Probabilistic Cues to Grammatical Category in English Orthography and their Influence During Reading

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Abstract

We investigated probabilistic cues to grammatical category (noun vs. verb) in English orthography. These cues are located in both the beginnings and endings of words – as identified in our large-scale corpus analysis. Experiment 1 tested participants' sensitivity to beginning and ending cues while making speeded grammatical classifications. Experiment 2 tested sensitivity to these cues during lexical decisions. For both tasks, words with consistent ending cues (with respect to grammatical category) were processed more quickly and with lower error rates than words with inconsistent ending cues. However, for beginnings, consistent cues resulted in lower errors but no differences in response times. The data reported here point to the multi-faceted nature of grammatical category representation and indicate that probabilistic orthographic cues relating to grammatical category have a clear influence on lexical processing particularly when these cues are located at the end of the word.

Key Words: grammatical category; probabilistic cues; orthography; corpus analysis.

Grammatical category distinctions, in particular the distinction between nouns and verbs, are found in all of the world's languages (Baker, 2001). The importance of decisions regarding the grammatical status of individual words during language acquisition (both L1 and L2) has been emphasised in the literature (e.g., Braine, 1992; Cassidy & Kelly, 1991; Gerken, Wilson, & Lewis, 2005; Pinker, 1984, 1987; Shi, Morgan, & Allopenna, 1998). In addition, Sereno and Jongman (1990) argued that normal communication requires such decisions (e.g., the distinction between nouns vs. verbs) to be made "constantly" and "with little effort" (p. 402).

The possibility that there is a rich source of probabilistic cues to grammatical category operating at the single word level is theoretically important for number of reasons. For instance, the existence of such cues does not fit easily with the traditional Saussurian view of arbitrariness between word-form and function. Of course, certain words such as onomatopoeiac words suggest there are sometimes links between form and meaning but there is growing interest in the possibility of a number of more *systematic* associations within languages (Gasser, Sethuraman, & Hockema, 2005). For example, researchers have identified significant associations between the phonology and gender of person names in English (Cassidy, Kelly & Sharoni, 1999; Cutler, McQueen & Robinson 1990).

Certainly, it is known that grammatical category distinctions can often be resolved at the phrasal level. For example, comprehension is facilitated when an ambiguous word is preceded by a syntactically constraining context: "Laurie took the *prune* out of the fruit bowl and ate it" (Folk & Morris 2003). However, the presence of effective cues to grammatical category operating at the phrasal level does not preclude the presence and

use of additional cues that operate at the single word level. Such an hypothesis is in line with a broader view of language processing as an example of statistical learning which is optimised through the use of *multiple* probabilistic cues (Monaghan, Chater, & Christiansen, 2005; Monaghan, Christiansen, & Chater, 2007; Morgan & Demuth, 1996; Morgan, Meier, & Newport, 1987; Newport & Aslin, 2004; Onnis, Monaghan, Richmond, & Chater, 2005).

Interestingly, in spite of the challenges posed to notions of arbitrariness and the clear role of phrasal-level constraints it is known that grammatical category information is sometimes reflected in individual words. It is noteworthy that, discussion of this topic has generally been limited to the role of morphological processes (morphological processing has been discussed by Butterworth, 1983; Cole, Segui & Taft, 1997; Marslen-Wilson, Tyler, Waksler & Older 1994; Taft & Forster, 1975; Vannest & Boland, 1999 amongst many others). In particular, derivational affixes can mark grammatical category (e.g., addition of the suffix 'ful' turns the noun root 'bliss' into an adjective). However, important questions remain with regard to our understanding of morphological processes. For example, there are complex issues to consider when examining the processing requirements of words with true affixes (e.g., 'cohabit' which includes the prefix 'co') versus words that share some orthography but do not incorporate an affix (e.g., 'coffee' where 'co' is not operating as a prefix). Moreover, monomorphemic words do not contain affixes of any kind – and yet they are members of various grammatical categories. For these reasons, it is worthwhile considering the possibility that there may be probabilistic cues to grammatical category that extend beyond derivational morphology.

Importantly, a number of studies have examined the role of non-morphological probabilistic cues to grammatical category in the *phonology* of English (e.g., Arciuli & Cupples, 2003, 2004; Farmer, Christiansen & Monaghan, 2006 adding to earlier contributions - see Kelly, 1992). In fact, phonological cues to grammatical category have now been identified in languages as diverse as French, Dutch, Turkish, Japanese, and Mandarin (Durieux & Gillis, 2001; Monaghan et al., 2005, 2007; Shi, Morgan, & Allopenna, 1998). These studies have demonstrated a rich source of probabilistic phonological information pertaining to grammatical category that includes stress patterns and manner and place of articulation amongst other cues.

A much smaller number of studies have attempted to investigate probabilistic cues to grammatical category in *orthography*. This is perhaps due to the long-standing misconception that English orthography is "chaotic and unprincipled" (see Kessler & Treiman, 2003 for discussion of this). Albrow (1972) referred to the "three letter rule" whereby content words can be distinguished from function words in usually containing three letters or more ('in' vs. 'inn'). Smith et al., (1982) also commented on the use of letter doubling to distinguish between common and proper nouns (the surname 'Kidd' vs. 'kid'). Recent studies have adopted a more comprehensive approach by incorporating both large-scale corpus analyses and behavioural testing. Arciuli and Cupples (2007) examined cues in the beginnings of disyllabic English words (onset plus first vowel: e.g., 'tu-', 'sta-', 'li-'), and Arciuli and Cupples (2006) examined cues in the endings of disyllabic English words (rime of final syllable: e.g., '-ip', '-ibe', '-oin'). Each study also tested participants' sensitivity to these cues using nonsense words containing either biasing beginnings or endings (in the respective studies). Results showed clear sensitivity

when participants were asked to use these nonsense words during an off-line sentence construction task (i.e., noun-like nonsense words tended to be used as nouns in sentences whereas verb-like nonsense words tended to be used as verbs). It is important to note that these previous studies did not directly compare the importance of beginnings vs endings – with regard to their effectiveness as cues to grammatical category.[1]

