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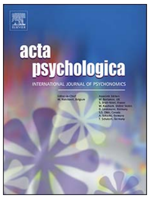

Stimulus orientation and the first-letter advantage

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ABSTRACT

A post-cued partial report target-in-string identification experiment examined the influence of stimulus orientation on the serial position functions for strings of five consonants or five symbols, with an aim to test different accounts of the first-letter advantage observed in prior research. Under one account, this phenomenon is driven by processing that is specific to horizontally arranged letter (and digit) strings. An alternative account explains the first-letter advantage in terms of attentional biases towards the beginning of letter strings. We observed a significant three-way interaction between stimulus type (letters vs. symbols), serial position (1–5), and orientation (horizontal vs. vertical) that was driven by a greater first-position advantage for letters than symbols when stimuli were presented horizontally compared with vertical presentation. These results provide support for the letter-specific processing account of the first-letter advantage, and further suggest that differences in visual complexity between letters and symbols play a minor role. Nevertheless, a first-position advantage for letters was observed in the vertical presentation condition, thus pointing to some role for attentional biases that operate independently of string orientation.

1. Introduction

Orthographic processing is the gateway to visual word recognition and reading (Grainger, 2018). A long tradition of research has thus explored the underlying mechanisms, such as the processes involved in encoding the identities and positions of letters in a word. Although there is a general consensus that letters are processed in parallel (e.g., Adelman, 2011; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Gomez, Ratcliff, & Perea, 2008; Perry, Ziegler, & Zorzi, 2010; Plaut, McClelland, Seidenberg, & Patterson, 1996), it is also generally acknowledged that letter processing efficiency varies as a function of the position the letters occupy within the written word (e.g., Rumelhart & McClelland, 1982). The present study addresses one specific aspect of such positional effects, the oft-reported advantage for processing of the initial letters of words – the so-called “first-letter advantage”.

Early letter identification processes involved in word recognition have been studied by briefly presenting strings of letters and asking participants to make a decision about the identity of a probed character at a specific location in the string. Results have consistently shown better accuracy for letters presented at fixation, as well as for the first and the last letters (e.g., Marzouki & Grainger, 2014; Merikle, Coltheart, & Lowe, 1971; Merikle, Lowe, & Coltheart, 1971; Mewhort & Campbell, 1978; Stevens & Grainger, 2003; Tydgat & Grainger, 2009). A similar pattern is found for strings of digits (e.g., Tydgat & Grainger, 2009; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010), but interestingly a different pattern is found for strings of symbols or shapes (Grainger, Bertrand, Lété, Beyersmann, & Ziegler, 2016; Hammond & Green, 1982; Mason, 1982; Tydgat & Grainger, 2009; Winskel, Perea, & Peart, 2014; Ziegler et al., 2010). Additionally, the first position advantage for letters has been shown to be particularly robust, surviving in experimental conditions that, on the contrary, had a detrimental effect on processing of the final letter (Tydgat & Grainger, 2009). Furthermore, a special status of letters in first position has been demonstrated in paradigms focusing on whole word recognition (e.g., Scaltritti & Balota, 2013), and even in sentence reading (e.g., Johnson & Eisler, 2012; Jordan, Thomas, Patching, & Scott-Brown, 2003).

According to one account of the first-letter advantage, the modified receptive field (MRF) hypothesis (Chanceaux & Grainger, 2012; Grainger, Dufau, & Ziegler, 2016; Grainger, Tydgat, & Isselé, 2010; Tydgat & Grainger, 2009), reading acquisition involves adaptive changes in order to optimize orthographic processing within the highly crowded context provided by printed texts. More precisely, for written languages that use an alphabetic script, learning to read involves the development of an array of gaze-centered location-specific letter detectors (Grainger & van Heuven, 2003), and that the receptive fields of these location-specific letter detectors become progressively more finely tuned as reading expertise develops. This adaptive tuning is hypothesized to involve both a change in size and a change in shape of the receptive fields of location-

