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Spelling to sound correspondences affect acronym recognition processes.

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ABSTRACT

A large body of research has examined the factors which affect the speed with which words are recognised in lexical decision tasks. Nothing has yet been reported concerning the important factors in differentiating acronyms (e.g. BBC, HIV, NASA) from non-words. It appears that this task poses little problem for skilled readers, in spite of the fact that acronyms have uncommon, even illegal, spellings in English. We used regression techniques to examine the role of a number of lexical and non-lexical variables known to be important in word processing in relation to lexical decision for acronym targets. Findings indicated that acronym recognition is affected by age of acquisition and imageability. In a departure from findings in word recognition, acronym recognition was not affected by frequency. Lexical decision responses for acronyms were also affected by the relationship between spelling and sound - a pattern not usually observed in word recognition. We argue that the complexity of acronym recognition means that the process draws phonological information in addition to semantics.

While much is known about the processes involved in reading and recognising written words, relatively little is known about acronyms (e.g. BBC, HIV, NASA). Having noted an increased research interest in acronyms over the last few years, Izura and Playfoot (2012) provided a detailed description of 146 acronyms in terms of their psycholinguistic characteristics such that future studies could be subject to the same level of control as is typical in studies of mainstream word reading. Subsequently we have examined the factors which influence performance in acronym naming (Izura & Playfoot, 2012) and semantic processing (Playfoot & Izura, 2013). An additional investigation of acronym characteristics and the effect these have on reading aloud has recently been conducted in French (Bonin, Meot, Millotte & Bugaiska, 2014). In the above papers it was shown that acronym processing was affected by broadly the same characteristics as mainstream words (e.g. frequency, imageability, age of acquisition) but with some nuances which we have argued to stem from the peculiar spelling to sound conversion inherent in acronyms. In this report we continue to explore the influence of acronym characteristics (in this case frequency, age of acquisition, imageability, orthographic neighbourhood, bigram frequency and length are considered, as well as the relationship between print and pronunciation) on processing, this time in relation to lexical decision performance. It was expected that some of the factors commonly known to affect word recognition will also affect acronym identification while acronyms idiosyncratic features (e.g., print to pronunciation patterns) might have a unique role on acronym processing. The specific predictions relating to each variable are discussed in more detail below.

In previous work (Izura & Playfoot, 2012; Playfoot, Izura & Tree, 2013), we have discussed subtypes of acronyms which vary with regard to the relationship between spelling and sound. The majority of acronyms are pronounced by naming each letter in turn (e.g. BBC, HIV).

We therefore describe this as the *typical* acronym pronunciation. A subset of acronyms (e.g. NASA) is pronounced following a more word-like pronunciation which Izura and Playfoot (2012) referred to as *atypical*. Further, acronyms differ in terms of the ambiguity of their print to pronunciation pattern. For acronyms which comprise consonants alone there is no question as to pronunciation – naming each letter in turn is the only way to generate a sensible output. Thus acronyms like BBC are described as unambiguous. When acronyms contain consonants and vowels they may be pronounced a letter at a time (HIV) or as a whole (NASA). There is nothing about the specific orthography that indicates which of these pronunciations is appropriate. We therefore describe acronyms such as this as ambiguous. Our examination of acronym characteristics in naming revealed that the effects of frequency, age of acquisition and imageability differed between acronym subtypes (Izura & Playfoot, 2012). A similar interaction may be observed in the lexical decision task reported here in spite of the fact that effects of spelling to sound correspondence are seldom reported in lexical decision tasks with mainstream words. Evidence suggests that such effects can be observed in word recognition if the stimulus items are particularly unusual with regard to the relationship between spelling and sound (e.g. Parkin, 1982; Seidenberg, Waters & Tanenhaus, 1984) or if the stimuli are low in frequency (Andrews, 1982; Seidenberg et al., 1984). It is possible, therefore, that the peculiar combination of characteristics inherent in acronyms may result in differences between ambiguous typical (HIV), ambiguous atypical (NASA) and unambiguous typical (BBC) acronym subtypes in relation to overall response times. Acronym print-to-pronunciation patterns might also modulate the effects of lexical variables such as age of acquisition, imageability and frequency on acronym recognition times.

Perhaps the most complete model of reading and word recognition is the Dual Route Cascaded model or DRC (Coltheart, Perry, Rastle, Langdon & Ziegler, 2001). This belongs to a class of model which proposes that known words are represented in an orthographic lexicon containing one node for each word in the vocabulary of the reader. Localist theories, such as this, account simply for word recognition processes. Once a letter string is presented a search of the orthographic lexicon begins. If a matching representation is found then the letter string must be a word. The speed with which an entry in the lexicon is accessed can be affected by a number of factors some of which will be discussed further. Importantly, recognition of a word is reliant on the orthographic lexicon, and orthographic information alone may be sufficient for an entry to be activated above a criterion threshold for responding. An alternative class of models, distributed connectionist models (e.g. Plaut et al., 1996; Harm & Seidenberg, 2004), posit that there is no orthographic lexicon but distributed representations. Connectionist attempts to model word recognition have relied on the semantic system (Plaut, 1997). One obvious problem with this account is that there are cases described in the neuropsychological literature that exhibit deficits in semantic processing without any significant decrease in the ability to perform lexical decision (e.g. the 6 cases highlighted by Coltheart, 2004). In attempting to rebut this criticism, Rogers, Lambon Ralph, Hodges and Patterson (2004) argued semantic deficits may only cause a problem when the stimuli were low in orthographic typicality. Rogers et al (2004) demonstrated that the lexical decision responses of participants with severe semantic impairment were less accurate than those with relatively mild damage to the semantic system, but only when target words were low in frequency or had unusual spellings. Essentially, a greater reliance is placed on the semantic system when the stimulus is difficult to process in terms of its orthography, and hence a smaller degradation of the semantic

system was required before errors occurred. We will revisit this in more detail below, but if Rogers et al.'s (2004) assumption is correct, then the unusual spelling patterns of acronyms would be likely to increase the demand on the semantic system when performing lexical decision. The DRC model, on the other hand, would not necessarily implicate semantic activation in successful lexical decision responses.

