***}	228.87^{***}	98.36^{***}	93.66^{***}	97.97^{***}	30.84^{***}
Step 2 (semantic)						
Auditory strength	−0.010	0.009	0.009	-0.066^{*}	-0.085^{**}	0.069^{*}
Visual strength	-0.069^{**}	-0.068^{**}	0.086^{**}	-0.084^{**}	-0.090^{***}	$0.059^{\dagger}$
Adjusted R^2	.524	.598	.390	.379	.398	.164
$F(8, 927)$	129.86^{***}	174.83^{***}	75.79^{***}	72.46^{***}	76.55^{***}	24.00^{***}
Adjusted ΔR^2	.003	.004	.005	.006	.010	.003
$\Delta F(2, 927)$	4.32^{*}	5.72^{**}	5.32^{**}	5.88^{**}	7.92^{***}	3.08^{*}

Note. RT = response time.
$^{\dagger}p = .061$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 3
Zero-Order Correlations, With Means and Standard Deviations, for Independent Predictor Variables in Study 2a (N = 863)

Variable	1	2	3	4	5	6	7	8	9
1. Age of acquisition	—								
2. Auditory strength	−.041	—							
3. Visual strength	−.296	−.180	—						
4. Log frequency	.363	.124	−.049	—					
5. Log^2 frequency	−.314	−.074	.029	−.639	—				
6. Length in letters	−.298	−.073	.021	−.614	.774	—			
7. Number of syllables	−.621	.271	.124	−.273	.301	.304	—		
8. Orthographic neighbors	−.608	.253	.109	−.287	.309	.316	.977	—	
9. Phonological neighbors	.319	.101	−.027	.818	−.541	−.579	−.283	−.286	—
M	7.47	1.69	3.59	5.80	4.78	11.70	2.69	8.04	1.73
SD	2.47	1.26	0.92	1.90	5.80	13.41	0.90	4.91	0.85

Results

Table 4 shows standardized coefficients and R^2 for each regression model. AoA was a significant predictor in all models, and, as expected, subsumed the effect of visual strength in both lexical decision and reading aloud. Critically, auditory strength continued to facilitate reading-aloud performance even when AoA was controlled, meaning that the size of the semantic effect for the reading-aloud task was marginally larger than for lexical decision, $t(2) = 5.05$, $p = .074$, Cohen's $d = .660$.

Study 2b: Disentangling Semantic Variables

These results raise the question of whether the facilitatory effect of visual strength observed in Study 1 is entirely due to AoA (i.e., given their relationship). Our theoretical account of perceptual attention would assume not; that is, the privileged status of early acquired words should be independent of how visual attention engaged during reading facilitates representing visual information in the referent concept, and so both variables should have independent predictive power. In order to test this assumption, we used principal components analysis (PCA) to partition the correlated variables of AoA, visual strength, and auditory strength into three orthogonal (uncorrelated) components. Although PCA is often used for dimensionality reduction, it is also used to address multicollinearity between variables without losing information by compressing variables into a smaller number of dimensions (Glantz & Slinker, 2001). Thus, by rotating principle components, one can retain an almost perfect correspondence between the components and the original variables, but with any problems of multicollinearity now eliminated. As such, it is possible to test for independent effects of AoA and visual strength in a regression analysis without their multicollinearity causing AoA to subsume visual strength (as in Study 2a).

Method

PCA (correlation matrix, varimax rotation) converged on three orthogonal components for AoA, auditory strength, and visual strength in four iterations. Component 1 corresponded to auditory

Table 4
Standardized Coefficients for Semantic Predictors, and R^2 Values per Hierarchical Step of Regression Models With Accompanying F Tests, for Response Times (in Milliseconds), Standardized Response Times (Z-Scores), and Accuracy Rates (%) in Study 2a

