
Seeing things from different angles – non-canonical orientation effects on visual word recognition reflect quantitative and not qualitative consequences.

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Running Head: Non-canonical letter string presentation and visual word recognition.

Seeing things from different angles – non-canonical orientation effects on visual word recognition reflect quantitative and not qualitative consequences.

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Abstract

For skilled readers, word recognition is an apparently effortless cognitive process that can be swiftly performed across various presentation formats. A seminal study by Driver and Bayliss (1995) investigated how two ‘real-world’ non-canonical orientations might disrupt visual word recognition of English words: namely, 90-degree *rotation* (e.g., the title on the spine of a book) and a vertical letter arrangement from top to bottom (e.g., the title on a building’s *marquee* banner). Driver and Bayliss found that rotation had a less detrimental impact on speed and accuracy than the marquee presentation, which they interpreted as evidence for the importance of preserving a word’s ‘principal axis’. The current study seeks to replicate the findings of the original experiment and include a *canonical* (typical) presentation, which was absent in the original work. This ‘baseline’ inclusion allows for a clearer assessment of the effects of non-canonical orientations on typical lexical processing in visual word recognition. Additionally, we systematically examined the potential attenuation of these orientation manipulations on two key variables relating to word items (frequency) and nonword items (pseudohomophony) respectively. Our findings broadly replicate those of Driver and Bayliss (1995), indicating a *graded* impact of non-canonical presentation (canonical > rotated > marquee). Lexical and non-lexical effects remained remarkably robust across all presentation formats, suggesting that access persists even when letter strings are presented in such unfamiliar orientations. We interpret this robustness as indicating that the effects of non-canonical presentation on lexical processing are *quantitative* rather than *qualitative* in nature.

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Introduction

The skill of reading words involves the process of visual word recognition, an ability adult readers can do both extremely quickly and accurately in a variety of contexts, that include varied presentation format, including reading words in in different fonts, CASE and sIzEs. However, most written languages have a ‘canonical’ orientation format; in English this is the horizontal left-to-right presentation. For the most part cognitive models of reading have been concerned with experimental manipulations that do not alter this ‘canonical’ orientation – but this belies the fact that in the ‘real world’ we often encounter familiar words in *atypical* orientations. For example, the letters on the spine of a book are often *rotated* (Figure 1a), and signage outside of a building can be presented from top to bottom in the *marquee* format (Figure 1b).

[Figure 1 near here]

This study aims to investigate how atypical orientation formats influence visual word recognition, as assessed through lexical decision tasks. The research focuses on understanding the effects of such non-canonical presentations on two key lexical variables established to impact word processing (the *frequency effect*) and nonword processing (the *pseudohomophone* effect, which we discuss below. In particular, we seek to revisit a seminal study on this issue (Driver & Baylis, 1995) both in an effort to replicate their key findings and to extend them further.

It is fair to say that many traditional cognitive models of reading, such as Coltheart et al’s (2001) Dual Route Cascaded (DRC) model, have tended to neglect the visual property of orientation, instead primarily focusing on canonical (horizontal) word presentation typical to English. In any case, the DRC model comprises two distinct processing pathways: a *lexical route*, which utilises the orthographic and phonological characteristics of words to access stored representations in the mental lexicon for direct recognition of familiar words, and a *non-lexical route*, which involves phonologically decoding unfamiliar words and non-words through grapheme-to-phoneme conversion rules when direct lexical access is unavailable. Information progresses through both pathways in parallel to facilitate word recognition. However, by concentrating on linear, canonical processing, the model fails to account for how words presented in different orientations may hinder or facilitate word recognition. Parallel Distributed Processing (PDP) models (e.g. Harm & Seidenberg, 2004; Plaut et al., 1996) provide an alternative computational framework that advocates for networks of interconnected units, where information is represented as activation patterns distributed across these units rather than stored word-level representation, enabling parallel processing. Yet, similarly to the DRC model, PDP models do not tend to account for how alternative orientations might influence activation patterns and processing efficiency. This is an apparent oversight considering the ‘real life’ examples we have described earlier. Although non-canonical orientations are encountered in day-to-day life, the information processing costs remain somewhat less understood.

In order to recognise words or read them aloud it is necessary to first identify the constituent letters and the order in which they occur. Without encoding the relative position, pairs of words that share the constituent letters (e.g. trial and trail) would be regularly confused. Cognitive models that attempt to detail how letter position is coded have also largely been based on the canonical presentation. The Local Combination Detectors model (Dehaene et al., 2005), for example, posits that there are neurons which, during reading acquisition, become attuned to specific and informative letter and bigram combinations. Presenting words in unfamiliar formats ought to disrupt the function of the local combination

detectors, and hence impact word processing. The SERIOL model (Whitney, 2001) also predicts that letter position coding should be adversely affected by changing the orientation of the letter string that is presented. Indeed, Whitney (2002) and Gomez and Perea (2014) have argued that word processing will be slowed when stimuli are presented in anything other than canonical format because readers must first perform mental rotation so that letter position coding based on horizontal orientation can be completed. Grainger and Holcomb (2007) similarly stated that any non-horizontal alignment of letters (i.e. not only rotation but also marquee) would necessitate a transposition so that letter position coding could be completed. In other words, because current models expect that the relative position of letters within a string is coded based on visuospatial coordinates, any deviation from the orientation encountered during learning will result in poorer reading performance.

