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Better the DVL You Know:

Acronyms Reveal the Contribution of Familiarity to Single-Word Reading

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Abstract

Current theories of reading are divided between dual-route accounts, which propose that separable processes subserve word recognition for orthographically regular and irregular strings, and connectionist models, which propose a single mechanism mapping form to meaning. These theories make distinct predictions about the processing of acronyms, which can be orthographically illegal and yet familiar, as compared with the processing of pseudowords, which are regular but unfamiliar. This study examined whether acronyms are processed like pseudowords and words. Event-related potentials (ERPs) were recorded as subjects viewed familiar and unfamiliar acronyms, words, pseudowords, illegal strings, and—as the targets of the substantive behavioral task—proper names. Familiar acronyms elicited repetition effects on the N400 component, a functionally specific index of semantic activation processes; repetition effects for familiar acronyms were similar in magnitude, timing, and scalp distribution to those for words and pseudowords. The similarity of the brain response to familiar-but-illegal and unfamiliar-but-legal classes of stimuli is inconsistent with predictions of dual-route models of reading.

The fluent reader's ability to rapidly and effectively move between print and meaning is a critical and extensively studied skill. Although there is yet no consensus about the mechanisms of visual word recognition, literature across many methodologies suggests that two critical factors are *familiarity*, the degree to which a stimulus is known to a reader, and *regularity*, the degree to which a stimulus conforms to orthographic conventions of the reader's language. Prominent models of word reading differ in the nature and importance of the roles assigned to these factors.

Dual-route theories (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) suggest that two computationally distinct processes are required to explain the observed range of reading abilities, behaviors, and impairments, and that regularity is the primary factor in determining which process is used. One route consists of a rule-based translation process that maps items with transparent orthography onto phonology, and thence to semantics. A second, direct route from orthography to semantics is proposed to subserve the recognition of irregular items and, in experienced readers, highly familiar regular items. Thus, dual-route theories crucially assume two pathways from form to meaning that are both neurally and functionally separable from each other and that entail different computations.

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In contrast, connectionist models (e.g., Harm & Seidenberg, 2004) have been used to argue that a single computational process could subserve all reading. In connectionist models, information flows freely among orthographic, semantic, and phonological representations, such that all subsystems work cooperatively to achieve word recognition. Connectionist models, therefore, allow recognition processes for irregular words, regular words, and pseudowords to proceed with functionally identical calculations. As the calculations required by connectionist models are functionally equivalent regardless of the familiarity or regularity of the orthographic input, equivalent computations will be attempted on all inputs to the system, regardless of their regularity or familiarity.

In electrophysiological research, only orthographically legal stimuli have been associated with event-related potential (ERP) responses linked to semantic access. One such response, the N400 component, is a central parietal negative-going voltage deflection that peaks around 400 ms after stimulus onset and seems to be a functionally specific marker of lexico-semantic processing (for review, see Kutas & Federmeier, 2000). The N400 is sensitive to repetition, exhibiting reduced amplitudes on second and subsequent presentations when repetitions occur after seconds or minutes. Such repetition effects are particularly robust (e.g., Deacon, Dynowska, Ritter, & Grose-Fifer, 2004; Rugg, 1985, 1990) and provide a means of comparing N400 responses across stimulus types differing in baseline characteristics. N400 repetition effects are elicited by words (Rugg, 1990) and pronounceable pseudowords (Deacon et al., 2004), but, notably, not by illegal strings (Rugg & Nagy, 1987).

Although this pattern suggests a critical role for regularity in reading, these data alone cannot resolve the dual-route and connectionist accounts' main disagreement about the nature and number of the processes underlying word recognition, as no study has yet fully crossed the critical factors of regularity and familiarity. Doing so requires a class of stimuli that are completely illegal—and therefore as opaque to phonological translation as illegal strings, requiring letter-by-letter readout—and nevertheless highly familiar, and the current study introduces acronyms (orthographically illegal strings of letters that constitute a severe abbreviation of much longer sets of words or letters) as just such a class. Dual-route and connectionist models make distinct predictions about the processing of illegal acronyms as compared with the processing of pseudowords. Under dual-route accounts, familiar-but-illegal acronyms must take the direct route to recognition because they violate the orthographic rules that form the basis for phonological translation; pseudowords, instead, must take the translational route because they have no preexisting representation available for direct access. Thus, according to dual-route accounts, N400 effects that have already been documented for regular items should be absent for illegal acronyms. In contrast, in connectionist models, familiar acronyms and pseudowords can be recognized using the same process, so repetition effects for familiar, illegal acronyms should be similar (if not identical) to those elicited by pseudowords and words.