In the current study, we extended previous research in three ways. First, we set out to *directly compare* the importance of consistent probabilistic cues to grammatical category in the beginnings and endings of words. As mentioned, while previous studies have examined probabilistic orthographic cues in either beginnings or endings no previous work has examined the influence of beginnings and endings simultaneously, which has implications for whether lexical processing is seen as a left-to-right serial process (e.g., the Dual Route Cascaded (DRC) model of reading, Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) or rather proceeds with information from all regions of the word available simultaneously in word identification (as in the parallel distributed processing "Triangle" model of reading, e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996).

Second, we conducted a large-scale corpus analysis in order to identify cues in beginnings and endings of *trisyllabic* English words with follow up behavioural testing to examine the processing of these cues during reading. To our knowledge no previous study has focussed on orthographic cues in trisyllables. The length of English words in

[1] We make no special claim for orthography taking precedence over phonology, we only claim that there are multiple cues to grammatical category some of which are realised in orthography. Note, though, that Kelly (2004) did find effects of orthographic-only features of words that assisted in stress assignment in reading, so there is the possibility that orthography has an additional effect over phonological processing in reading.

terms of syllable number is, itself, a strong cue to grammatical category. Verbs tend to have fewer syllables than nouns. Kelly (1992) reported that, in child-directed language, most monosyllables tend to be verbs and there are fairly even numbers of disyllabic verbs and nouns. Of particular relevance to the current study, only 8% of trisyllabic words in child-directed speech are verbs. It is an open empirical question as to whether probabilistic orthographic cues to *verb* status, in particular, are strong enough to override length cues when processing trisyllables. Cassidy and Kelly (2001) tested children's classification of monosyllabic and trisyllabic nonsense words as either nouns or verbs in the absence of information other than length of the nonwords. They found that monosyllabic nonwords were more likely to be classified as verbs and trisyllabic nonwords as nouns. What would happen, however, if all the stimuli were the same length, and more subtle orthographic cues distinguished nouns from verbs? Would the classification of trisyllabic stimuli as nouns override these other probabilisitic contributors to grammatical category, or would a combination of cues determine processing? The current study provides an investigation of these issues.

Third, this study examined the reading of *real words* during *speeded tasks* as opposed to the processing of nonsense words during off-line tasks such as sentence construction (e.g., Arciuli & Cupples, 2006; 2007; Cassidy & Kelly, 2001). While nonsense words allow the researcher to manipulate the cues of interest and side-step the influence of other variables known to affect reading (e.g., frequency, imageability, etc.), demonstrating sensitivity to probabilistic orthographic cues using real words during on-line processing provides greater insight into the extent to which these probabilistic cues permeate normal language processing.

Corpus Analysis of Beginnings and Endings

We limited our focus to the categories of noun and verb (the largest grammatical categories). Using the CELEX database (Baayen, Pipenbrock, & Gulikers, 1995), we selected all trisyllabic nouns and verbs that were unambiguous with regard to grammatical category (i.e., they were only used as either a noun or a verb in the CELEX classification) and that were listed with a frequency of 1 or more. We excluded any words with hyphens, stops or apostrophes. There were 14638 words in total – 9680 nouns and 4958 verbs. This represents a significantly larger proportion of verbs than reported by Kelly (1992), which is likely to be due to the large number of very low frequency words in the CELEX database. However, it is clear that there is a large difference in the numbers of nouns and verbs (ratio 2:1).

We automatically segmented the letters in each word that reflected the word's beginning (onset and first vowel) and the letters that corresponded to the word's ending (rime of final syllable). This definition of beginnings and endings is taken from the earlier work of Arciuli and Cupples (2006; 2007). So, for a word like 'dinosaur' the beginning was 'di' and the ending was 'aur'. There were 581 distinct beginnings and 946 distinct endings. Importantly, the number of beginnings and endings extends well beyond the known set of affixes (prefixes and suffixes) – according to Fudge's (1984) list of around 250 prefixes and around 50 suffixes of English (details provided below).

Having segmented beginnings and endings we then utilised discriminant techniques. In a discriminant analysis higher percentages indicate higher discriminative power (i.e., higher classification accuracy). Our analysis showed that the 581 beginnings correctly classified 73.5% of nouns and 56.4% of verbs (67.7% of all words) which was

significantly better than chance, Wilks' lambda = .871, df = 580[2], $p < .001$. The 946 endings correctly classified 97.5% of nouns and 83.1% of verbs (92.6% of all words). Once again, this was significantly better than chance, Wilks' lambda = .254, df = 945, $p < .001$. To test generalisability, we repeated the analyses using leave-one-out classification. The results were very similar: 67.5% and 90.9% correct classification for beginnings and endings, respectively, Wilks' lambda = .875, df = 580, and Wilks' lambda = .261, df = , 890, $p < .001$. Once again nouns were more accurately classified than verbs for each analysis, with similar proportions to the original analyses.