It is thus worth sketching out the findings of related studies that have explored the impact of non-canonical presentation of words and nonwords that are relevant to our own proposed work. As we will see, non-canonical presentation has been shown to have negative impacts on other kinds of reading tasks (such as reading speed). For example, Byrne (2002) reported that non-canonical formats (right-rotated, left-rotated and marquee formats) significantly *slowed* reading speeds (see also Yu et al, 2010) with what they dub “*vertical texts*”, which is the marquee format of focus in our work). In addition, the study explored another well-established phenomenon in the domain of word recognition - the *word frequency effect*. This is the observation that words encountered more frequently in a language (high frequency words) are recognised and consequently processed more quickly than less frequent words (low frequency words) – discussed further below. In this case Byrne (2002) sought to determine whether such lexical effects are attenuated by a non-canonical format presentation (i.e., rotated 90 degrees left/right or marquee), and surprisingly they no evidence for this outcome – in fact, the lexical frequency effect was *increased* for word reading speed relative to the canonical (horizontal) base line. At the same time reading speed showed a graded effect across the non-canonical presentations (i.e., marquee RT > rotated RT > canonical) – that is the marquee (vertical) presentation provoked the generally slowest reading speeds.

Related work, has specifically focused on the rotation presentation condition by systematically manipulating the degree of orientation change. Porter and Arblaster (2020) reported faster reading speed and higher accuracy for canonical (horizontal) orientations compared to those rotated 90 degrees clockwise or anticlockwise (consistent with Bryne, 2002). These results also align with those of Firth et al., (2007), who systematically manipulated rotated word presentation (orientations at 15, 45 and 90 degrees) and found that reading speed increases significantly as the text deviates further from the canonical position. Notably, there is evidence of a non-linear effect, since the slowing of reading speed becomes much more pronounced beyond a certain degree of tilt (i.e., 90 degrees > 45 = 15 degrees).

The consequences of non-canonical orientation have also been investigated with respect to the *repetition priming paradigm*. In this case, the typical finding is that subsequent responses to a stimulus is faster if it (or similar) has been repeated. Benyhe and Csibri (2021) investigated the degree to which systematically rotating the prime stimulus affects the repetition priming effect on word recognition speed and accuracy. They presented a rotated prime (at various angles from 0 to 360 degrees) followed by an upright target, measuring the time it took for participants to read the target aloud. It was found that priming was effective with rotations from 0 up to 60 degrees from the upright position, but the effect diminished with larger rotations. Priming was strongest when the prime was presented upright, suggesting that word recognition becomes less efficient as the rotation angle increases. This particular finding is interesting in that it further supports the presence of a non-linear relationship between word recognition speed and accuracy, akin to the observations of Firth

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et al., (2007). Again, indicating that beyond a particular degree of orientation of rotation, the consequences of word reading speed can be much more severely disrupted.

Although the above work appears to indicate that changing presentation format can have consequences on word reading speed and accuracy, there is much less evidence on visual word recognition performance. For example, Perea, Marcet and Fernández-López (2018) found that whilst the marquee presentation elicited significantly faster reaction times than the rotated presentation, the rotated presentation led to significantly fewer errors. However, this was during a masked priming lexical decision task designed to investigate how the format affects the recognition of letter identity and position – and thus perhaps less relevant to the whole word visual word recognition processes we seek to explore here. It is also important to note the absence of a canonical (horizontal) presentation - the significant implications of such an omission are discussed further below. These inconsistencies highlight the need for further investigation into whether such effects exist in a standard lexical decision paradigm that prioritises the effects of orientation alone. As far as we are aware, there is only a single study (Driver & Bayliss, 1995), that has systematically explored such effects of orientation change on the target items for visual word recognition, and thus we would argue further work is needed.

Driver and Baylis (1995) undertook a key study exploring the impact of non-canonical presentation of letter strings on lexical decision performance. In their study, participants made judgements about letter strings arranged in columns with each letter upright (such as in Figure 2 above) which we will refer to as *marquee* format, or *rotated* clockwise at a 90-degree angle (such as in Figure 1 above – they dubbed this ‘tilted’). The focus of the work was to determine the degree to which either of these manipulations had a greater or lesser degree of interference on lexical decision performance. In particular, the focus was on a hypothesis that the ‘canonical’ orientation for English words related to a ‘principal axis’ (imagine a horizontal line from left to right running through the letter string) – this was despite the fact that no such ‘canonical’ condition was included. In any case, the simple point the authors made is that in rotating a letter string the ‘principal axis’ is maintained, whereas this is not true for the marquee format - the prediction therefore being the latter would have a *greater disruptive* impact (akin to the findings for reading speed undertaken by Bryne, 2002). On the other hand, from the perspective of the participant viewer the letters in marquee remain in a ‘standard’ format (i.e., upright), which is not true for rotated items (see Figures 1 & 2). Their key finding was consistent with the ‘principal axis’ prediction, that marquee presentation had a greater *relative* impact than tilting on speed and accuracy. Such results held true when controlling for spacing differences between formats and using alternating case to disrupt familiar global shapes, thus proving the format effect was not due to the preservation of global envelopes in the marquee format. Interestingly, the advantage of the marquee presentation became more pronounced as the letter strings increased in length, which suggests that the ‘principal axis’ plays a more vital role as the complexity of the string increases. They also considered the word frequency effect (Preston, 1935) in order to determine if this lexical variable interacted with presentation format.