	Lexical decision			Reading aloud		
Predictor	RT	zRT	Accuracy	RT	zRT	Accuracy
Step 1 (lexical)						
Adjusted R^2	.528	.598	.389	.378	.384	.153
$F(6, 856)$	161.99^{***}	214.94^{***}	92.63^{***}	88.45^{***}	90.42^{***}	26.97^{***}
Step 2 (lexical-semantic)						
AoA	0.168^{***}	0.193^{***}	-0.323^{***}	0.154^{***}	0.186^{***}	-0.260^{***}
Adjusted R^2	.544	.619	.449	.391	.403	.191
$F(7, 855)$	147.98^{***}	201.24^{***}	101.40^{***}	80.20^{***}	84.12^{***}	30.09^{***}
Adjusted ΔR^2	.016	.021	.060	.013	.019	.038
$\Delta F(1, 855)$	30.45^{***}	48.10^{***}	93.75^{***}	19.33^{***}	28.74^{***}	41.21^{***}
Step 3 (semantic)						
Auditory strength	−0.032	−0.019	0.046	-0.075^{**}	-0.095^{***}	0.077^{*}
Visual strength	−0.025	−0.021	0.007	−0.040	−0.038	0.003
Adjusted R^2	.544	.619	.450	.395	.409	.194
$F(9, 853)$	115.36^{***}	156.53^{***}	79.23^{***}	63.59^{***}	67.41^{***}	24.10^{***}
Adjusted ΔR^2	.000	.000	.001	.004	.006	.003
$\Delta F(2, 853)$	1.09	0.64	1.35	3.70^{**}	5.67^{**}	$2.72^{\dagger}$

Note. RT = response time.
$^{\dagger} p = .066$. $^{*} p < .05$. $^{**} p < .01$. $^{***} p < .001$.

Table 5
Zero-Order Correlations, With Means and Standard Deviations, for Independent Predictor Variables in Study 2b Where Semantic Predictors Are Partitioned Into Orthogonal Components by Principal Components Analysis (PCA; N = 863)

Variable	1	2	3	4	5	6	7	8	9
1. PCA component for age of acquisition	—								
2. PCA component for auditory strength	.005	—							
3. PCA component for visual strength	.024	.010	—						
4. Log frequency	.375	.137	.026	—					
5. Log^2 frequency	−.325	−.086	−.032	−.639	—				
6. Length in letters	−.310	−.085	−.038	−.614	.774	—			
7. Number of syllables	−.610	.260	.053	−.273	.301	.304	—		
8. Orthographic neighbors	−.600	.241	.037	−.287	.309	.316	.977	—	
9. Phonological neighbors	.332	.114	.039	.818	−.541	−.579	−.283	−.286	—
M	−0.037	0.008	0.020	5.80	4.78	11.70	2.69	8.04	1.73
SD	0.968	0.993	0.990	1.90	5.80	13.41	0.90	4.91	0.85

strength (r = .995), Component 2 corresponded to AoA (r = .986), and Component 3 corresponded to visual strength (r = .982). All three components accounted for approximately equal proportions of total variance in the original variables (33.36%, 33.36%, 33.28%, respectively). We then ran identical regression models to Study 2a, except these PCA components were used in place of their rating equivalents in Steps 2 and 3 (see Table 5 for means and correlations).

Results

As expected, when the overlapping variance between AoA and visual strength was partitioned, the effect of visual strength was restored to lexical decision and reading-aloud performance so that results replicated the pattern of effects from Study 1 (see Table 6). Unlike in Study 2a, in which AoA's shared variance with visual strength leads it to subsume the effect of the weaker visual strength variable, we observe independent effects of AoA and visual strength in the present study because their multicollinearity has been removed. Hence, the effect of visual strength in Study 1 is not an artifact of AoA. In other words, both AoA and visual strength are meaningful predictors of word-processing performance: Early acquired words are processed faster, regardless of the perceptual strength of their referent concept, and visually strong words are processed faster, regardless of when they were acquired. As with Study 1, the size of the overall semantic effect was similar for reading aloud and lexical decision, $t(2) = 2.82$, $p = .212$, Cohen's $d = 1.053$.

Discussion

Lexical decision performance is facilitated by how strongly a word's referent is visually experienced, whereas reading-aloud performance is facilitated by the strength of both visual and auditory experience. As predicted by accounts of perceptual attention on conceptual processing (Connell & Lynott, 2012b), the

Table 6
Standardized Coefficients for Orthogonal Components of Semantic Predictors by Principal Components Analysis (PCA), and R^2 Values per Hierarchical Step of Regression Models With Accompanying F Tests, for Response Times (in Milliseconds), Standardized Response Times (Z-Scores), and Accuracy Rates (%) in Study 2b