We tested the predictions of the two classes of models by measuring ERPs from subjects viewing words, pseudowords, acronyms, illegal strings, and proper names (which were the targets of the behavioral task), focusing on N400 repetition effects as a means of assessing semantic access while controlling for differences in stimulus properties across item types. Items with low neighborhood density (N) are known to elicit N400s with relatively small amplitude (Holcomb, Grainger, & O'Rourke, 2002), and orthographically illegal items typically have considerably lower N than orthographically regular items. Orthographic regularity and N are therefore confounded, making interpretation of raw N400 responses across categories problematic. For this reason, we used magnitude of the N400 repetition effect as a primary measure of semantic access. Of critical interest was whether familiar

acronyms would yield N400 repetition effects and, if so, how these effects would compare with those elicited by regular stimuli.

METHOD

Subjects

Twenty subjects (9 female; mean age = 20) were recruited from the University of Illinois and were compensated with money or course credit. All were neurologically normal, right-handed, monolingual English speakers with normal or corrected-to-normal vision.

Stimuli

Stimuli were three- and four-letter strings in six categories: 61 acronyms, with a mean frequency of 126 appearances in the Sydney Morning Herald (SMH; Dennis, 1995) corpus; 62 illegal strings, with a mean wild-card (n-gram) frequency of 196.6 appearances in the Kuçera-Francis (KF; Kuçera & Francis, 1967) corpus; 32 low-frequency words, with a mean frequency of 256 appearances in SMH; 32 high-frequency words, with a mean frequency of 1,994 appearances in SMH; 31 regular, pronounceable pseudowords that were derived from low-frequency items in SMH and had a mean KF n-gram frequency of 0.03; and 100 proper English first names.

Acronyms and illegal strings were composed of all consonants or all vowels. For purposes of analysis, each subject's responses to a paper-and-pencil questionnaire assessing acronym knowledge were used to divide the acronyms into "familiar" and "unfamiliar" groups for that subject.

All categories of stimuli were matched for length and, with the exception of high-frequency words and names, frequency. N-gram frequencies of illegal strings and pseudowords were matched with the written frequencies of low-frequency words on the basis of a wild-card analysis of the KF corpus. Examples are presented in Table 1.

Stimuli were divided randomly into six lists with the constraint that each list have the same number of high-frequency words, low-frequency words, normatively familiar (as indicated by a previous norming study of 238 University of Illinois undergraduates) acronyms, normatively unfamiliar (as indicated by the same norming study) acronyms, pseudowords, illegal strings, and names as every other list. Within each list, stimuli were ordered randomly with the constraint that each acronym, illegal string, word, and pseudoword was repeated one time within its list at an interitem lag of 3 to 6. Presentation of each list was followed by a short break, and each participant received all six lists in individually randomized order.

Stimuli were presented one at a time in white on the black background of a 22-in. computer monitor with a resolution of 640 × 480. A fixation arrow was continuously present in the center of the screen. The trial structure was as follows: 500-ms warning, 500-ms stimulus presentation, 1,000-ms response interval, 1,000-ms blink interval.

Procedure

Subjects were seated 100 cm away from a computer monitor and instructed that their task was to respond with a button press when they saw a "common English proper first name" in the stimulus stream. A practice block preceded the experimental lists.

Electroencephalographic Recording

The procedure for electroencephalographic (EEG) recording was identical to that described in Lee and Federmeier (2006), with the exception that scalp impedances were kept below 5 kΩ.

RESULTS

As noted, acronym knowledge was assessed individually for each participant. On average, participants were familiar with 31.6 of the 61 acronyms (52%).

Difference waves were computed by subtracting the average waveform elicited by second presentation of items in a stimulus class from the average waveform elicited by first presentation of items in that class; Figure 1 shows difference waves at a representative site for familiar acronyms, words, illegal strings, and pseudowords.

For words, pseudowords, and familiar acronyms, repetition effects were characterized by a negative-going peak around 400 ms; unfamiliar illegal items showed little electrophysiological change with repetition. For stimulus categories that did display change with repetition (words, pseudowords, and familiar acronyms), analysis of difference-wave mean amplitude indicated no main effect of stimulus or interaction of stimulus type with electrode in any epoch preceding or following our 250- to 450-ms N400 window (all *F*s < 2.75).