We have already touched on the word frequency effect earlier in our discussion of the work on reading undertaken by Bryne (2002), but it is worth considering this variable manipulation in a bit more detail. As we have mentioned, the word frequency effect relates to the perhaps unsurprising fact that individuals process and visually recognise high frequency words much faster and more accurately than low frequency words (Preston, 1935, Schilling, Rayner and Chumbley, 1998; Gerhard and Barry, 1999). The DRC model (Coltheart et al., 2001) accounts for the word frequency effect by suggesting that high frequency words are processed through the lexical route, benefitting from stronger and more extensive representations in the mental lexicon developed through frequent exposure. This familiarity

facilitates faster and more direct retrieval. In contrast, low frequency words are less familiar, requiring more effortful decoding and phonological processing, resulting in slower recognition times and higher error rates. Additionally, PDP models (e.g. Plaut et al., 1996) can also explain this effect through the emphasis on pattern recognition; where individuals learn to identify the patterns associated with high frequency words through repeated exposure (Harm & Seidenberg, 2004). As a result, processing high frequency words is typically faster and more accurate due to their familiarity. Central to both these theoretical accounts of word frequency effects is the assumption that they emerge as a principle of access to stored representational information – and thus so long as a letter string is ‘perceived’ as a word their effects will follow. However, critical to our work is the degree to which non-canonical presentation somehow ‘alters’ the lexical status of a string of letters during word recognition – that is the extent to which the consequences of *marquee*/rotated presentation reflect a *quantitative* or *qualitative* impact on subsequent visual recognition. Put simply, does non-canonical presentation alter the perception of a letter string such that typical lexical access no longer occurs (a qualitative change)? The role of manipulating effects linked to lexical status helps unpack this question since if the disruption of non-canonical presentation genuinely qualitatively changes letter string perception, key effects like frequency effects should no longer remain, or at least be severely attenuated. The fact that frequency effects are so ubiquitous, would imply a subsequent null effect is perhaps striking.

Driver and Baylis (1995) found the frequency effect was present regardless of presentation format (a finding that echoes that of Bryne, 2002 for word reading speed). However, much like Perea et al (2018), unfortunately this study did not include a ‘baseline’ condition (i.e., canonical presentation), so although it is clear higher frequency items were responded to faster in both the non-canonical scenarios, we are not certain whether this magnitude is *proportionally smaller* than would have been typically observed with canonical items. Similarly, Driver and Bayliss (1995) indicate that in general *rotated* items are faster than *marquee* items, but without a canonical baseline again we are none the wiser about the relative impact of either to the typical presentation. Put simply, the absence of a baseline condition leaves a substantial gap in the understanding of the true impact of orientation relative to typical performance levels. As a consequence, the current study sought to *replicate* this earlier work and include a baseline ‘canonical’ condition.

The inclusion of a manipulation of word frequency enables a window on the effects of non-canonical presentation for the *lexical processing* of words. However, we were also interested in manipulating a variable linked to the *non-lexical processing* of nonwords – non-lexical processing in this case referring to the rules-based conversion of orthography to phonology that allows for the naming and correct rejection of nonwords. The basic logic being, if non-canonical manipulations disrupt reading to the extent that words are not processed as words, it is likely that something similar happens to nonwords. Again, models of letter-position coding predict that informative and familiar bigrams are identified based on visuospatial coordinates (i.e. L is to the left of A). This relative position is important for the conversion from orthography to phonology when processing nonwords. In the DRC (Coltheart et al., 2001) graphemes are converted to phonemes serially. This means that inaccurate letter position identification will result in sounds being compiled in the wrong order. If non-canonical presentation disrupts letter position identification then nonword processing will also be affected and this should result in an observable modulation of the *pseudohomophone effect* in lexical decision. The pseudohomophone (PSH) effect, first described by Martin (1982), refers to the finding that in lexical decision tasks, nonwords that *sound* like real words when read aloud (e.g., *SKOOL*), take longer to reject than nonwords that do not resemble real words phonologically (e.g., *ZOOL*). Although theoretical explanations vary (see Reynolds & Besner, 2005; Harm & Seidenberg, 2001), they generally

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agree that the effect reflects *lexical interference*—suggesting that it may diminish or disappear when the perception of the nonword is qualitatively altered. If we assume the PSH effect arises because phonological decoding activates a stored representation of a real word, then disrupting the conversion from orthography to phonology should *reduce* this interference. In other words, when letter strings are presented in familiar spatial canonical arrangements (e.g., standard horizontal orientation), the conflict between the spelling and sound of PSHs is likely to produce the effect. However, when the letters are presented in a non-canonical format - either rotated or presented in a marquee format - the disruption to orthographic processing may delay or interfere with grapheme-to-phoneme conversion, thereby reducing the effect. Though it remains an open empirical question the degree to which different types of non-canonical presentation may attenuate the effect to different extents. Including both PSHs and regular nonwords in word recognition orientation studies expands the scope of investigation and provides key insights into how different visual formats influence the processing of orthographic and phonological information—forming the basis for the present study.

In summary, the primary aim of the present study is to replicate and extend the seminal work of Driver and Baylis (1995) in investigating the impact of non-canonical presentation of items in visual word recognition. Firstly, consistent with their work, we will present items in either a rotated (90 degree) or marquee format – whilst also critically including the canonical form of presentation as a relative baseline. Secondly, we will determine the degree to which two critical lexically driven effects: (a) word frequency for words and (b) pseudohomophone status for nonwords may be attenuated by non-canonical manipulations. Drawing on the previous work of Driver and Baylis (1995) we expect to replicate their key observations – namely that an overall advantage (shown through faster reactions times and fewer errors) will exist for the rotated format over the marquee format during a lexical decision task and that the word frequency effect will persist in both of these formats though it remains open the degree to which this is attenuated relative to baseline.