The frequency effect is perhaps the most common finding in the word recognition literature (Monsell, 1991). High frequency words are recognised faster than low frequency words in the lexical decision task (Connine, Mullenix, Shernoff, & Yelen, 1990; Fredriksen & Kroll, 1976; Hino & Lupker, 2000; Hudson & Bergman, 1985; Turner, Valentine & Ellis, 1998). The consensus is that words encountered often are somehow easier to retrieve. It is argued that high frequency words have a higher level of resting activation than low frequency words and that they therefore require less additional activation before recognition. As acronyms have lexical representations (Brysbaert, Speybroeck & Vanderelst, 2009) frequency effects should be observed in lexical decision responses. As mentioned above, interactions between frequency and spelling to sound correspondences have been observed in lexical decision tasks (Seidenberg et al., 1984) and similar interactions are expected here.

Age of acquisition (AoA) effects are prominent in studies using the lexical decision task (e.g. Butler & Hains, 1979; Cortese & Schock, 2013; Morrison & Ellis, 1995; Morrison & Ellis, 2000). The common finding is that words which were learned early in life are recognised more quickly than late acquired words. Ellis and Lambon-Ralph (2000) suggested that AoA effects are likely to be observed when the mapping between a stimulus (e.g. a written word) and the required output (e.g. its pronunciation) is arbitrary. The consequence of this arbitrary link is that words learned later in life cannot benefit from knowledge that the individual has already acquired. Spelling to meaning mappings are less predictable than those between spelling and sound. Thus late acquired words (or acronyms) are unable to draw on previously acquired information and significant effects of age of acquisition should be exhibited in lexical decision performance. An alternative hypothesis is that AoA effects have a semantic root (Brysbaert, Van Wijnendaele, & De Deyne, 2000; Cortese & Khanna, 2007). Brysbaert et al (2000) proposed that late acquired words are learned by relating the new concept to a previously existing conceptual representation. As a result of this learning process the early acquired words have more conceptual connections than late acquired words. This highly populated network benefits recognition and production. As acronyms are frequently coined to abbreviate a novel concept at the cutting edge of science or technology, it may be particularly difficult to relate a late acquired acronym to any existing representation in the semantic system. Thus late acquired acronyms are unlikely to be accessed often, sharing few connections with other words. Either of the above hypotheses would predict significant AoA effects in acronym recognition. It is also possible that the relationships between spelling, pronunciation and meaning for acronyms may be particularly arbitrary. This is especially true, perhaps, for typically pronounced ambiguous acronyms (i.e. HIV) because the translation from orthography to phonology is particularly irregular. Therefore possible interactions between AoA and spelling to sound correspondences were explored.

The ease with which a stimulus evokes a mental image (imageability) has been consistently reported to affect responses in the lexical decision task. Greater accuracy and faster responses are normally found for highly imageable words (e.g. Balota, Cortese, Sergent-Marshall, Spieler & Yap, 2004; Cortese & Khanna, 2007; Cortese & Schock, 2013), especially when the words are of low frequency. High frequency words are recognized so fast that imageability does not have the opportunity to show its influence. However, low frequency words take longer to be recognized and therefore they are able to benefit recognition from semantic activation. Plaut and Shallice (1993) argued that highly imageable words have richer semantic representations than low imageable words. Thus low frequency but high imageable words receive more semantic input than low imageable words, and recognition times are faster as a result. Acronyms are also likely to benefit from being imageable, particularly as their orthography is so uncommon in English. Highly imageable acronyms are predicted to elicit faster recognition times than their less imageable counterparts. James (1975) indicated that concreteness (a variable which is strongly correlated with imageability) had a greater impact on lexical decision latencies when the non-words were pronounceable than when they were not. This suggests that the level of lexical activation that is required is dependent on the experimental context. In the case of acronyms, where the majority of the nonwords were unpronounceable there may be reduced imageability effects or interesting interactions between acronym subtype and imageability. **This would also be expected following the predictions of Rogers et al (2004) with regard to the differential reliance on the semantic system in lexical decision tasks contingent on the level of orthographic typicality.**

Orthographic neighbourhood (commonly referred to as "N"; Coltheart, Davelaar, Jonasson & Besner, 1977) is a metric of the similarity of the form of a written word to other words in the language. N is defined as the number of words that can be created by changing a single letter in a given word without altering the position of any of the other letters. A number of studies (Andrews, 1989; 1992; Forster & Shen, 1996; Sears, Hino & Lupker, 1995) reported that words with large N were recognised at shorter latencies than words with few neighbours. Andrews (1989) suggested that neighbourhood size supports sublexical spelling to sound mappings. Thus low frequency high N words receive additional input from the sublexical route and recognition responses are facilitated. The same is unlikely to be true for acronyms. It is rare for acronyms to share spelling to sound mappings with their orthographic neighbours (EEG versus LEG). Sublexical processes would not help in the recognition of acronyms. Thus it could be expected that N effects in lexical decision for acronyms may be null or inhibitory. An alternative approach to measuring the similarity between the orthographic forms of words is to consider the frequency with which pairs of letters occur together in the English language. This is known as bigram frequency. In general the evidence suggests that bigram frequency has little impact on word recognition responses although some effects have been reported when the stimuli have been of low frequency (Biederman, 1966; Broadbent & Rice, 1968; Rumelhart & Siple, 1974; Rice & Robinson, 1975). In addition, the way in which acronyms are created often leads to strings in which the letter patterns are unusual or even illegal (i.e. low in bigram frequency) suggesting a low likelihood to observe bigram effects in acronym recognition.