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specific letter detectors. The size and shape of receptive fields determines the precise region of the visual field for which changes in visual information cause changes in letter detector activity. Smaller receptive fields result in reduced visual interference from flanking letters, and therefore more efficient orthographic processing. Importantly, it is also hypothesized that the shape of receptive fields of letter detectors receiving information from the left visual field is modified, with a leftward elongation (for languages read from left-to-right) which, for a constant size, leads to a reduction in their rightward extent, thus reducing the interference exerted from rightward flanking letters. This provides a mechanism for prioritization of the processing of the leftmost letter in a word, that is, the initial letter, deemed crucial for word identification (Clark & O'Regan, 1999; Stevens & Grainger, 2003), and for orthography-to-phonology conversion (Perry, Ziegler, & Zorzi, 2007). The hypothesized change in shape of letter detectors in the left visual field led to the prediction that letter identification should be hampered more by leftward flankers than rightward flankers when target and flankers are presented in the left visual field, and that no such asymmetry should be seen for letters in the right visual field nor for symbol or shape stimuli in either visual field. Evidence that this is indeed the case has been provided in three studies that manipulated visual field and either the number (Chanceaux, Mathôt, & Grainger, 2013; Grainger et al., 2010) or the visual complexity (Chanceaux, Mathôt, & Grainger, 2014) of flanking stimuli located to the left or to the right of target stimuli.

However, two recent studies have challenged the MRF hypothesis (Aschenbrenner, Balota, Weigand, Scaltritti, & Besner, 2017; Castet, Descamps, Denis-Noël, & Colé, 2017). In the Aschenbrenner et al. study, words were presented (33 or 50 ms) between visual masks. Two alternative responses were then displayed, one corresponding to the target word and the other representing a distracter, for a recognition test. Crucially, the target and the distracter word differed by only a single letter, and the position of the mismatching character was manipulated (see Adelman, Marquis, & Sabatos-DeVito, 2010). The authors found that participants were faster and more accurate when the mismatching character for the distracter occurred in the first position. Importantly, this same first position advantage was found even when target words where displayed in a vertical orientation. This latter finding challenges the MRF hypothesis. As noted above, according to the MRF account, location-specific letter detectors are horizontally aligned, and capture letter identity at a given location with respect to fixation (Grainger & van Heuven, 2003). Only the receptive fields receiving input from left visual field, moreover, would feature the leftward elongation (Chanceaux et al., 2013, 2014; Grainger et al., 2010). It is thus not clear how a first position advantage should arise for words displayed vertically. Aschenbrenner and colleagues thus proposed an attentional account, where spatial attention is automatically shifted towards the first letter upon stimulus presentation independently of stimulus orientation, thus prompting a more efficient processing of the initial letter in both conditions. However, the use of word stimuli in the Aschenbrenner et al. study may have resulted in attention being drawn to the beginning of stimuli independently of their orientation. As a more stringent test of the MRF hypothesis, it is important to examine whether the same pattern would be observed with random consonant strings. This was the main aim of the present study.

The present experiment also provides a test of another explanation for differences in the processing of letter and symbol strings proposed by Castet et al. (2017). These authors found that such differences disappeared in conditions similar to those of the Tydgat and Grainger (2009) study when visual complexity was controlled for, and especially when using a pre-cued as opposed to a post-cued partial-report procedure.[1] Castet et al. therefore suggested that prior observations of differences between letters and symbols might be due to mechanisms involved in post-cued partial report, and more specifically, due to more efficient short-term memory storage for letter stimuli compared with symbols. A simpler explanation for the Castet et al. (2017) findings, however, would be that pre-cueing enables attention to be focused at the cued location, thus reducing effects of the surrounding context (for example, the classic word superiority effect disappears with a pre-cue procedure – e.g., Johnston & McClelland, 1974). Crucial, with respect to the present experiment, is that any potential effects due to short-term memory should not be influenced by stimulus orientation.