Method

Participants

Overall, 92 participants signed up for the study. According to participant-provided demographic data, the mean age of the participants was 22.34 years ($SD = 5.95$). Sixty-two of the participants identified as female, 21 as male and 9 as non-binary. Any participant who had received a diagnosis of dyslexia (or any other language disorder) or did not have fluent proficiency in English was excluded from the analysis.

Design

The study took a within-subjects design. The key independent variable was orientation, with letter strings being presented in canonical format, rotated 90-degrees clockwise or marquee. For *word* stimuli, there was a second independent variable of frequency (high versus low); for *non-word* stimuli, the second independent variable was type (pseudohomophone versus non-pseudohomophone). As a consequence we ran analyses on the word trials and nonword trials separately. For the word trials a linear mixed models approach for our analysis was conducted to formally examine the two dependent variables (GLMM for accuracy/LMM for RTs). The model was specified with Frequency and Presentation as fixed effects, forming a 2 (Frequency: High, Low) $\times$ 3 (Presentation: Canonical, Marquee, Rotated) factorial design, with participant included as a random effect. The random effects structure included random intercepts and random slopes for Lexicality across participants, allowing for individual differences in response patterns (see Results for further specific information). For the nonword trials a similar approach was also undertaken, but the model was specified with Pseudohomophony and Presentation as fixed effects, forming a 2 (Pseudohomophony: PSH, NW) $\times$ 3 (Presentation: Canonical, Marquee, Rotated) factorial design, with participant again included as a random effect.

Materials

The lexical decision task comprised 75 high frequency and 75 low frequency words (drawn from Weekes, 1997), along with 75 pseudohomophones and 75 non-pseudohomophonic nonwords from Howard and Best's (1996) list. All stimuli were between 4 and 6 letters in length. Participants were presented with one of three versions of the task. Version 1 allocated a subset of 25 of each stimulus type to the canonical format, a subset of 25 to the rotated format and the remaining subset of 25 to the marquee format. Versions 2 and 3 assigned the same subsets of items to different presentation orientations, so that across all the versions of the task every stimulus had been presented at every orientation. Within each version of the task, the order in which the items appeared was randomised.

Procedure

Participants were given instructions to complete the lexical decision task as accurately and quickly as possible, pressing the 'L' key if they believed the stimulus to be a real word and the 'A' key if they believed it was not. Within a single trial, a fixation cross was shown in the centre of the screen for 500 milliseconds, after which the stimulus was displayed on the

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screen until the participant gave a response. Following this response, a blank screen appeared for 2 seconds before the next trial began. There were 300 randomised trials, with breaks after every # trials. During these intervals, participants were asked to press the keyboard to continue the study when they wished to do so. Upon study completion, a debrief form was presented containing the rationale of the study and what would happen with the information given. The study was then terminated, and participants were redirected to the original research website. An average of 20 minutes was needed for the entire study.

Results

Data cleaning:

Overall, we recruited 92 participants - a first pass examining the distribution of mean accuracies for all our participants found two individuals over three standard deviations lower than the group. As a consequence their data were removed. A similar investigation of mean reaction times (RTs) found two participants with mean RTs which were abnormally slow (>3 SDs lower than the group mean) and thus they too were removed as outliers. Our subsequent analyses focused on the remaining 88.

Word analyses:

Accuracy

As discussed earlier we sought to explore the impact of non-canonical presentation on the word *frequency effect* to replicate the seminal work of Driver & Bayliss, 1995. In Figure 2 we present the estimated marginal means for our various conditions along with error bars (95% confidence intervals) – in this case we were interested in seeing the degree to which the standard frequency effect may be *attenuated* by our different non-canonical presentations, with the inference that if this ubiquitous lexical effect were eliminated this likely constitutes a *qualitative* change to the perceived stimulus. However, Figure 2 appears to suggest the frequency effect occurs for accuracy performance in all cases, and our subsequent analyses will explore this further.

[Figure 2 near here]

A generalized linear mixed model (GLMM) was conducted to examine the effects of Frequency and Presentation on response accuracy with participants included as a random effect. The model was specified with Frequency and Presentation as fixed effects, forming a 2 (Frequency: High, Low) $\times$ 3 (Presentation: Canonical, Marquee, Rotated) factorial design. The random effects structure included random intercepts and random slopes for Frequency across participants, allowing for individual differences in response patterns and the GLMM was fit using a binomial/logit link function. Our analyses revealed a main effect of Frequency, $\chi^2(1) = 122.10$, $p < .001$, indicating overall accuracy of responses was generally higher for High Frequency items. There was also a significant main effect of Presentation, $\chi^2(2) = 57.24$, $p < .001$, and a significant interaction between Frequency and Presentation, $\chi^2(2) = 24.11$, $p < .001$, which we further explore below. If we focus on the main effect of Frequency across presentation conditions (see Figure 1) we see that this was significant in all three presentations instances: (a) Canonical High/Low Frequency ($z = 10.98$, $p < .001$, $d^+ = 0.093$ (SE = 0.008), with a 95% CI of [0.076, 0.11], (b) Rotated High/Low Frequency ($z = 9.73$, $p < .001$, $d^+ = 0.091$ (SE = 0.009), with a 95% CI of [0.072, 0.109], and (c) Marquee High/Low Frequency ($z = 7.41$, $p < .001$, $d^+ = 0.071$ (SE = 0.01), with a 95% CI of [0.052, 0.09]. As a consequence, it seems the lexical frequency effect on observed accuracy scores is pervasive regardless of presentation condition.