Increasing word length has generally been shown to increase response latency in word recognition tasks although not always in a linear manner (Balota et al., 2004; New, Ferrand, Pallier & Brysbaert, 2006). However, a particularly relevant finding is reported in New et al.'s (2006) analysis of lexical decision responses drawn from the English Lexicon Project (Balota, Cortese, Hutchison, Neely, Nelson, Simpson, & Treiman, 2000). In analysis 3, New et al (2006) ran multiple regressions on successive pairs of word lengths (3-4 letters up to 12-13 letters) and found that between 3 and 5 letters increasing word length was facilitatory. Length effects were not significant from 5 to 8 letters, and each additional letter then had an inhibitory effect. The majority of the acronyms considered here are between 3 and 5 letters in length (there is one 6 letter acronym, NASCAR), and hence it is possible that a facilitatory word length effect will be observed in the lexical decision task. Specifically, the finding reported by New et al. (2006) would lead to the prediction that acronyms containing more letters may be recognised more quickly.

Method

Participants

Twenty students from Swansea University (5 male, 15 female) participated in this experiment. Participants ranged in age from 18 to 24 years (mean 20 years), and all were native English speakers. Participants had no impairments in reading or vision. Course credit was offered as a reward for participation.

Materials

All 146 acronyms from Izura and Playfoot (2012) were used as targets in the lexical decision task. The values for each of the variables considered were drawn from the database compiled in the above paper. One hundred and forty six non-words and non-acronyms were also created. Non-words were generated by changing one letter of an acronym or a mainstream word. Non-words were between 3 and 5 letters in length (mean = 3.15). The same proportion of non-words and acronyms were pronounceable as a word-like unit. Specifically, 85 non-words contained only consonants (as there were 85 unambiguous acronyms), and the remaining 61 non-words comprised vowels and consonants in a plausible combination in English.

Procedure

Stimuli were presented one at a time in black capital letters on a white screen (19-inch monitor) in size 12, Times New Roman font. Trials were separated by a fixation cross which appeared in the middle of the screen for 1500ms. An item appeared in the middle of the screen and remained there until the participant made a response. Participant responses were indicated via a 5 button serial response box. Participants were asked to press the rightmost button with the right index finger if the item on the screen was an acronym and the leftmost button using the left index finger if the item was a non-word or a non acronym. Trials were randomised for each participant. This was controlled by E-Prime (Schneider, Eschmann & Zuccolotto, 2002) using a Dell computer with an Intel Pentium 4 1.5 GHz processor. The computer programme automatically logged reaction times and response accuracy.

Results

Reaction Times analyses

Three participants gave correct lexical decision responses to fewer than 75% of the acronyms included in the task and were, therefore, excluded from further analyses. Errors (15.5%) and responses detected more than 2.5 standard deviations above or below the mean (2.4%) were removed from the analyses of the reaction times of the remaining 17 participants. Correlations between harmonic means of response times, percentage accuracy and each of the numerical variables considered in this study are presented in Table 1.

The negative correlation between imageability and reaction times indicates that highly imageable acronyms have a tendency to be recognised with greater speed. Similarly, highly imageable acronyms are recognised more accurately than acronyms which were low imageability. This imageability effect in lexical decision has been commonly reported in mainstream word recognition studies (e.g. Balota et al. 2004). Another characteristic of words shown to correlate with lexical decision latency and accuracy is frequency, such that responses to frequently occuring words were given quickly and accurately (Connine et al, 1990; Fredriksen & Kroll, 1976; Hudson & Bergman, 1985; Turner et al, 1998). This finding is mirrored in the recognition of acronyms.

[Table 1 about here]

Accuracy correlated positively with rated and printed frequency measures meaning that high frequency acronyms were recognised with greater accuracy than low frequency acronyms. In addition, significant negative correlations with frequency were also observed in the reaction time data, indicating that participants took longer to recognise low frequency than high frequency acronyms. Reaction times and accuracy also correlated with age of acquisition such that acronyms acquired early were recognised with greater accuracy and shorter latencies than late acquired acronyms. These age of acquisition effects parallel the advantage for early acquired words reported in the literature (Butler & Hains, 1979; Morrison & Ellis, 1995; Morrison and Ellis, 2000). Acronyms with high bigram frequency and those which had more letters were more likely to be correctly recognised than shorter or lower bigram frequency acronyms.

[Table 2 about here]

The print-to-pronunciation classification of acronyms (i.e., unambiguous, ambiguous typical or ambiguous atypical) correlated with reaction times and accuracy. Ambiguous atypical acronyms (NATO) were recognised fast and accurately while unambiguous acronyms were recognised more slowly. Ambiguous typical acronyms correlated negatively with accuracy, indicating that this type of acronym elicited more of errors.