We performed a repeated measures analysis of variance (ANOVA) on mean amplitude between 250 and 450 ms, with factors of stimulus type (word, pseudoword, familiar acronym, unfamiliar acronym, illegal item) and electrode (26 scalp sites). This analysis revealed a marginal effect of stimulus type, $F(4, 76)$ 5 2.24, p = 5 .09, η^2 = .09, and an interaction of stimulus type and electrode, $F(100, 1900) = 2.39$, $p = .02$, $\eta^2 = .08$. A follow-up ANOVA constrained to 8 central parietal electrodes revealed an effect of stimulus type, $F(4, 76) = 4.03$, $p = .01$, $\eta^2 = .14$, but no interaction with electrode, $F(28, 532)$ 5 1.36. Over these central parietal sites, the amplitude of the repetition effect for familiar acronyms differed from that for illegal items, $F(1, 19) = 8.42$, $p_{rep} = .95$, $\eta^2 = .19$, and unfamiliar acronyms, $F(1, 19) = 13.00$, $p_{rep} = .95$, $\eta^2 = .23$, but not from that for words, $F(1, 19) = 1.45$, or pseudowords ($F < 1$). Repetition effects for illegal items and unfamiliar acronyms did not differ from each other over these central parietal sites, $F(1, 19) = 1.04$, nor did effects for words and pseudowords ($F < 1$). Magnitude of the N400 repetition effect for words, pseudowords, familiar acronyms, unfamiliar acronyms, and illegal strings, averaged over central parietal sites, is depicted in Figure 2, which shows that the effects were nonzero for words, $F(1, 19) = 11.10$, $p_{rep} = .97$, $\eta^2 = .04$; pseudowords, $F(1, 19) = 6.03$, $p_{rep} = .93$, $\eta^2 = .04$; and familiar acronyms, $F(1, 19) = 15.23$, $p_{rep} = .99$, $\eta^2 = .10$; but not for unfamiliar acronyms, $F < 1$, or illegal items, $F(1, 19) = 1.34$.

An ANOVA conducted individually over the middle central and middle parietal channels yielded no effect of stimulus type (words, pseudowords, or familiar acronyms) on peak latency of the repetition effect, *F*s < 1.

Using data from 16 channels, we assessed the topography of the repetition effect for words, pseudowords, and familiar acronyms in a repeated measures ANOVA with factors of hemisphere (right or left), laterality (lateral or medial), and anteriority (prefrontal, frontal, central parietal, occipital). There was no main effect of stimulus type, nor any interactions of stimulus type with any distributional factor (all *F*s < 1.60). A direct comparison of familiar acronyms and pseudowords indicated no differences in the topography of the repetition

effect. Figure 3 presents the difference waves for familiar acronyms at all 26 scalp channels, alongside the distribution of N400 repetition-effect potentials elicited by these items.

DISCUSSION

We examined the effects of incidental repetition on ERPs to words, pseudowords, acronyms, and illegal strings. Of key interest was determining whether familiar acronyms would elicit N400 repetition effects of the type previously seen for pseudowords and words. Because regularity is a critical gating factor for dual-route models, according to those accounts, the response to familiar, but completely illegal acronyms should resemble that to illegal strings; that is, no N400 repetition effect would be expected, and if there were any repetition effect observed at all, it would be expected to be distinct from the effects for pseudowords and words. In contrast, connectionist accounts, in principle, allow all items—regular and unfamiliar, as well as illegal and familiar—to engage the same processes during visual word recognition.

We replicated previous findings that illegal strings do not elicit N400 repetition effects, and demonstrated that acronyms that happened to be unknown by individual participants elicited responses identical to those elicited by illegal strings. However, repetition effects elicited by familiar acronyms were characterized by significant reductions in negativity in the 250- to 450-ms epoch, with latency and topography characteristic of an N400 effect. The repetition effects elicited by familiar acronyms were indistinguishable in time course, magnitude, and scalp topography from those elicited by words and pseudowords. The striking difference in electrophysiological response to illegal strings as a function of whether or not they constitute an acronym familiar to a reader clearly shows that orthographic regularity is not necessary for eliciting repetition effects on the N400, and this result is inconsistent with the predictions of dual-route models.