Moving to the observation of the different presentation formats across word Frequency type, we undertook planned comparisons across presentation conditions. Firstly, for the High Frequency items we found an accuracy pattern consistent with a *graded effect* of *Canonical > Rotated > Marquee*: (a) relative to our 'baseline' accuracy was significantly higher for Canonical vs Rotated ($z = 4.38$, $p < .001$, $d^+ = 0.025$ (SE = 0.006), with a 95% CI of [0.014, 0.037] and for Canonical vs Marquee ($z = 6.28$, $p < .001$, $d^+ = 0.044$ (SE = 0.007), with a 95% CI of [0.03, 0.058] and (b) comparing the two atypical orientations, there was significantly higher accuracy for Rotated vs Marquee ($z = 2.77$, $p = 0.006$, $d^+ = 0.019$ (SE = 0.007), with a 95% CI of [0.006, 0.032]. Interestingly, this pattern changed for the Low Frequency items with an accuracy pattern consistent with *Canonical > Rotated = Marquee* (a) relative to our 'baseline' accuracy was significantly higher for Canonical vs Rotated ($z = 2.27$, $p = .02$, $d^+ = 0.023$ (SE = 0.01), with a 95% CI of [0.003, 0.043] and for Canonical vs Marquee ($z = 2.23$, $p = .03$, $d^+ = 0.022$ (SE = 0.01), with a 95% CI of [0.003, 0.042] and (b) across the two atypical orientations, accuracy was effectively identical, Rotated vs Marquee ($z = -0.04$, $p = 0.97$, $d^+ = 0.0001$ (SE = 0.01), with a 95% CI of [-0.021, 0.020].

Overall, our analysis of words in this case yielded two key findings: (1) the word frequency effect on accuracy was large and ubiquitous across all presentation types and (2) the effect of presentation type varies across the frequency types; for High Frequency items there was a *graded effect* of presentation type (Canonical > Rotated > Marquee), whilst for Low Frequency the pattern was of poorer performance of the two atypical orientations relative to baseline only. The inclusion of a baseline provided an important indicator in that it demonstrated that atypical orientation does generally decrease accuracy, even though across Rotated/Marquee the pattern changes depending on the frequency of the targets.

Reaction Times:

A linear mixed-effects model was conducted to examine the effects of Frequency and Presentation on reaction times with participants included as a random effect. The model was specified with Frequency and Presentation as fixed effects, forming a 2 (Frequency: High,

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Low) $\times$ 3 (Presentation: Canonical, Marquee, Rotated) factorial design. The analysis revealed a significant main effect of Frequency, $F(1,13107)=24.83$, $p<.001$, indicating generally faster mean RTs for High Frequency vs Low Frequency items across the board (see Figure 3). As before, there was also a significant main effect of Presentation, $F(2,13107)=84.90$, $p<.001$, and planned contrasts demonstrated the same graded effect observed for accuracy *Canonical* < *Rotated* < *Marquee* (see Figure 3) - (a) relative to our ‘baseline’ reaction time was significant faster for Canonical vs Rotated ($z=7.61$, $p<0.001$, $d^{\wedge}=0.206$ (SE = 0.027), with a 95% CI of [0.153, 0.259] and for Canonical vs Marquee ($z=12.97$ $p<0.001$, was $d^{\wedge}=0.351$ (SE = 0.027), with a 95% CI of [0.298, 0.404] and (b) across the two atypical orientations reaction time was also significantly different, with Rotated faster than Marquee ($z=5.36$, $p<0.001$), $d^{\wedge}=0.145$ (SE = 0.027) and a 95% CI of [0.092, 0.198]. Finally, unlike for accuracy, there was no significant interaction between Frequency and Presentation $F(2,13107)=0.33$, $p=.719$.

[Figure 3 near here]

In sum, both RT and accuracy analyses demonstrated that the Frequency effect was robust across all presentation formats, with little evidence of any kind of attenuation in either case. The inclusion of the baseline condition demonstrated that both Rotated and Marquee presentations result in slower and less accurate performance, but that Marquee is generally associated with even worse performance than Rotated (consistent with the work of Driver & Bayliss, 1995 and Byrne, 2002 for word reading). However, this pattern was not observed for accuracy with low Frequency items.

Nonword analyses:

Accuracy

A generalized linear mixed model (GLMM) was conducted to examine the effects of Nonword type and Presentation on response accuracy with participants included as a random effect. The model was specified with Nonword type and Presentation as fixed effects, forming a 2 (Nonword type: NW, PSH) $\times$ 3 (Presentation: Canonical, Marquee, Rotated) factorial design. This determined a significant main effect of Nonword type, $\chi^2(1)=9.57$, $p=0.002$, indicating overall accuracy of responses was consistently slightly lower for PSH items (NW=0.928, PSH=0.914, see Figure 3), and a significant main effect of Presentation type, $\chi^2(2)=9.191$, $p=0.01$ (Canonical = 0.929, Rotated = 0.913 and Marquee = 0.921). Planned contrasts demonstrated a different pattern to that often observed with the word targets - (a) relative to our ‘baseline’ accuracy was significant higher for Canonical vs Rotated ($z=2.95$, $p<0.003$, $d^{\wedge}=0.016$ (SE = 0.005), with a 95% CI of [0.005, 0.027], but not for Canonical vs Marquee ($z=1.45$ $p=0.147$), $d^{\wedge}=0.007$ (SE = 0.005), with a 95% CI of [-0.003, 0.017] and (b) across the two atypical orientations accuracy was also not significantly different; Rotated vs Marquee ($z=1.58$, $p=0.114$), $d^{\wedge}=0.009$ (SE = 0.005), with a 95% CI of [-0.002, 0.019]. Finally, there was no interaction between Nonword type and Presentation ($\chi^2(1)=0.71$, $p=0.70$).