Some examples of distinctive cues are beginnings such as 'ca-' which is a strong predictor of nouns with 2.4% of nouns beginning with this cue (compared to 1.4% of verbs). Conversely 'be-' was a strong predictor of verbs beginning 1.6% of verbs (compared to only 0.5% of nouns). The ending '-um' was found in 0.3% of nouns and none of the verbs, and '–ate' was an ending for 4.5% of verbs and 0.2% of nouns.

These results suggest that endings are a more reliable cue to grammatical category than beginnings. This is perhaps not so surprising when one considers that English, in common with the majority of world languages, is a suffix-taking language (Hawkins & Cutler, 1988). However, the important point to note is that the beginnings and endings we discuss here are not determined using morphological boundaries. Moreover, the number and nature of the beginnings and endings identified in our corpus analysis do appear to extend well beyond known affixes. Using the list of English affixes compiled by Fudge (1984), only 6.98% of our endings are classified as suffixes and only 1.72% of our

[2] Variables that failed the tolerance test (too little variance) were omitted from the discriminant analyses, though in each analysis there was just one variable failing: "zu-" for the beginnings, and "ytes" for the endings.

beginnings are classified as prefixes.

The categorisation advantage for endings may be due to the requirement to identify words quickly from their beginnings in continuous speech, therefore shared categorical information is better stored toward the end of the word (Cutler, Hawkins & Gilligan, 1985). The better classification for nouns was due, at least in part, to the greater number of distinct beginnings and endings for nouns – as would be expected from the fact that there were twice as many nouns in our corpus. Of the 1527 possible beginnings and endings in the database, 1301 of them occurred in nouns, whereas 761 occurred in verbs. This greater variability of noun cues, and the high incidence of them occurring only as nouns, meant that there was more opportunity to distinguish this category based on its orthographic cues.

We also tested whether combining beginning and ending cues assisted in classification over using just beginnings or endings for determining the grammatical category of nouns and verbs. After combining cues 97.9% of nouns and 85.3% of verbs (93.6% overall) were correctly classified, which was highly significant, Wilks' lambda = .223, df = 1516, $p < .001$. Thus, combining cues resulted in more accurate classification than using just beginnings or endings, though the highly accurate classification based on only endings (90.9% of words) was only improved slightly by considering beginnings as well.

Another approach in determining the influence of non-morphological beginnings and endings (as opposed to prefixes and suffixes) is to analyse just the monomorphemic trisyllables in the CELEX database. It should be noted that this test is highly conservative because the monomorphemic set in CELEX excludes any morphologically complex word

– not just those which contain affixes (e.g., the word 'hotdog' is excluded even though it does contain a 'beginning' and an 'ending' and does not contain any known prefix or suffix). This resulted in 604 monomorphemic unambiguous trisyllabic nouns and verbs. Analysis of this word set produced 144 different beginnings and 162 different endings. Discriminant analysis of the beginnings resulted in correct classification of 91.7% of nouns and 73.9% of verbs (91.1% of all words), which was significantly better than chance, Wilks' lambda = .765, df = 144, $p < .001$. For the discriminant analysis for endings, 99.0% of nouns and 69.6% of verbs were correctly classified (97.8% overall accuracy). Again, this was significantly better than chance, Wilks' lambda = .398, df = 161, $p < .001$.

These results indicate that there is a rich source of probabilistic cues to grammatical category in English trisyllables in beginnings and endings of words. Three important questions remain: (1) Do participants use these cues in their language processing? (2) What is the relative importance of beginnings versus endings during language processing? (3) Do combined cues assist over using just beginnings or endings for classification?

Experiment 1 – Speeded Grammatical Classification

The speeded grammatical classification task has been used in several previous studies (e.g., Arciuli & Cupples, 2003; Davis & Kelly, 1997; Kacinik & Chiarello, 2002; Sereno & Jongman, 1990). It involves explicit attention to grammatical category and, essentially, taps the ability to broadly categorise words as being either nouns or verbs under time pressure.

Method

Participants. Thirty-two native speakers of English from the Charles Sturt University first-year undergraduate Psychology program participated in exchange for course credit.

Materials. Our corpus analysis allowed us to clearly identify whether the beginning and ending of each trisyllablic noun and verb of English is more typical of its own grammatical category or of the opposing grammatical category (using a > 50% criterion) – allowing us to provide the strongest test of our hypothesis. For example, take the word 'entertain' which has the beginning 'e-' and the ending '-ain'. Our corpus analysis showed that 68% of trisyllables beginning with 'e-' are verbs and 67% of trisyllables ending in '-ain' are verbs. It is important to remember that these cues are probabilistic. As a consequence, it is possible to find nouns that either begin with 'e-' (e.g., 'elephant') or end in '-ain' (e.g., 'porcelain'). In the case of 'entertain', both 'e-' and '-ain' are strongly associated with verb status and are in line with the word's actual grammatical category – thus, the word 'entertain' has consistent orthographic cues to grammatical category.

Experimental items consisted of 80 trisyllabic words which were designed for a factorial analysis, with consistent/inconsistent cues (with regard to the words' actual grammatical category) at word beginnings, and consistent/inconsistent cues (with regard to the words' actual grammatical category) at endings as factors. So, of the 80 experimental items, 20 words had consistent cues in line with their actual grammatical category in both beginnings and endings (e.g., as mentioned, 'entertain' is a verb and both its beginning 'e-' and ending '-ain' are strongly associated with verb status), 20 had consistent cues only in beginnings (their endings had cues that were strongly associated

with the other grammatical category – e.g., 'bewilder' is a verb with a beginning 'be-' that is strongly associated with verbs but has an ending '-er' that is more strongly associated with nouns), 20 had consistent cues only in endings (their beginnings had cues that were strongly associated with the other grammatical category – e.g., 'persecute' is a verb with an ending '-ute' that is strongly associated with verbs but its beginning 'pe-' is more strongly associated with nouns), and 20 had cues that were entirely inconsistent with their actual grammatical status (in fact, cues in both their beginnings and endings were strongly associated with the other grammatical category – e.g., 'jettison' is a verb but both its beginning 'je-' and its ending '-on' are most often seen in nouns). Within each of these four word sets there were 10 nouns and 10 verbs.