In the present experiment, we therefore tested target-in-string identification accuracy with a post-cued partial report procedure as used by Tydgat and Grainger (2009) among others, and with strings of five consonants or five symbols. Strings could be presented either horizontally or vertically, and in both cases centered on fixation. The MRF hypothesis predicts a first position advantage exclusively for horizontally displayed strings of letters. The attentional account (Aschenbrenner et al., 2017) predicts a first position advantage for both horizontal and vertical orientations, but whether the first position advantage for vertical displays selectively arises only for letter stimuli is an empirical question. The crucial comparison with symbols will shed light on the extent to which any observed first-position effects are related to orthographic processing, or are the result of generic processing mechanisms such as visual interference or memory scanning.

2. Method

2.1. Participants

Thirty-two participants (21 females; $M_{age} = 22.63$; $SD_{age} = 3.67$) took part in the experiment. Two participants performed at chance-level, and were thus replaced. Participants provided written informed consent before participating, and they were compensated with 5€.

2.2. Materials and design

Stimuli consisted of arrays of 5 characters. Two types of characters were used: consonant letters presented in uppercase (R, N, D, M, B, K, G, H, S), and symbols (%, /, ?, @, }, µ, £, §, and <). For each stimulus type, 180 different arrays of 5 characters were created. Each one consisted of a quasi-random sequence of characters, with each of the target characters being presented 4 times at each of the five target positions and 80 times at a non-target position. The arrays never contained a repeated character.

There were 3 experimental factors, all manipulated within participants. These were a) target type (letters vs. symbols), b) target position (positions 1 to 5), and c) orientation of the array (horizontal vs. vertical). Following Aschenbrenner et al. (2017) we used "marquee" style (i.e., stimuli remain upright) for the vertical presentation condition (see Fig. 1). For each stimulus type, the main set of 180 arrays was divided into two subsets of 90 arrays each. One set appeared in vertical orientation, the other in horizontal orientation. The presentation of the two sets in vertical and horizontal orientation was counterbalanced across participants.

2.3. Apparatus and procedure

The experiment and data acquisition were controlled by E-Prime 2 software. Participants were seated in front of a computer screen at a distance of approximately 60 cm. Stimuli were displayed in black on a light gray background in 21-point Courier New font. For both vertical and horizontal displays, the center-to-center distance between adjacent characters subtended a visual angle of approximately 0.6°.

Participants read the instructions and went through a practice phase of 20 trials. Each trial began with a fixation cross which remained on the screen for 506 ms, followed by a blank screen 506 ms. Target strings

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[1] The only, albeit limited, evidence for a first-letter advantage in the Castet et al. (2017) study can be seen in the post-cued and standard spacing condition of their Experiment 1, where the size of the effect might have been limited by a number of participants performing at ceiling.