Connectionist models, however, are able to explain this pattern by appeal to the hypothesis that the visual word-recognition system is sensitive primarily to familiarity. Words are clearly familiar, and because the familiar acronyms in this experiment included only acronyms familiar to individual subjects, these stimuli were also clearly familiar. At a whole-item level, pseudowords are presumably novel. However, a pronounceable pseudoword overlaps considerably with at least one word, and often with several. Under connectionist accounts, it is not surprising, therefore, that a stimulus like *dawk* elicits N400 repetition effects similar to those seen for words, as presentation of *dawk* activates the semantics of lexical neighbors such as *dark* and *dank*, priming those overlapping items for easier access when they are again activated by a second presentation of *dawk*. According to connectionist accounts, then, regularity per se is not a critical determinant of processing, though regularity can affect processing through its covariance with familiarity.

Dual-route theories, however, may have difficulty explaining the current pattern of results. Such theories can accommodate a pattern in which words and pseudowords elicit similar responses, on the assumption that both are processed along the translational pathway. However, in that case, illegal acronyms must be processed using the separable mechanisms of direct access. Alternatively, a dual-route theory could explain the similarity in response to words and familiar acronyms with the suggestion that, in experienced readers, both are processed via the direct route, which preempts the need for translation from orthography to phonology and therefore is not sensitive to the illegality of the acronyms. However, in that view, pseudowords should be processed differently, because they are presumably novel and therefore cannot have a preexisting representation available for direct access. Thus, although words might take either the direct or the translational route to meaning, pseudowords and acronyms should always be processed differently. The finding that repetition of illegal

acronyms and repetition of unfamiliar pseudowords have indistinguishable effects on an electrophysiological component linked to access to meaning seems incompatible with dual-route accounts.

The strongest extant evidence in support of dual-route accounts comes from double dissociations observed in dyslexia—in particular, the fact that phonological dyslexics are able to read aloud exception words but not pseudowords, whereas surface dyslexics are able to read aloud pseudowords but not exception words. This pattern has been cited as evidence that exception words and pseudowords follow different routes from orthography to pronunciation. The current study focused on the processes mapping form to meaning and should not be taken to suggest that acronyms and pseudowords are not differentiated at *any* point in the processing stream. Indeed, it seems reasonable to assume that the computations involved in pronouncing acronyms and pseudowords must be distinct downstream of the processes examined here, as illegal acronyms are read aloud as a listing of letters, whereas pseudowords are not. The contribution of our data is to show that words, pseudowords, and familiar acronyms engage identical processes of semantic access, as repetition of all three stimulus types yields reductions of statistically similar size, time course, and distribution in the amplitude of the N400. This similarity in the response to items that are illegal but familiar and to items that are legal but unfamiliar is inconsistent with a core hypothesis of dual-route models, namely, that regularity serves as a critical factor in determining which of two distinct mechanisms is used to map meaning onto orthography.

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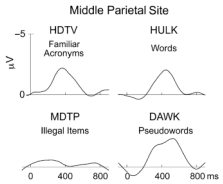

Fig. 1.

Grand-average difference waves (first minus second presentation) for familiar acronyms, words, pseudowords, and illegal strings at the middle parietal channel (with an example from each stimulus category indicated above the category name).

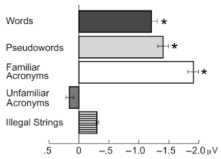

Fig. 2.

Mean amplitude of the 250- to 450-ms epoch of repetition-effect difference waves, averaged over central parietal channels. Results are shown separately for words, pseudowords, familiar acronyms, unfamiliar acronyms, and illegal items. Repetition effects larger than zero at a confidence level of .05 are indicated by an asterisk. Error bars represent the standard errors of the means.

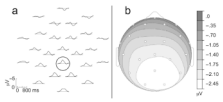

Fig. 3.

Familiar-acronym repetition effect. Grand-average repetition-effect difference waves for familiar acronyms at all 26 scalp channels are displayed in (a), with the middle parietal waveform circled. The distribution of the effect (top view of the head) between 325 and 375 ms after stimulus onset is shown in (b).

TABLE 1

Example Stimuli

Stimulus type	Example stimuli
Normatively familiar acronym	HDTV, MVP
Normatively unfamiliar acronym	IAEA, MDF
Illegal string	MDTP, NKS
Low-frequency word	HULK, GIN
High-frequency word	HAT, MAP
Pseudoword	DAWK, PEX
Proper first name	AMY, ABE