[Figure 4 near here]

In summary, for correct rejection accuracy of Nonwords we saw the standard effect of pseudohomophony that was ubiquitous across all presentation formats, suggesting again no attenuation of atypical orientation on a key lexical effect for word recognition (akin to that observed for the Frequency effect). Interestingly, the typical *graded effect* of orientation seen for word accuracy was *not* present for nonword accuracy – with some evidence that *rotated* presentation was the worst performer. However, we are cautious to make much of this observation given the generally very small observed differences.

Reaction time analyses

A linear mixed-effects model was conducted to examine the effects of Nonword type and Presentation on reaction times (Figure 5) with participants included as a random effect. The model was specified with Nonword type and Presentation as fixed effects, forming a 2 (NW type: Pseudohomophones, NWs) $\times$ 3 (Presentation: Canonical, Marquee, Rotated) factorial design. The analysis revealed that there was no significant main effect of nonword type, $F(1,13107)=0.43$, $p=0.51$, but there remained a significant main effect of Presentation, $F(2,13107)=20.45$, $p<.001$ (Canonical = 1.045, Rotated = 1.303 and Marquee = 1.503), and again the interaction between Condition and Presentation was not significant, $F(2,13107.00)=1.48$, $p=.228$. As before we further explored the main effect of presentation and determined that: (a) there was a significant difference between the Canonical and Rotated conditions, $z=-3.59$, $p<.001$, $d^{\wedge}=-0.258$ (SE = 0.072), with a 95% confidence interval (CI) of [-0.117, -0.399], (b) a significant difference between the Canonical and Marquee conditions, $z=-6.38$, $p<.001$, estimated difference in marginal means $d^{\wedge}=-0.458$ (SE = 0.072), with a 95% CI of [-0.317, -0.598] and (c) a significant difference between the Marquee and Rotated conditions, $z=-2.78$, $p=0.005$, estimated difference in marginal means $d^{\wedge}=-0.2$ (SE = 0.072), with a 95% CI of [-0.059, -0.34].

[Figure 5 near here]

Overall it seems that the key graded effect of presentation format is observed in speeds of responses for *both* words and nonwords. The effect of pseudohomophony was somewhat mixed, being present only on accuracy – but in neither case is there any evidence that this non-lexical variable interacted with presentation format.

GENERAL DISCUSSION

As mentioned earlier the current study was an attempt to replicate the work of Driver and Bayliss (1995) and improve things by including a baseline and two different experimental manipulations targeting lexical and non-lexical processing: namely word frequency and nonword pseudohomophony, where only the former was previously investigated. In that seminal work, they reported two key things. Firstly, for reaction times, items presented in a rotated (tilted) format were always faster than marquee (upright), regardless of the lexical status of the strings (i.e., words or nonwords) or the frequency of the words. For accuracy, the pattern was a little different in that a similar rotated > marquee pattern was observed but only for words. Unfortunately, mean scores were not reported, and although median scores were provided this was only via a figure in the manuscript – making direct comparison to our

observed values impossible. However, a casual inspection of the figure in their publication also highlights quite high error rates - ~10% for high frequency and ~20+% for low frequency items and it is not clear why that should be the case (perhaps a few extremely poor performers in their N=30 sample?). Though we are naturally reluctant to assume it may reflect differing population literacy levels since our study and theirs use undergraduate psychology students.

In any case, our work appears to generally replicate the findings of Driver and Bayliss (1995) with respect to the impact of the presentation variable, but our inclusion of a canonical condition clarifies that for visual word recognition, non-canonical presentation is generally worse than a 'typical' baseline (replicating the work of Bryne, 2002 in their observation of reading speeds). Critically the inclusion of this baseline enables us to interpret the pattern as a *graded* effect (canonical > tilted > marquee), the consequences of which are true for the speed of processing of both words and nonwords (directly replicating the work of Driver and Bayliss, 1995 – albeit with a better powered study in our case). The story for accuracy in our case was a little different, in that this same graded pattern was (a) most obviously observed for accuracy for *high frequency items* and (b) less apparent with nonwords, with a hint that rotation may have proportionally greater impact relative to baseline (though we would suggest caution in that interpretation). Nonetheless, as commented earlier, it is apparent that errors rates were generally much higher in the original study which may explain our divergent findings. In general, we can echo a point made by the original authors that, in light of the fact that rotated format is clearly superior to marquee – “*that the many publishers who print titles along book spines using tilted letters cannot all be wrong!*”

In addition, our findings overlap with that of Driver and Bayliss (1995) in that we also observed a ubiquitous frequency effect both for speed and accuracy measures, which with the inclusion of a baseline condition in our case, were reasonably commensurate with typical (canonical) word processing (unknown in their study). In addition, we also observed a pseudohomophony effect (on accuracy) for nonwords which was also remarkably robust to differing forms of non-canonical presentation. Overall, we would interpret these patterns to mean that these unusual presentation formats do not *qualitatively change* their perception in visual word recognition - namely, that lexical and non-lexical derived effects are present across all types of letter string presentation be they canonical or non-canonical. We would argue that the fact that lexical effects did not appear to interact with these non-canonical presentation formats must indicate that access to some form of representation of the whole word still occurs. In the DRC (Coltheart et al., 2001) tradition, this access is in the form of individual word representations in the visual input lexicon (for words), and via a feedback loop from the output of grapheme-phoneme conversion processes to the phonological output lexicon (for pseudohomophones). Our findings therefore indicate that rotation of stimuli, or presenting them in marquee format, does not sufficiently disrupt lexical access or GPC conversion sufficiently to eliminate these effects. A different mechanism by which effects of frequency and pseudohomophony occur is proposed in PDP models (e.g. Harm & Seidenberg, 2001; 2004) but the findings of the current study nevertheless indicate that lexical processing is not *qualitatively* different when stimuli are presented in non-canonical formats. It is also important to note that we observed differences in RT that followed the pattern of canonical < rotated < marquee. This pattern is interesting as they pertain to letter position coding. Witzel et al (2011) showed that transposed-letter priming effects can be observed in marquee presentation, which they argued could be accommodated by assuming that letter position coding was ordinal (first letter, second letter) rather than visuospatial