For each word we assessed overall length (number of syllables or number of letters), the length of beginnings and endings (number of letters), written word-form frequency[3], orthographic neighbourhood size (Coltheart's N, determined from the CELEX database) and morphological family, again determined from the CELEX database according to the method described in Schreuder and Baayen (1997). Imageability scores were not available for these words so we collected ratings using a separate group of 30 participants who judged a random ordering of the words on a 7-point scale from 1 (not at all imageable) to 7 (highly imageable). Statistical tests including beginning cues (consistent/inconsistent), ending cues (consistent/inconsistent) and grammatical class as factors (2x2x2 ANOVAs) demonstrated that the stimuli were matched on all of these variables. Specifically, there were no main effects of beginning cue or ending cue and no significant interactions between these variables and

[3] Lemma frequency was also not significantly different across the groups, for both main effects and all interactions.

grammatical class. The solitary significant effect was a main effect of grammatical class with regard to morphological family size ($F(1,72) = 53.91$, $p = .0001$). As would be expected, verbs exhibited a larger morphological family than nouns (overall means of 4.83 and 2.25 respectively). Mean values for each of the matching variables are provided in Table 1.

INSERT TABLE 1 ABOUT HERE

We attempted to select words that did not contain beginnings that are known prefixes or endings that are known suffixes, however, due to the constraints imposed in the use of real, grammatically unambiguous trisyllables that must also be matched on a number of different variables (listed below) a very small percentage did contain such overlap (e.g., 're' in 'redirect' is a 'beginning' by our definition but also a prefix as listed by Fudge, 1984). There was an even number of these kinds of items across conditions. Experimental stimuli are listed in the Appendix.

Procedure. Participants were told they would see one word at a time on the computer screen. Their task was to classify each word as being either a noun or a verb – as rapidly as possible. Before beginning they were given a reminder of what 'noun' and 'verb' refer to and several examples of nouns and verbs. They were given with the opportunity to clarify and ask questions. Half of the participants pressed the right response button if the word was a noun (and the left response button if the word was a verb) and the order of

responses was reversed for the other half. Item presentation and data collection was controlled using E-prime (Schneider, Eschman, & Zuccolotto, 2002).

Each trial involved the presentation of a fixation cross (+) positioned in centre of the computer monitor for 500 ms, followed by the word target. Participants were encouraged to respond as quickly and accurately as possible. Trials were response contingent (with a timeout of 2000 milliseconds).

Results and Discussion

In an initial 2x2x2 ANOVA we found no significant interactions involving grammatical class so, for simplicity, we report the collapsed analyses across nouns and verbs. Thus, we performed 2x2 ANOVAs with consistent/inconsistent beginning cues and consistent/inconsistent ending cues as independent variables, and response time and error rate as dependent variables.

In all of the analyses in the current study we only report the by-subjects analyses, as items analyses are not necessary when items are effectively controlled across conditions (Raaijmakers, Schrijnemakers, & Gremmen, 1999).

Response Times. Errors were excluded from analyses of response times. Means and 95% CIs are presented in Figure 1 (all CIs presented in the current study were based on Masson & Loftus, 2003).

INSERT FIGURE 1 ABOUT HERE

There was a significant main effect of consistent/inconsistent endings, $F(1, 31) = 7.35$, $MSe = 44211.49$, $p < .05$, $\eta^2 = .19$, indicating that consistent probabilistic orthographic ending cues with respect to category resulted in quicker grammatical category decisions. When endings were consistent, the estimated marginal mean was 1059ms compared to 1096ms when ending cues were inconsistent. The effect of beginnings was not significant, $F(1, 31) = 2.39$, $MSe = 13558.93$, $p = .13$, $\eta^2 = .07$, with estimated marginal means for consistent beginnings cues 1067ms and for inconsistent beginning cues 1087ms. The interaction between consistent/inconsistent beginnings and endings was also not significant, $F < 1$, indicating that responses to the type of cue were accounted for by the main effects.

Error Rates. Means and 95% CIs are presented in Figure 2.

INSERT FIGURE 2 ABOUT HERE

There was a significant main effect of consistent/inconsistent endings, $F(1, 31) = 42.76$, $MSe = 3644.44$, $p < .001$, $\eta^2 = .58$, indicating that errors were lower when consistent ending cues were present (estimated marginal mean = 24%) compared to when absent (35%).[4] For errors there was also a significant main effect of consistent/inconsistent beginnings, $F(1, 31) = 6.59$, $MSe = 599.44$, $p < .05$, $\eta^2 = .18$, with consistent beginning cues resulting in lower error than inconsistent beginning cues (estimated marginal means

[4] Error rates most likely reflect a number of variables such as the low frequency of some items, emphasis in task instructions to respond rapidly and the fact that this study examined processing of multisyllabic words. Most previous studies of online single word reading have examined the processing of monosyllables. Jared and Seidenberg (1990) investigated the naming of disyllabic words and reported error rates comparable to ours in some experiments.

27% and 32%, respectively). There was no significant interaction between beginning and ending cues, $F < 1$.