A multilevel hierarchical regression model (Miles & Shevlin, 2001) was used to assess the predictive power of the variables on lexical decision performance. This technique allows for the variance that can be explained by the variables entered at one level of the hierarchy to be removed before the next set of variables is considered so that the unique contribution of each factor can be determined. This technique also has the advantage of maintaining statistical power even when large numbers of variables are entered into the overall regression model. Before beginning the main analysis, the three printed frequency measures provided by Izura and Playfoot (2012) were assessed to determine which provided the greatest change in the proportion of the variance in recognition times that was explained by the multilevel model. The log transformation of the printed frequencies derived from the Bing search engine accounted for the greatest proportion of variance (see Table 2) and therefore this was the measure selected for subsequent analyses. In order to introduce acronym print-to-pronunciation patterns into the analyses, two of the dummy variables, ambiguous typical and ambiguous atypical, were included in the analyses while unambiguous acronyms worked as the reference category. Both dummy variables were entered in step 2 of each analysis so the results could be meaningfully compared to the reference category. Four potential interactions between variables (combining age of acquisition, imageability, printed and rated frequency with acronym print to pronunciation characteristics) were also examined. In order to create the interaction terms the continuous variables (printed and rated frequency, AoA and imageability) were centred, and multiplied by each of the dummy variables representing acronym print-to-pronunciation characteristics. The correlations between the variables considered were not sufficiently strong to cause concerns over collinearity.

As in Izura and Playfoot (2012) a series of four multi-level regression analyses were carried out as the result of alternating the submission of only one of the measures of phonological word length (number of syllables or number of phonemes) and one of the letter frequencies (bigram or trigram frequencies). A summary of the results from the four analyses can be seen in Table 3.

[Table 3 about here]

Regression lines were plotted to further examine the interactions. Figure 1 shows that acronyms with high imageability ratings were recognised more quickly than low imageability acronyms. This imageability effect was greater for ambiguous atypical acronyms than for either of the typically pronounced acronym types.

[Figure 1 about here]

The pattern of responses in plotting recognition latencies against age of acquisition (Figure 2) indicated that ambiguous typical acronyms were recognised more quickly if they had been acquired early in life. The recognition times for unambiguous acronyms showed a slight trend towards an advantage for those which were acquired earlier. For ambiguous atypical acronyms, however, the effect of age of acquisition was reversed such that responses were slightly slower for early acquired acronyms than for late acquired acronyms.

[Figure 2 about here]

Error analyses

To analyse the error data, four logistic regressions were performed, alternating the measure of phonological length and letter frequency entered into the final step of the multilevel model. Analysis 1 contained syllable length and bigram frequency, analysis 2 assessed syllable length and trigram frequency, analysis 3 describes the model including phoneme length and bigram frequency, and phoneme length and trigram frequency were entered into the fourth analysis. Accuracy was entered as dummy variable (1 indicating a correct response, 0 indicating an error). Log transformed frequency from the Bing search engine was entered as the printed frequency measure. Wald statistics are presented below in Table 4.

[Table 4 about here]

Imageability, printed frequency, bigram frequency and trigram frequency significantly predicted accuracy across all four analyses. When the analyses included bigram frequency (i.e. analysis 1 and analysis 3), main effects of number of orthographic neighbours were revealed. The interaction between printed frequency and ambiguous atypical acronym status was significant in all four analyses. Figure 3 shows the mean printed frequency of acronyms grouped by the accuracy of the responses. The mean frequency of ambiguous atypical acronyms which were incorrectly rejected in the lexical decision task was higher than the frequency of acronyms successfully recognised. For typical acronyms, mean printed frequency for correct answers were higher than for incorrect responses.

[Figure 3 about here]

Discussion

Recognition latencies for ambiguous atypical acronyms such as NASA were significantly faster (723ms) than for unambiguous acronyms (e.g. BBC, 770ms) as revealed in the second step of the regression analysis. Responses to ambiguous typical acronyms (HIV) were not significantly different in RT from those in unambiguous acronym trials. In studies of mainstream word recognition which use RT measures, effects of spelling to sound characteristics are seldom significant (Hino & Lupker, 2000; Seidenberg et al., 1984; Waters & Seidenberg, 1985). **From the perspective of the DRC model, this might be because lexical access does not necessarily require phonological information and it is possible for lexical access to occur from orthography alone. Without proposing the existence of lexical representations to access, connectionist models also make room for lexical decision responses to be made on the basis of orthography alone via activity in the direct links between the orthographic and semantic systems. However, regularity effects have been observed in lexical decision tasks in which particular emphasis is put on phonological processing (Parkin, 1982; Waters, Seidenberg & Bruck, 1984). It may be that lexical decision for acronyms is one such task. In both of the above studies, lexical decision latencies were longer when words had particularly unusual spelling to sound correspondences, or when orthography of the word ending was unique. Ambiguous typical acronyms have unusual pronunciations when compared to mainstream words, and this could be a factor in delaying their recognition. Responses to unambiguous acronyms in the current study were also slow. Unambiguous items are strings of consonants – often creating orthography that is unique in English. This, too, would result in slower lexical decision responses.**

Another possibility is that the effects of spelling to sound correspondences we observed in the current study are due to the relationship between the orthography of acronyms and non-words. Waters et al. (1984) suggested that lexical decision responses will only be affected by phonology when orthographic information is insufficient to allow recognition, or not completed before phonological information has been accessed. This is likely to be a factor in acronym recognition. The unusual, or illegal spelling of acronyms makes it difficult to distinguish them from non-words on the basis of orthography alone. In this case, the speed with which the pronunciation can be computed will influence the speed with which lexical activation can be accrued. For ambiguous atypical acronyms (NASA, NATO) the phonology is similar to that of mainstream words, and can be computed quickly. This bolsters the activation in the orthographic lexicon and aids recognition. It might be the case that the phonological retrieval for ambiguous but typically pronounced acronyms (HIV, IBS) is more difficult to assemble because the system is not so used to naming individual letters, and because typically pronounced acronyms are phonologically longer. Thus the recognition of ambiguous typical acronyms does not benefit as much from phonological activation and lexical decision responses are slower.