(leftmost letter, one-from-the-leftmost letter). Their findings could equally be accounted for by assuming a mental transposition of the non-horizontal stimulus to allow for the coding of visuospatial coordinates (Grainger & Holcomb, 2007). We argue that our findings (and those of Witzel et al., 2011) are more readily accommodated by the latter account. In the rotated condition, the word as a whole matches the relative position of letters once it has been mentally rotated back to horizontal; in the marquee condition the stimulus needs to be more extensively reconfigured. We suggest that the rotation takes less time than the reconfiguration, but that after that initial process has been completed the word recognition proceeds as it does for canonically presented words.

In their original study, Driver and Besner (1995) considered whether the effects of word frequency might interact with presentation format, suggesting that high-frequency words—being highly familiar—may also be more strongly associated with *canonical presentation* (see Besner, 1989; Haber & Haber, 1981). This led to the prediction that disrupting this familiarity through non-canonical formats might have some attenuation effect. However, their study lacked a canonical baseline condition, making it difficult to assess this claim directly. Our study addressed this limitation by including such a baseline and attempting a broader replication and a larger sample size. Importantly, we did observe a pattern somewhat consistent with their prediction, but only for accuracy, and only in a graded way – the inclusion of our baseline condition clearly demonstrated that speed of processing appears to be universally impacted by non-canonical presentation. With this graded pattern of disruption confirmed and the additional observation that lexical access must persist, we are left with the question: why might rotated presentation still prove superior to marquee presentation? In their original work Driver & Bayliss (1995) argued for a “*role of principle axis of letter strings in providing a reference frame to which component letters are described*”, with the inference that so long as this ‘principle axis’ is maintained there will be an information processing advantage. We might well accept this suggestion, with one important caveat, which is that severe disruption to such a ‘principle axis’, argued to be the case with the marquee format, does not qualitatively change word perception sufficient to massively attenuate classic lexical effects such as frequency for words or pseudohomophony for nonwords – *lexical access must persist regardless*.

Statements and Declarations

Ethical considerations

This study was approved by the Ethics Committee of [REDACTED FOR PEER REVIEW] University (Ethics Code: 1 2023 6467 7497) on 5th December 2023. All participants provided written informed consent prior to enrolment in the study. This research was conducted ethically in accordance with the World Medical Association Declaration of Helsinki.

Consent to participate

Participants provided written consent to take part in the research, and for anonymised research data to be published.

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article

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Figure 1 - Examples of non-canonical letter orientation in the real world. Panel A shows what we refer to as "marquee" presentation in the current study; Panel B shows strings rotated 90 degrees clockwise.

107x103mm (300 x 300 DPI)

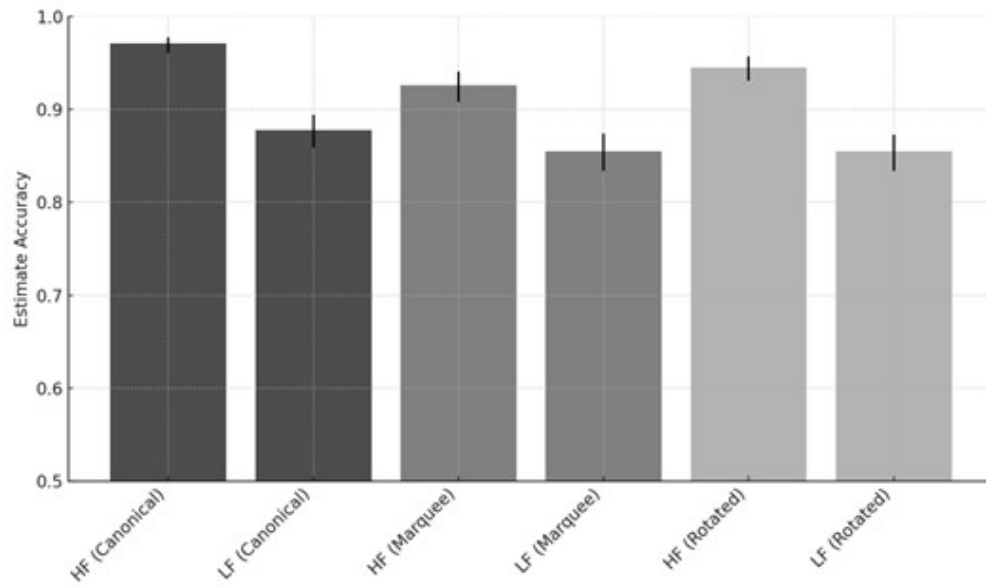


Figure 2 –Word accuracy estimate means by presentation and frequency conditions.