These results clearly demonstrate sensitivity to orthographic cues to grammatical category. Endings consistent with grammatical category facilitated grammatical category judgments in terms of both response time and accuracy, whereas beginning cues only had an effect on accuracy. The stronger effect for endings is in line with the results of our corpus analysis and, as such, reflects a statistical property of the language. In Experiment 2 we tested whether such sensitivity could be detected in a task that did not explicitly require attention to grammatical category.

Experiment 2 – Speeded Lexical Decision

Our aim was to determine whether participants were sensitive to probabilistic cues to grammatical category in a task where noun versus verb judgements are not explicitly requested. We were also interested to know whether consistent probabilistic cues to grammatical category assist participants in determining lexicality as do other variables such as frequency, neighbourhood size and imageability. We used a standard, single item presentation lexical decision task, which has been standardly used as a measure of speed and ease of lexical access, and results in response times that are correlated with naming times.

Method

Participants. A separate group of 29 native speakers of English from the Charles Sturt University first-year Psychology program participated in exchange for course credit.

Materials. Experimental items consisted of the same 80 trisyllabic words used in Experiment 1. We also included 80 trisyllabic nonwords which conformed to the phonotactic constraints of English (e.g., 'jovulet', 'pelody').

Procedure. Participants were told they would see a string of letters appear on the computer screen. Their task was to classify each string as being either a real word or a nonsense word – as rapidly as possible. Participants pressed the right response button if the string of letters constituted a real word and the left button if it was a nonsense word. As in Experiment 1, participants were asked to respond as quickly and accurately as possible and item presentation and data collection were controlled using E-prime (Schneider, Eschman, & Zuccolotto, 2002).

As in Experiment 1, each trial included the presentation of a fixation cross (+) on the computer monitor for 500 ms. The participant then saw the target and responded. Trials were response contingent (with a timeout of 2000 milliseconds).

Results and Discussion

As in experiment 1, we conducted a 2x2 ANOVA with consistent/inconsistent beginning cues and consistent/inconsistent ending cues as independent variables, and response time and accuracy as dependent variables.

Response Times. Means and 95% CIs are presented in Figure 3.

INSERT FIGURE 3 ABOUT HERE

All errors were excluded from analyses of response times. As with the grammatical judgment task, there was a main effect of consistent/inconsistent ending cues, $F(1, 28) = 12.92$, $Mse = 49419.59$, $p < .005$, $\eta^2 = .32$, with consistent cues responded to more quickly than inconsistent cues (estimated marginal means 896ms and 937ms, respectively). There was no significant main effect of consistent/inconsistent beginning cues, $F(1, 28) = 1.66$, $Mse = 7941.68$, $p = .21$, $\eta^2 = .06$, once again a similar finding to the grammaticality judgment task. The interaction between consistent/inconsistent beginning and ending cues was also not significant, $F < 1$. As in Experiment 1, words with consistent orthographic cues in line with their grammatical category at the *end* of words elicited faster responses that those with no cues or cues only at the beginning.

Error Rates. Means and 95% CIs are presented in Figure 4.

INSERT FIGURE 4 ABOUT HERE

The results paralleled the effects found for the grammatical category judgment task. There was a significant main effect of consistent/inconsistent endings, $F(1, 28) = 14.03$, $Mse = 775.86$, $p < .001$, $\eta^2 = .33$ (27% errors for consistent endings and 32% errors for inconsistent endings).[5] There was also a significant main effect of consistent/inconsistent beginnings, $F(1, 28) = 7.03$, $Mse = 484.22$, $p < .05$, $\eta^2 = .20$ (consistent beginnings eliciting 27% errors, and inconsistent beginnings 31%). The interaction was not significant, $F < 1$.

[5] As in Experiment 1, these error rates most likely reflect a number of variables.

These results, like those of Experiment 1, indicate sensitivity to probabilistic orthographic cues to grammatical category. Once again, endings had an influence on both response times and accuracy, whereas beginnings only affected accuracy of lexical decision judgments.

General Discussion

Our corpus analyses revealed clear evidence that probabilistic cues to grammatical category are present in both beginnings and endings of trisyllabic English words, and indicated that these cues may be more reliable at word endings. Follow-up behavioural testing in two experiments showed that participants are sensitive to these cues, and that there is an apparent greater reliance on endings than beginnings, particularly in influencing the response time for tasks. Words with consistent endings (i.e., an ending that was a cue for the word's actual grammatical category) elicited faster and more accurate responses than words that have inconsistent cues to grammatical category in their endings (i.e., an ending that is a cue for the opposite grammatical category to that exhibited by the word). Words with consistent beginnings were responded to more accurately. Sensitivity to beginnings has been reported in previous offline studies of such effects (e.g., Arciuli & Cupples, 2007), however, in the current study, only endings had an online effect on processing in terms of response times. Hence, the relative reliability of ending cues compared to beginning cues noted in the corpus analyses appears to be instantiated in the lexical processing of participants in grammatical category and lexical decision judgment tasks.

We suggest that the relative reliability of beginnings and endings in reflecting grammatical category is an embedded property of the language processing system. Hawkins and Cutler (1988) hypothesised that the requirement to identify the word quickly in speech processing forces shared category-level information to be towards the end of the word. Though this pressure comes from serial processing of speech, the same asymmetries of information are to be found in the orthography for alphabetical writing systems. The experimental results presented here make an important contribution by indicating that readers are sensitive to this property of the language, and that this property extends beyond the presence of morphology – grammatical category is marked by letter sequences that do not consist of morphemes, and these have an influence on lexical access.