It is also of note that although regularity effects are seldom observed in lexical decision, some aspects of phonology *do* have an impact on recognition latency. For example, Lukatela, Eaton, Sabadini and Turvey (2004) demonstrated that lexical decision responses can vary on the basis of phonological vowel length in written words. Specifically they compared words in which the duration of the same phoneme differed due to the voicing of the consonant that followed. Vowel sounds preceding voiced

consonants are typically longer. For example, the /I/ sound represented by *ea* in the word *plead* is longer than the same sound in the word *pleat.* Lukatela et al (2004) showed that words in which the vowel sound had a longer duration also took longer to respond to in a visual lexical decision task. This factor was not considered in the current study. Consonant letter names tend to be voiced, hence vowel sounds may be slightly elongated in ambiguous typical acronyms like HIV. This might contribute to the finding of faster reaction times in atypical (NASA) acronyms than typical (HIV) acronyms. However, there were no significant differences in lexical decision RT between ambiguous typical acronyms and unambiguous acronyms like DVD - the majority of the latter class of acronyms do not contain vowels at all. If it is the case that responses to ambiguous typical acronyms were slowed by virtue of the duration of a vowel sound then similar logic would also need to be applied to unambiguous acronyms. However, it is not clear how this could be achieved.

The importance of the predictor variables and interactions on acronym recognition times were examined in the third step of the analyses. In all the analyses performed, RT was predicted by imageability and age of acquisition as was expected based on previously reported findings illustrating the role of these variables in word recognition tasks. Cortese and Schock (2013), for example, reported effects of imageability and AoA on polysyllabic word recognition (the vast majority of acronyms are also polysyllabic). The contribution of imageability and age of acquisition in the current study supports the conclusions of Brysbaert et al. (2009) that acronyms are lexicalised items. Neither AoA nor imageability interacted with measures of spelling to sound consistency in Cortese and Schock's (2013) report, making the significant interactions we observed in acronym recognition of empirical and theoretical importance. The

regression lines plotted in our Figure 1 showed that highly imageable ambiguous typical acronyms were recognised more quickly than their less imageable counterparts. Imageability had an even greater effect on the latency of lexical decision responses to ambiguous and atypical acronyms. Similarly, Figure 2 shows a differential effect of age of acquisition on typical and atypical acronyms. Among ambiguous typical acronyms (HIV), early acquired items were recognised more quickly than those learned later in life. The effect of age of acquisition on recognition latencies for ambiguous atypical and unambiguous acronyms was very small, with the regression lines being almost horizontal. One potential explanation for these interactions refers again to the idea that the recognition for acronyms is generally slow. We have already discussed how spelling to sound patterns may influence acronym recognition by bolstering the activation of nodes in the orthographic lexicon. The DRC model proposes that there are bidirectional connections between the orthographic lexicon and the semantic system. Highly imageable acronyms can be activated in the semantic system via orthography, and this semantic activation feeds back to the orthographic lexicon, influencing recognition. This accounts for the effect of imageability. DRC also proposes bidirectional connections between the phonological lexicon and the semantic system. When acronym pronunciation is computed quickly, the phonological information can *also* activate the semantic system, which in turn can help to increase the activation of the representation in the orthographic lexicon. Simply put, the response to all highly imageable acronyms is helped by activity in the semantic system stemming from orthography, but when the pronunciation of the acronym is easily generated there is an additional boost because the semantic system is being activated from phonology as well.

Similar logic can be applied to interactions with AoA. The arbitrary mappings hypothesis (Ellis & Lambon Ralph, 2000) states that age of acquisition effects are observed whenever the mappings required are unpredictable. Here, AoA had an impact on the responses to ambiguous but typically pronounced acronyms (HIV) and unambiguous acronyms (BBC). This type of acronym could be pronounced following GPC rules, but the correct pronunciation requires that each letter is named in turn. Thus the mapping between spelling and sound is particularly arbitrary and therefore an AoA effect was observed. The pronunciations for ambiguous and atypical acronyms such as NATO follow grapheme phoneme correspondence rules as regular words do. Therefore it could be argued that ambiguous atypical acronyms are relatively consistent in their spelling to sound mappings in the English language and therefore there was little contribution of age of acquisition. Again, once pronunciation has been computed for an acronym, it is possible for activation to feed back to the orthographic lexicon. The quicker the computation of phonology, the greater the opportunity for feedback activation to influence the recognition response.