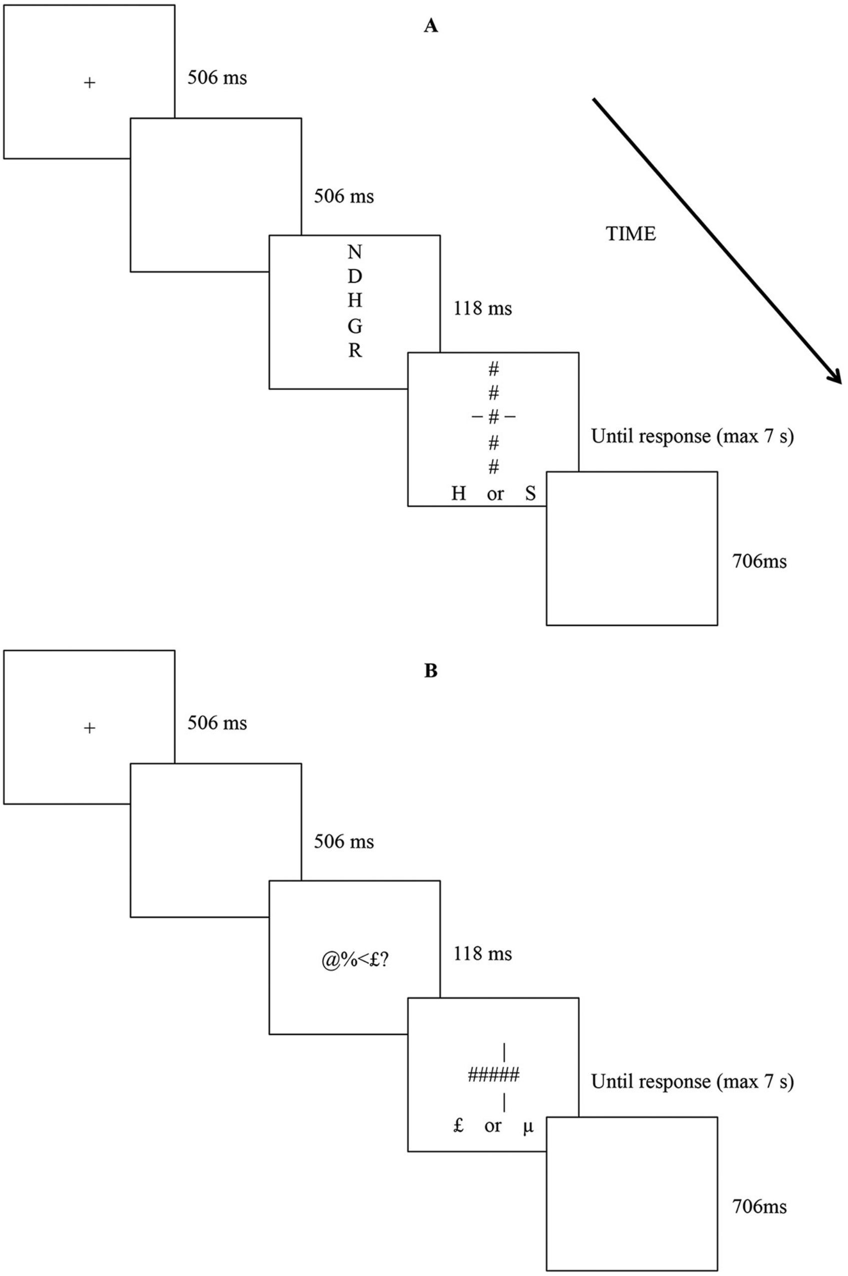

Fig. 1. Representation of the experimental procedure. Panel A represents a trial in which the target string was made of letters in vertical orientation, and the participant was required to report the identity of the third letter from the top. Panel B represents a trial in which the target string was made of symbols in horizontal orientation, and the participant was required to report the identity of the fourth letter from the left.

were then displayed for 118 ms, and immediately masked by a string of 5 hash marks (vertically or horizontally arranged according to target orientation). The backward mask was accompanied by visual cues, signaling the position of the target character to be reported. For vertical arrays, target position was signaled by two hyphen marks (—), one appearing to the left of the target position, the other to right, immediately flanking the corresponding hash mark. The same was true for arrays presented horizontally, except that the cues were vertical bars (|). Two characters were presented as response alternatives below the backward mask, one to the left and one to the right of the screen vertical midline. For each character at each position, the correct alternative appeared once as the left response, and once as the right response. The position of the correct alternative for each string was counterbalanced across participants. Participants were instructed to choose which one of the alternative responses was the character actually presented in the array at the cued position, by pressing the corresponding left or right arrow on the computer keyboard. After the response, the screen was cleared for 706 ms, and then the next trial started. Accuracy, but not speed, was emphasized. All conditions appeared randomly intermixed across trials. Participants could take a short break at intervals of 90 trials. The experiment lasted approximately 35 min. The procedure is schematically represented in Fig. 1.

3. Results

The proportion of accurate responses as a function of conditions are displayed in Fig. 2.

Accuracy was analyzed using generalized linear mixed effects models in R (R Core Team, 2015) using the lme4 package version 1.1-13 (Bates, Maechler, Bolker, & Walker, 2015). In the analyses we also used the car version 2.15 (Fox & Weisberg, 2011), ggplot2 (Wickham, 2009), and multicomp version 1.4-6 (Hothorn, Bretz, & Westfall, 2008) packages. The model considered the fixed effects of Stimulus Type (letters vs. symbols), Orientation (horizontal vs. vertical), and Position (1–5), the resulting two- and three-way interactions, and random effects for participants and items. We included by-participants random slopes