Using trisyllables presented a unique opportunity to investigate the competing influence of syllable number versus orthographic cues in the processing of verbs, in particular. The majority of English trisyllables are nouns (our corpus analysis revealed a noun to verb ratio of 2:1). Importantly, it has been shown that participants are sensitive to syllable number as a cue to grammatical category when processing nonsense words (Cassidy & Kelly, 1991, 2001). In view of this, it could be argued that, when processing real words, trisyllabic verbs with particularly verb-like spellings may not elicit an advantage in processing compared to trisyllabic verbs with noun-like spellings – because syllable number tends to indicate noun status and this cue may compromise the competing orthographic cue. The results of the current study demonstrate that, in fact, orthographic cues to grammatical category over-ride length cues (at least, in the

processing of real words during the tasks employed here) and that such probabilistic cues affect lexical processing.

The corpus analyses of beginnings and endings cues indicated an additional asymmetry in that nouns were better classified than verbs for all the discriminant analyses across the whole lexicon of English. However, it is important to note that the individual cues tested in our behavioural experiments were selected on the basis that they provided reliable information for both nouns and verbs. When all cues in the language are considered there is an advantage for classifying nouns, but single cues can still be used effectively by the individual as an influence on responding to verbs.

We expect that the effects of probabilistic cues such as those reported here are access effects (see, e.g., Arciuli & Slowiaczek, 2007) and this assumption is consistent with other studies that show on-line effects of interactions between phonological and grammatical category information in lexical access (Farmer et al., 2006). However, further research is needed to confirm that these effects reflect access processes rather than post-access decision processes. Another intriguing question for future research is the issue of whether the effects seen here are due to facilitation by consistent cues or conflicts caused by inconsistent cues. The absence of interactions between cues indicates that it is the presence of consistent cues that facilitate lexical processing rather than inconsistent cues impeding access. If the effects were inhibitory then one would expect a large improvement in performance when both beginning and ending cues were present, and this was not observed.

The current study provides investigation of sensitivity to orthographic cues to grammatical category in real words using speeded tasks. This broadens the importance of

our findings considerably in showing that participants are sensitive to orthographic cues even when the stimuli already have semantic cues (by virtue of them being real words) that may assist grammatical classification (e.g., Pinker, 1984), though these cues may have been weak in the current study as some of the words were low frequency. Moreover, participants are sensitive to these cues during a speeded task such as lexical decision that does not require explicit attention to grammatical status.

This study adds to the growing body of research indicating that probabilistic cues to grammatical category operate at the single word level and, of particular interest, that these cues appear to extend beyond inflectional and derivational morphology. Of course, these findings do not undermine the importance of morphology but do suggest that there are pervasive cues in word-forms that extend passed morphological boundaries. Such findings challenge traditional notions of arbitrariness between word-form and function. They also point to the multi-faceted nature of grammatical category representation. As such, they have important consequences for cognitive models of language processing. Where language modellers may have incorporated grammatical category information only at the phrasal level or perhaps in conjunction with morphological processes it is timely to consider that grammatical category information is also reflected probabilistically in word-forms (in both phonology and orthography).

Indeed, these results provide clear constraints for computational models of lexical processing and reading. First, the results indicate that higher levels of processing, such as grammatical class, have an influence on lexical access even when grammatical class is not directly probed, as in the lexical decision task. Such results are readily consistent with parallel distributed processing models of reading (e.g., Plaut et al., 1996), where multiple,

interacting levels of representation can be available to the reading system. Hence, a model that has as input an orthographic representation of the word and a phonological output representation, can also activate grammatical class information, either as a part of the semantic representation, as in Harm and Seidenberg's (2004) implementation, or as a separate level of representation. The effects we have observed would be consistent with the reading system learning the regularities in mapping between orthography and grammatical class. In such a model, when the word's grammatical class is consistent with the generalities learned between orthography and class then the conversion to phonology can proceed more quickly than when there is a mismatch between the orthography and the word's grammatical class.

The observation of multiple, interacting levels of representation in reading would require more substantial refining of models of reading that propose a lexicon that mediates orthographic and phonological representations in reading, as in Coltheart et al.'s (2001) DRC model (and the same refining equally applies to hybrid models based on the DRC, such as Perry, Ziegler, and Zorzi's, 2007, CDP+ model). Such models invoke a combined left-to-right serial input for converting letters and sets of letters into streams of phonemes and also a lexical route where localist lexical representations are activated based on the orthographic input. For words that have a regular pronunciation (where the letter to phoneme mapping is usual), the system is proposed to respond without accessing anything other than the pronunciation rules in the letter to phoneme conversion system, and any influence of grammatical class on processing would be difficult to tally with such a system. For words that are irregularly pronounced, the lexical route is accessed and it is

possible that some adaptation to this lexical route could be applied to include grammatical class as an influence on lexical access.

The effect of seriality in our model, where word endings are more influential in determining response times to words than word beginnings, also poses a challenge to some models of reading. Again, the parallel distributed processing tradition of models of reading can be adapted without altering any of the processing principles associated with such models to incorporate the effects we have observed. As endings are more reliable indicators of grammatical class, the model is more likely to learn to rely on the word endings for generating information about class. Consequently, the influence of word endings would be an emergent effect of a system that responds to the statistical properties of the mappings between orthography, phonology, and grammatical class. However, models that propose serial input to the reading system, whereby letters are inputted from left to right into the reading system, as in the DRC model, require greater adaptation to reflect our behavioural data. The influence of endings in such serial systems would require that the endings occur after the whole string has been processed, and are thus inconsistent with the reading of regular words in the system.