Connectionist models refer to the generation of a semantic code as integral to lexical decision, as opposed to the activation of a stored representation proposed in DRC. As the mapping between orthography and semantics is always arbitrary AoA effects should always be observed in lexical decision, irrespective of consistency. On the face of it, the interactions we report in relation to acronyms might be more problematic for connectionist models, but they are not incompatible with the connectionist framework. A common finding in studies of reading aloud is that responses are elicited faster by pseudohomophones (non-words that would be pronounced to sound the same as an existing word e.g. SKOOL) than by other non-words (e.g. Borowsky, Owen & Masson,

2002; McCann & Besner, 1997; Reynolds & Besner, 2005). According to Harm and Seidenberg's (2001) connectionist account this can be explained by suggesting that the phonological code generated by SKOOL through the direct orthography to phonology pathway feeds back to the semantic system and activates the real word SCHOOL. The activation in the semantic system boosts the phonological code ready for output. This is particularly useful in reading non-words, because they are unlikely to elicit much activation via direct orthography-semantics links. Presumably a similar orthography-phonology-semantics pathway is available when processing *any* written item. Thus the predictability of the mapping between spelling and sound could have an influence on the speed of the activation of a semantic code. Under the assumption that accessing semantics via phonology is slower than accessing semantics directly from orthography (because fewer steps are needed in the latter), it follows that AoA by consistency interactions would likely only be observed if the connections between orthography and semantics are weak enough that generating a semantic code is slow. We think it is possible that acronyms may be an example of such stimuli, either because of the number of senses in which they might be used or because they are relatively unfamiliar to the reader. This could explain why we observed an interaction between AoA and spelling to sound patterns when Cortese and Schock (2013) did not in an analogous study. Mainstream words generate a semantic code, and thus lexical decision responses, quickly enough that processing by an orthography-phonology-semantics pathway has not been completed.

Some of the predicted effects were not obtained. A facilitatory effect of increasing letter length was expected based on the findings of New et al. (2006). This effect was not observed in the data. One plausible explanation for this is that the vast majority of the acronyms included were three letters long, and all were presented centrally. The result of this is that a single fixation would allow for all the letters in an acronym to be perceived at once, and that visual acuity would be at its highest. O'Regan and Jacobs (1992) reported no effect of letter length when participants viewed four or five letter words with a central fixation. The same may be the case in the current experiment. In line with our expectations, N effects were also absent in the lexical decision task. Again, the literature provides a potential explanation for this finding. An interaction between frequency and N is commonly reported such that a large orthographic neighbourhood is beneficial to the recognition of low frequency words, but not for frequently occurring words (Andrews, 1989; Balota et al., 2004; Forster & Shen, 1996). Andrews (1989) suggested that these interactions are a result of sublexical spelling to sound mappings assisting in recognition (which are particularly supportive of infrequent words). As it is rare for acronyms to share spelling to sound mappings with their orthographic neighbours (EEG versus LEG), sublexical processes would not help in the recognition of acronyms.

In sum the findings of the regression analyses on lexical decision latency can be accounted for by suggesting that acronyms are stored in the mental lexicon but are processed in a different way to other items also represented in the lexicon. As with mainstream words differentiating non-words from meaningful acronyms in a lexical decision task is a complex process which draws on phonological information, order of learning and imageability.

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Table 1. Correlations between predictor variables, reaction times and accuracy.

	Reaction Times	Percentage Accuracy
Number of Letters	n.s.	.047†
Number of Syllables	n.s.	n.s.
Number of Phonemes	n.s.	n.s.
Number of orthographic neighbours	n.s.	n.s.
Imageability	-.224**	.339**
Rated Frequency	-.170**	.210**
Printed Frequency (Google)	-0.73*	.129**
Printed Frequency (Bing)	-.086**	.108**
Printed Frequency (AltaVista)	-.069*	.117**
Age of acquisition	.097**	-.178**
Bigram Frequency	n.s.	.062*
Trigram Frequency	n.s.	n.s.

Note: n.s. indicates that the correlations was not significant, **p< .001, *p< .01, †p< .05

Table 2 – Acronym printed frequencies comparisons

	Log AltaVista Frequency	Log Google Frequency	Log Bing Frequency
B	-.013	-.012	-.015
SE B	.003	.003	.003
β	-.076†	-.078†	-.094†
R^2	.203	.204	.206
ΔR^2	.006	.006	.009

Note † $p < .05$

Table 3. Standardized regression coefficients (β) for the four multilevel analyses carried out on acronym recognition times.

	Analysis 1	Analysis 2	Analysis 3	Analysis 4
Step 2				
Ambiguous Typical			-.032	
Ambiguous Atypical			-.046†	
Step 3				
Number of Letters	-.019	-.021	-.039	-.037
Number of orthographic neighbours	-.018	-.023	-.017	-.021
Imageability	-.250**	-.258**	-.255**	-.263**
Rated Frequency	-.023	-.018	-.019	-.015
Printed Frequency[1]	-.056	-.058	-.059	-.061
Age of Acquisition (AoA)	-.069†	.073†	-.064	-.067†
Trigram Frequency		-.030		-.024
Bigram Frequency	-.020		-.008	
Number of Syllables	.009	.009		
Number of Phonemes			.042	.040
AoA by Ambiguous Typical	.121**	.121*	.120**	.120**
AoA by Ambiguous Atypical	.001	.006	-.001	-.004
Rated Frequency by Ambiguous Typical	-.051	-.057	-.056	-.061
Rated Frequency by Ambiguous Atypical	.020	.015	.015	.011
Printed Frequency by Ambiguous Typical	-.017	-.014	-.014	-.011
Printed Frequency by Ambiguous Atypical	.028	.034	.027	.034
Imageability by Ambiguous Typical	.127*	.133*	.131*	.137*
Imageability by Ambiguous Atypical	-.039	-.034	-.008	-.030
R^2	.283	.283	.283	.283

[1] The printed frequency value used in these analyses was taken from the Bing search engine.

Note: ** $p < .001$, * $p < .01$, † $p < .05$

Table 4. Wald statistics for the four multilevel analyses carried out on acronym lexical decision accuracy.