139x83mm (96 x 96 DPI)

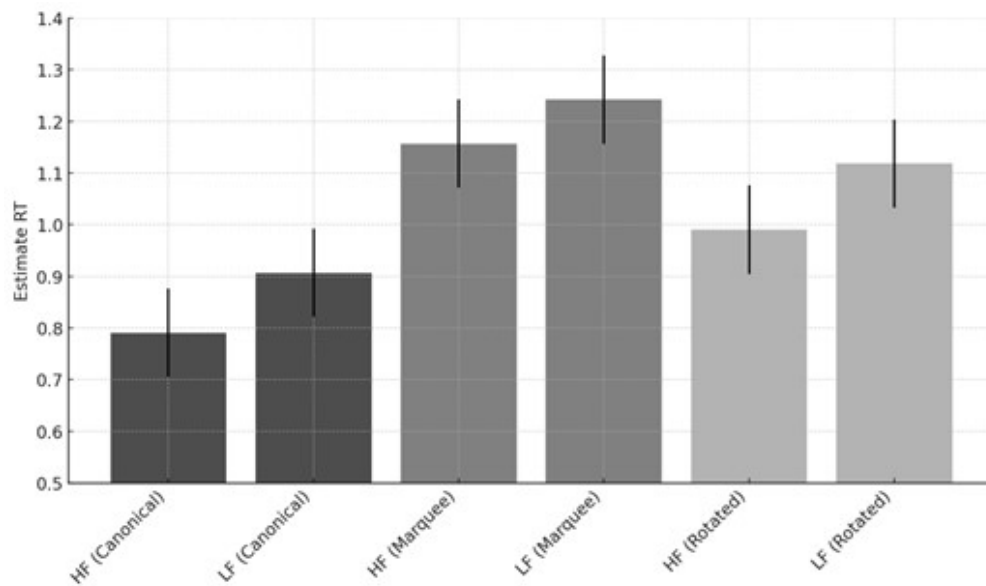


Figure 3 –Word reaction time estimate means by presentation and frequency conditions.

136x81mm (96 x 96 DPI)

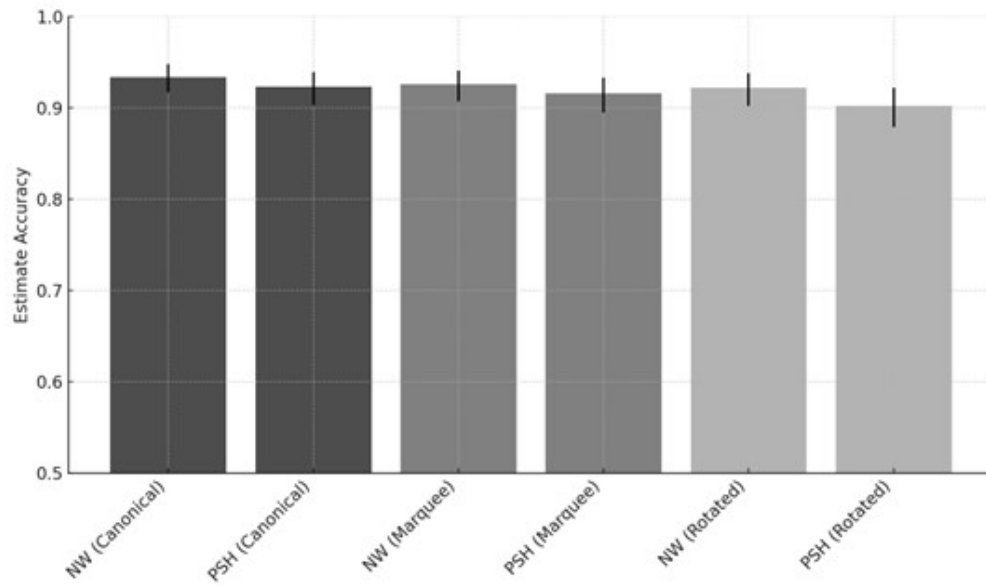


Figure 4 – Nonword accuracy estimate means by presentation and type conditions.

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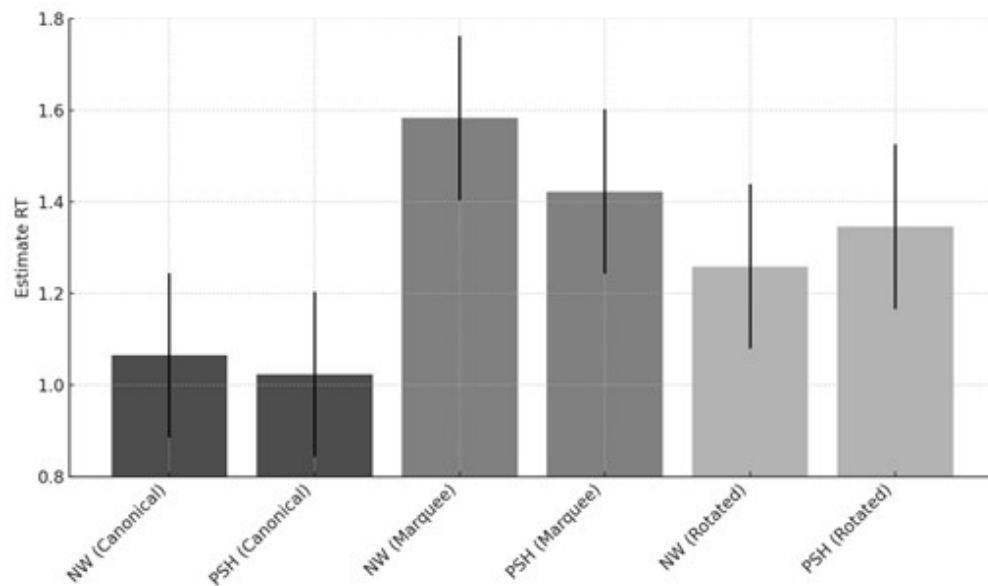


Figure 5 – Nonword reaction time estimate means by presentation and type conditions.

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