In short, our corpus analyses and behavioural experiments have indicated that word endings are more influential in lexical access than word beginnings for trisyllabic words, and that multiple, converging levels of representation seem to be implicated when words are read. Such patterns in the behavioural data provide useful constraints for extending current models of monosyllabic reading to address reading of polysyllabic words.

Finally, the current study demonstrates that adults are sensitive to these orthographic cues to grammatical category. To date, many studies investigating the presence and use of probabilistic cues to grammatical category in single words have focussed mainly on language acquisition processes – in new word learning tasks. It could be hypothesised that such sensitivity may decline with increasing language learning as participants begin to rely more on distributional cues that operate at the phrasal level. Conversely, cues that are important during language development may become instantiated in adult lexical access – and continue to operate in combination with other types of cues (i.e., distributional cues) to ensure maximum speed, accuracy and versatility. This study adds to a growing body of research (e.g., Arciuli & Cupples, 2006, 2007; Farmer et al, 2006) demonstrating that, in fact, sensitivity to these cues continues into adulthood and remains an important part of skilled language processing.

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Appendix

Beginning Consistent		Beginning Inconsistent	
Ending Consistent	**Ending Inconsistent**	**Ending Consistent**	**Ending Inconsistent**
capsicum	bewilder	automate	canoodle
decorate	cellulose	breathalyse	carburet
entertain	centipede	decathlon	circumvent
evanesce	cyclamate	dinosaur	dialect
fuselage	decipher	dominate	diatribe
fusillade	disobey	epithet	disrepute
holograph	doctorate	esplanade	dividend
intercede	encompass	genuflect	domineer
interject	endanger	ingenue	electrode
introduce	gibberish	intestine	emirate
iodise	illumine	maximise	gallivant
marathon	malaprop	mechanise	intellect
novella	marakesh	persecute	jettison
pedantry	mismanage	pugilist	malinger
polygon	palimpsest	reckoner	millipede
redirect	paradise	simulate	pettifog
reminisce	pastorate	televise	retrospect
semester	reconcile	utensil	sequester
stalagmite	sulphuret	vanilla	sultanate
supervise	upholster	vivisect	terrify

Table 1. Mean values for matching variables.

Variable	Beginning Consistent				Beginning Inconsistent			
	Ending Consistent		Ending Inconsistent		Ending Consistent		Ending Inconsistent	
	N	V	N	V	N	V	N	V
Log Frequency	2.1	2.3	2.1	1.9	2.2	1.8	2.9	1.9
Total	2.2		2.0		2.0		2.4	
Imageability	4.3	4.5	3.6	4.5	4.5	4.5	3.9	3.3
Total	4.4		4.0		4.5		3.6	
Length	8.2	8.4	8.8	8.4	8.0	8.6	8.5	8.3
Total	8.3		8.6		8.3		8.4	
Neighbourhood Size	.20	.30	.10	.10	.20	.30	.00	.10
Total	.25		.10		.25		.05	
Morphological Family Size	1.9	5.2	1.8	5.0	2.1	4.7	3.2	4.4
Total	3.6		3.4		3.4		3.8	