	Analysis 1	Analysis 2	Analysis 3	Analysis 4
Step 2				
Ambiguous Typical			6.193†	
Ambiguous Atypical			9.085*	
Step 3				
Number of Letters	.475	.849	.004	.921
Number of orthographic neighbours	4.342†	2.206	4.552†	2.513
Imageability	50.577**	51.121**	49.777**	49.836**
Rated Frequency	.402	.426	.327	.431
Printed Frequency	8.273*	12.225*	9.261*	12.899**
Age of Acquisition (AoA)	1.294	.393	1.234	.612
Trigram Frequency		6.312†		5.563†
Bigram Frequency	10.608*		9.995*	
Number of Syllables	.733	.357		
Number of Phonemes			.036	.226
AoA by Ambiguous Typical	.068	.154	.160	.160
AoA by Ambiguous Atypical	.170	.073	.085	.044
Rated Frequency by Ambiguous Typical	.038	.156	.140	.233
Rated Frequency by Ambiguous Atypical	2.354	2.296	2.613	2.506
Printed Frequency by Ambiguous Typical	.901	1.710	1.022	1.718
Printed Frequency by Ambiguous Atypical	4.159†	4.936†	5.014†	5.824†
Imageability by Ambiguous Typical	1.009	.969	1.196	1.055
Imageability by Ambiguous Atypical	2.963	2.937	3.136	3.188

Note: ** $p < .001$, * $p < .01$, † $p < .05$

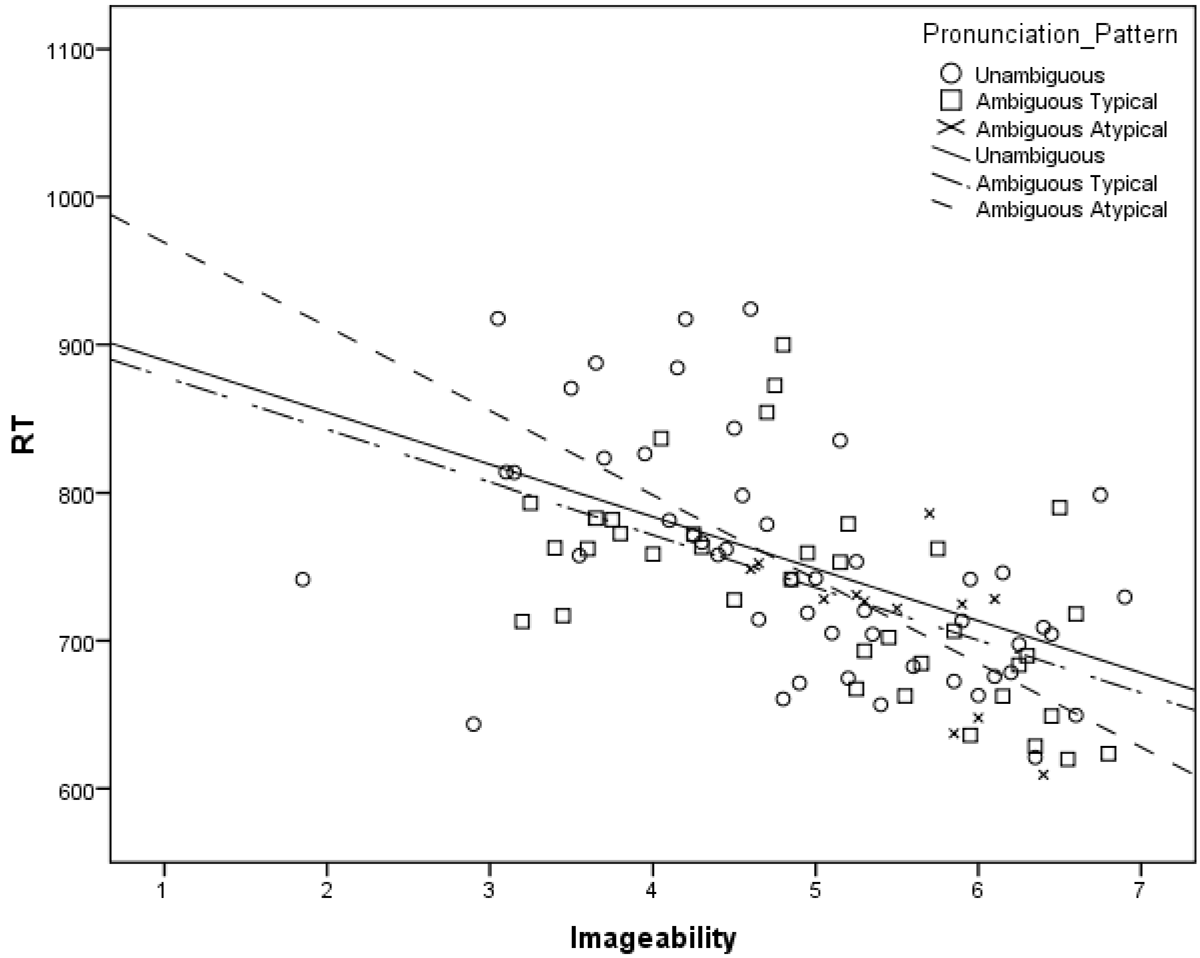

Figure 1 - Regression lines between Reaction Times and imageability for the different types of acronyms.