Predictor	Lexical decision			Reading aloud		
	RT	zRT	Accuracy	RT	zRT	Accuracy
Step 1 (lexical)						
Adjusted R^2	.528	.598	.389	.378	.384	.153
$F(6, 856)$	161.99***	214.94***	92.63***	88.45***	90.42***	26.97***
Step 2 (lexical-semantic)						
PCA AoA	0.155***	0.181***	−0.311***	0.138***	0.169***	−0.250***
Adjusted R^2	.542	.617	.445	.389	.400	.189
$F(7, 855)$	146.73***	199.31***	99.85***	79.32***	82.98***	29.62***
Adjusted ΔR^2	.014	.019	.056	.011	.016	.036
$\Delta F(1, 855)$	26.37***	42.73***	87.17***	15.53***	23.83***	38.43***
Step 3 (semantic)						
PCA auditory	−0.034	−0.023	0.055*	−0.075**	−0.096***	0.085*
PCA visual	−0.049*	−0.050*	0.057*	−0.057*	−0.059*	0.040
Adjusted R^2	.544	.619	.450	.395	.409	.194
$F(9, 853)$	115.36***	156.53***	79.23***	63.59***	67.41***	24.10***
Adjusted ΔR^2	.002	.002	.005	.006	.009	.005
$\Delta F(2, 853)$	3.07*	3.20*	4.34*	5.58**	8.09***	4.07*

Note. Step 1 is identical to Step 1 in Table 4. RT = response time; AoA = age of acquisition.
* $p < .05$. ** $p < .01$. *** $p < .001$.

perceptual attention involved in reading interacts with the perceptual aspects of a word's meaning to affect how quickly and accurately that word is processed. Implicitly directing visual and/or auditory attention in different kinds of visual word recognition task facilitates the representation of visual and/or auditory information in the meaning of a word, which in turn contributes to the processes that drive a lexical decision or reading-aloud response. In addition, these semantic effects are not eliminated by AoA, as had been previously observed for imageability in reading aloud (Cortese & Khanna, 2008). AoA has no effect on the predictive ability of auditory strength in reading aloud, and—when it is decoupled from the correlated variable of visual strength—the unique variance of both AoA and visual strength independently facilitated both lexical decision and reading aloud. This pattern of effects suggests word learning varies with age in how it relies on different modalities of perceptual experience: Children tend to learn labels for strongly visual concepts early on, and shift increasingly to weakly visual concepts as they get older. The labels for strongly auditory concepts, however, are learned at a relatively constant rate.

The predictive power of visual strength in lexical decision and reading-aloud performance, and of auditory strength in reading aloud alone, offers strong evidence for the role of semantic information in early, low-level word recognition, where the meaning of the word mediates orthographic and/or phonological activation (Coltheart et al., 2001; Plaut et al., 1996). Moreover, because the observed semantic effects were approximately equal in both lexical decision and reading-aloud tasks (indeed, tending to be slightly larger in reading aloud), our findings do not support the idea that semantic effects in lexical decision are reliant on participants prioritizing semantic information in order to make a meaningful/nonmeaningful distinction (Balota et al., 2004). Rather, our explanation for the semantic effects of visual and auditory strength is that task-specific implicit perceptual attention preactivates modality-specific systems and thereby facilitates the representation of semantic information that relates to those modalities. Although the perceptual attention account has been discussed in the context of other conceptual tasks such as property verification (van Dantzig et al., 2008), modality detection (Connell & Lynott, 2010), and size comparison (Connell et al., 2012), it had not previously been applied to visual word recognition. The present data's support for the unique modality-specific predictions of the perceptual attention account has implications for current theories and models of visual word recognition. There is not a discrete "semantics box" that contains meaning during word processing, as suggested by classic schematics of the parallel distributed processing triangle model (Plaut et al., 1996; cf. Dilkina et al., 2008) or dual-route cascaded model (Coltheart et al., 2001). Rather, meaning is distributed across many of the same systems that are involved in perceiving the shape of letters and the sound of phonemes, and implicit task demands affect which aspect of a representation is most active at any one time.

Unlike current accounts of semantic effects that assume a "cold start," where meaning activation for a particular word relies on feed-forward activation from orthography after the word is presented (e.g., Balota et al., 2004; Dilkina et al., 2008; Yap et al., 2012), our account of visual and auditory strength effects is that of a "warm start," where some of the systems required to represent meaning are preactivated by the perceptual attention involved in reading. Thus, the extent to which particular words are subject to semantic effects will depend on the visual strength of the referent concepts when the task in question is lexical decision, and on the visual and auditory strength of the referent concepts when the task is reading aloud. Furthermore, because perceptual information is not always represented during shallow conceptual processing (Connell & Lynott, 2013; Lynott & Connell, 2010; Solomon & Barsalou, 2004), particularly when participants respond rapidly (Louwerse & Connell, 2011), the extent of any facilitation from perceptual attention will depend on the exact task demands, available cognitive resources, and processing goals (Connell & Lynott, 2012b). Future research should establish whether and when word-processing tasks differ in how perceptual attention produces modality-specific semantic effects.

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Received May 3, 2013
Revision received August 20, 2013
Accepted August 26, 2013 ■