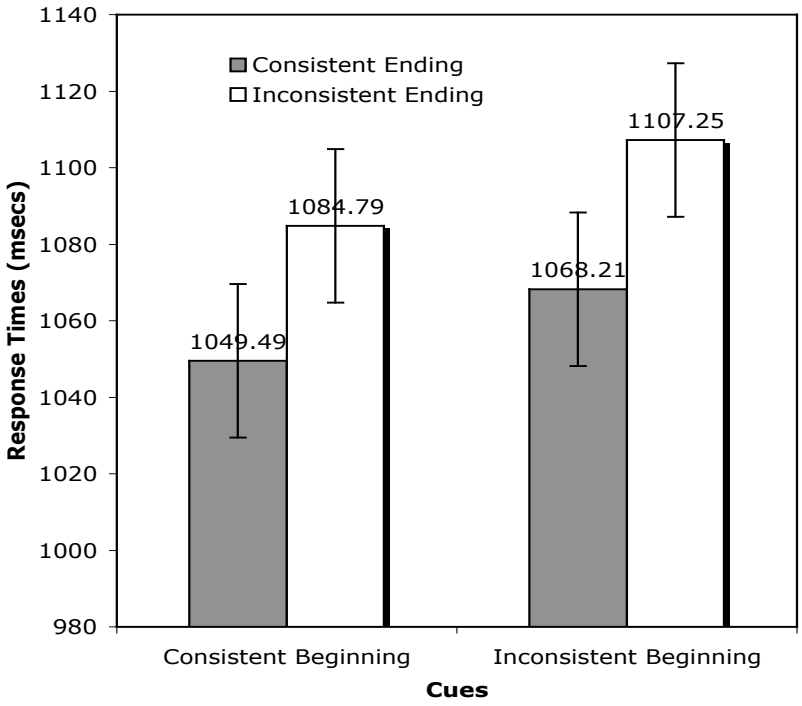

Figure 1: Mean response times for grammatical classifications with 95% CIs

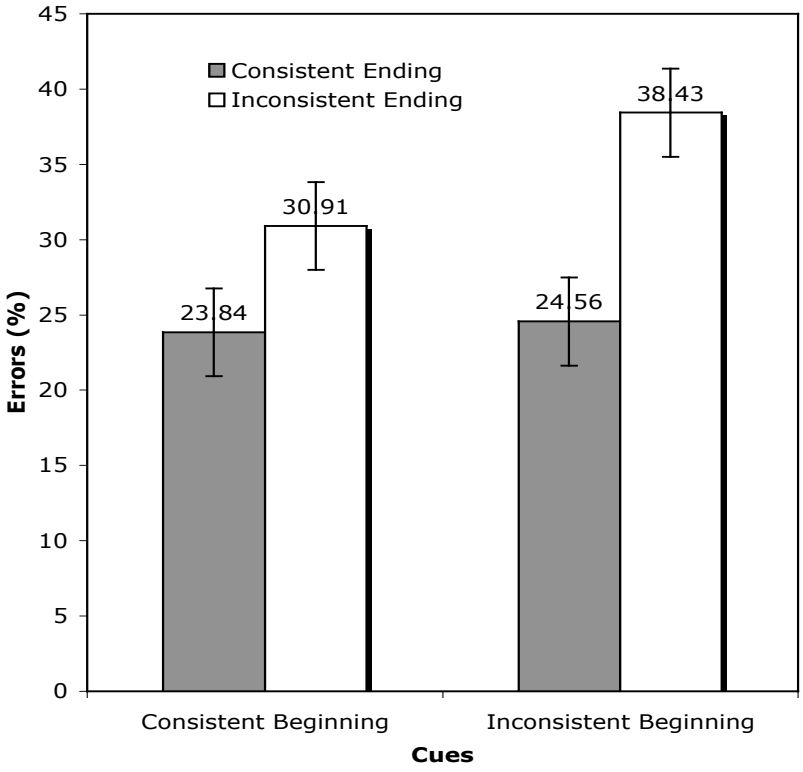

Figure 2: Mean error rates for grammatical classifications with 95% CIs

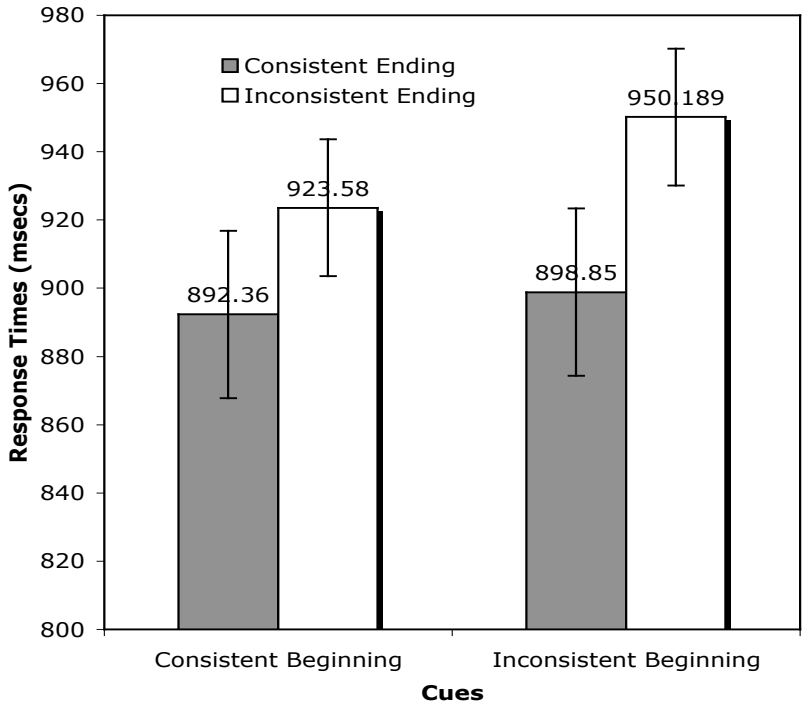

Figure 3: Mean response times for lexical decisions with 95% CIs

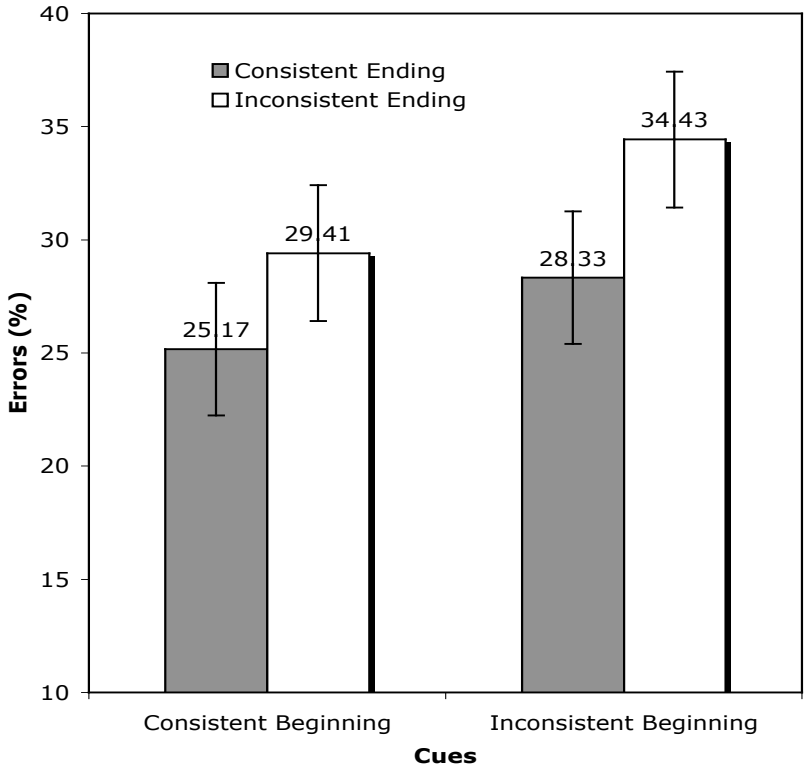

Figure 4: Mean error rates for lexical decisions with 95% CIs