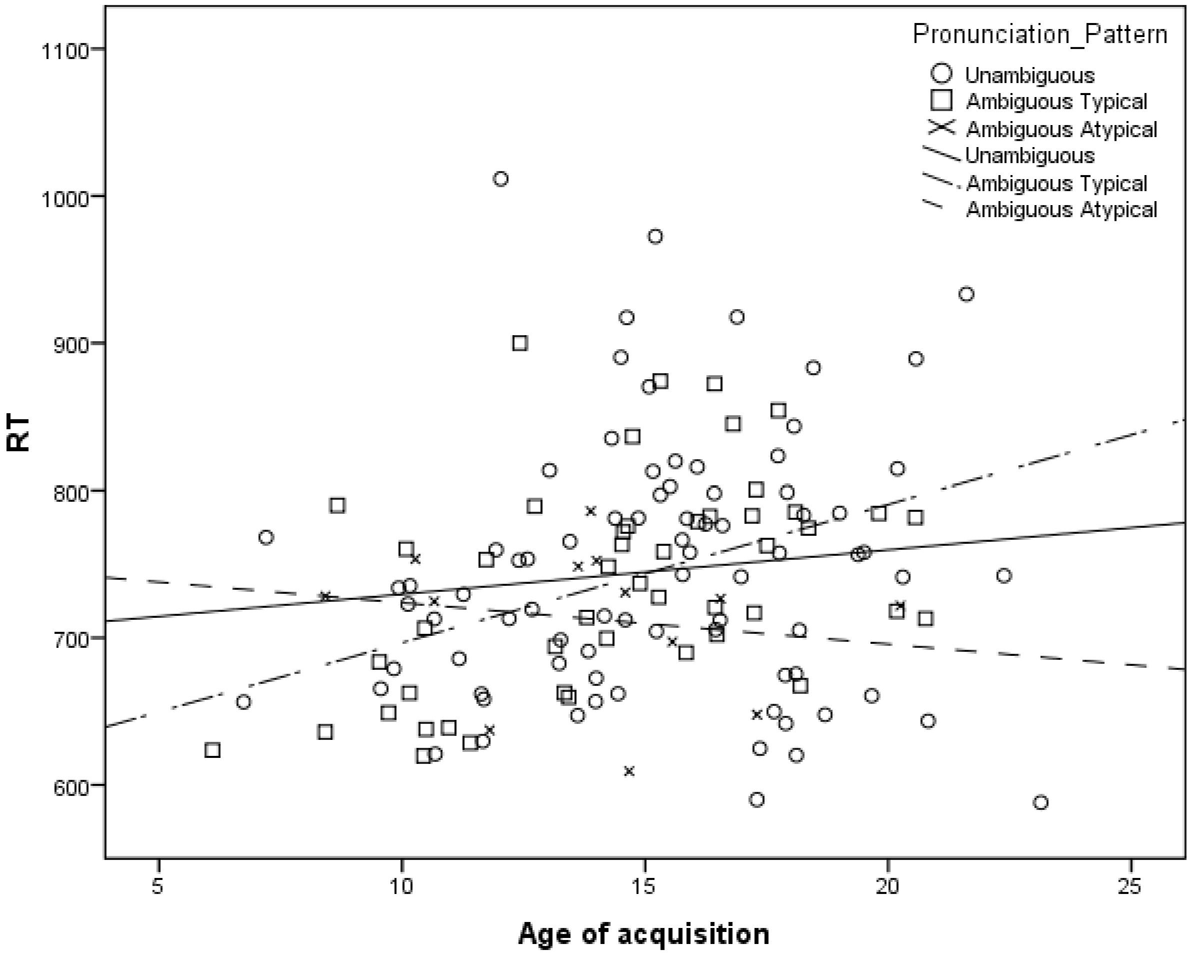

Figure 2 - Regression lines between Reaction Times and age of acquisition for the different types of acronyms.

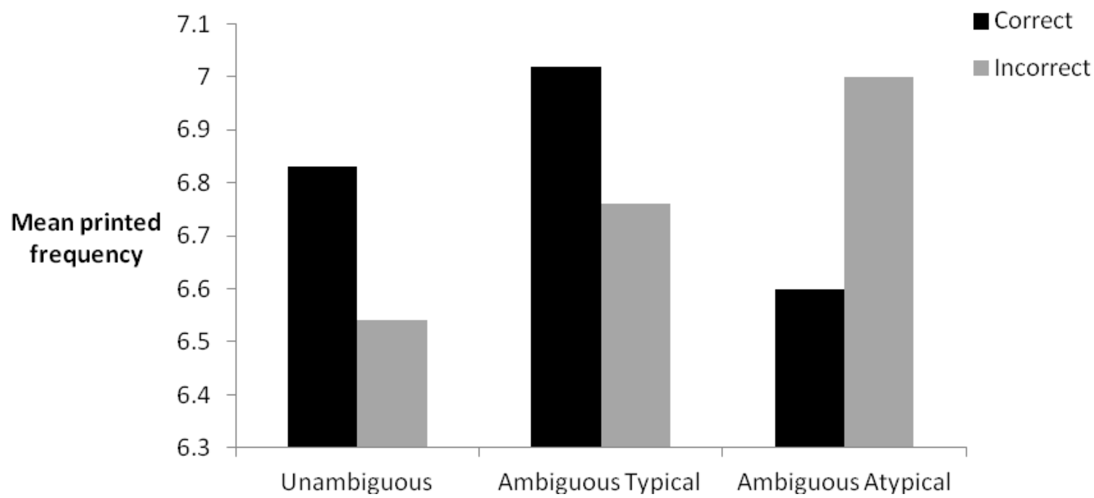

Figure 3 – Mean printed frequency of correct and incorrect responses to each type of acronym.