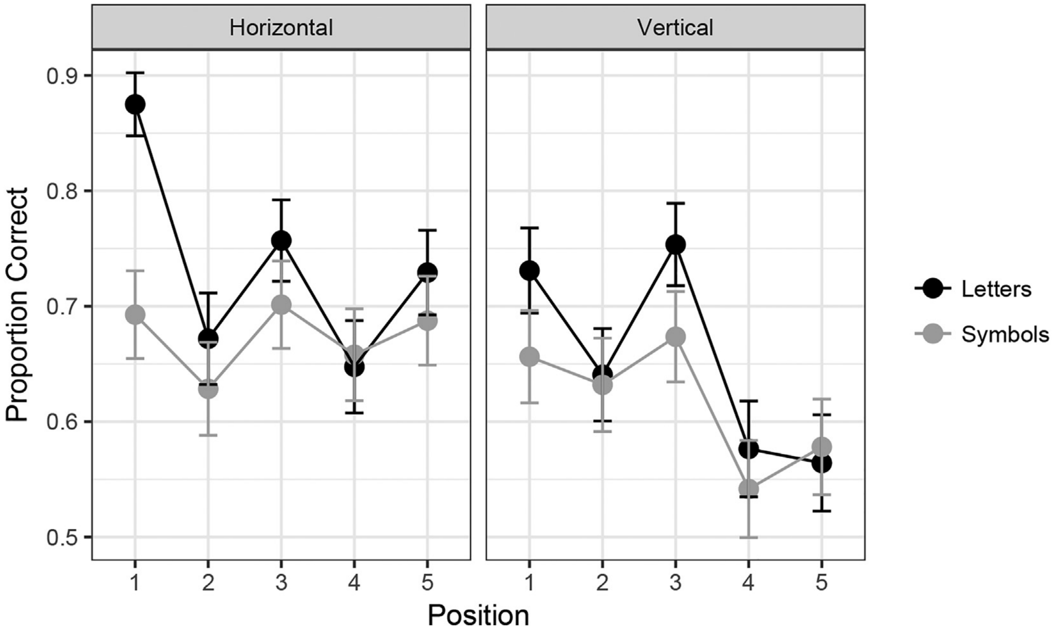

Fig. 2. Mean proportion of correct responses (y axis) as a function of Orientation (left panel = horizontal; right panel = vertical), Stimulus Type (black lines = letters; gray lines = symbols), and position (x axes). Error bars represents 95% confidence intervals (adjusted for within-participants variables following Morey, 2008).

for the main effects of Stimulus Type and Position.[2] The significance of each fixed term was established by using a chi-square deviance test between a full model including all the fixed effects (and their interactions) against simpler models which excluded the fixed effect under examination. Models comparison is summarized in Table 1. Importantly, the three-way interaction significantly improves goodness-of-fit.

We ran separate models for horizontal and vertical orientations, considering the fixed effects of Stimulus Type, Position, and their interaction, together with random intercepts for participants and items and by-participants random slopes for the simple effects of Stimulus Type and Position. The two-way interaction between Stimulus Type and Position was significant for horizontally displayed strings (χ^2 [4] = 31.18, p < 0.001), and approached conventional significance for vertically displayed strings (χ^2 [4] = 8.86, p = 0.06).[3]

Pairwise comparisons conducted on the estimates from the main model including all the three factors and interactions (with false discovery rate correction) indicated that, for both horizontal and vertical orientations, accuracy was higher for letters in first position compared to symbols in the same position (Horizontal: $b = 1.25$, $SE = 0.18$, $z = 6.93$, $p < 0.001$; Vertical: $b = 0.41$, $SE = 0.16$, $z = 2.60$, $p = 0.01$). This difference was significantly stronger in horizontal orientation ($b = 0.84$, $SE = 0.21$, $z = 4.03$, $p < 0.001$). Further, for both orientations accuracy was better for letters in first position, compared to letters in second position (Horizontal: $b = 1.39$, $SE = 0.20$, $z = 6.94$, $p < 0.001$; Vertical: $b = 0.51$, $SE = 0.18$, $z = 2.84$, $p = 0.005$). The difference was again significantly stronger in horizontal orientation ($b = 0.88$, $SE = 0.21$, $z = 4.28$, $p < 0.001$).

Table 1
Results of the chi-square deviance tests performed for the purpose of models comparison.

Fixed term	Chi-square	DF	p
Stimulus type	48.00	1	< 0.001
Orientation	39.84	1	< 0.001
Position	66.74	4	< 0.001
Stimulus type × orientation	16.24	1	< 0.001
Stimulus type × position	34.16	4	< 0.001
Orientation × position	34.40	4	< 0.001
Stimulus type × orientation × position	17.23	4	0.002

Note. DF = degrees of freedom.

4. Discussion

A post-cued partial report procedure was used to investigate the influence of stimulus orientation on target-in-string identification accuracy for strings of consonants and strings of symbols. Characteristic W-shaped serial position functions were found, with overall improved accuracy at the first, last, and central locations. Most important is that the W-shape was found to be more exaggerated for letter stimuli compared with symbol stimuli, and more exaggerated with horizontal stimulus presentation than vertical presentation. These influences of stimulus type and orientation were primarily driven by differences in performance at the first position in strings, where a much larger advantage was found for letter stimuli presented horizontally (see Fig. 2).

These results are in line with the predictions of the MRF hypothesis, according to which a first-position advantage should be more pronounced for letter strings than symbol strings, and particularly so with horizontally aligned strings. However, the fact that a significant difference between letters and symbols at the first position was also found with vertically oriented stimuli, suggests that attention might be preferentially attracted to the beginning of letter strings independently of their orientation (Aschenbrenner et al., 2017). Caution must nevertheless be exercised when drawing such a conclusion, since the interaction between Stimulus Type and Position only approached

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[2] Following Barr, Levy, Scheepers, and Tily (2013) we started by fitting the maximal complexity structure for random effects (with random slopes for all fixed effects and interactions, correlations between random effects, and correlations between random intercepts and random slopes), and we progressively simplified it by removing random slopes associated with the smallest amounts of variance until we were able to obtain convergence.

[3] As the key element in these analyses is the initial element in the string, following the suggestion of an anonymous reviewer, we replicated these analyses considering only the first two positions. The three-way interaction was significant (χ^2 [1] = 6.26, p = 0.01). When running separate models for the two orientations, the two-way interaction between Stimulus Type and Position (here limited to positions 1 and 2) was significant for horizontally displayed strings (χ^2 [1] = 14.79, p < 0.001), whereas for vertical ones only a trend towards conventional significance was found (χ^2 [1] = 2.70, p = 0.10). The pattern concerning positions 1 and 2 therefore reinforces the conclusions drawn on the basis of the complete pattern of results.

conventional significance under vertical presentation, and this remained the case even when only positions 1 and 2 were taken into consideration (see footnote 3). Finally, the much larger first-position advantage seen for letters compared with symbols under horizontal presentation, undermines any account of differences between letters and symbols expressed in terms of generic processing mechanisms that should be impervious to stimulus orientation.

Why then did Aschenbrenner et al. (2017) fail to find a significant influence of stimulus orientation on the first-letter advantage? In the Introduction we suggested that the reason might be that word stimuli were tested in their study, as opposed to the meaningless strings tested in the present experiment, and that words might automatically attract attention to their beginnings, independently of stimulus orientation. However, other methodological differences might be the source of the diverging results between their study and the present experiment. Aschenbrenner et al. tested stimuli of varying length, and used shorter stimulus exposures (33 and 50 ms). Moreover, the alternatives proposed for response in 2AFC were entire words (see also Adelman et al., 2010; Scaltritti & Balota, 2013). In general, this particular procedure generates serial position functions where accuracy decreases monotonically across position, and without improved accuracy for the central position that is typical of studies using partial report and random letter strings (see Fig. 2). It is possible that the nature of the response alternatives might determine allocation of attention, with attention being more evenly distributed across the stimulus when the alternatives involve the whole string rather than a single letter. Again, such attentional biases might operate independently of stimulus orientation, explaining the pattern observed by Aschenbrenner et al. (2017). Although attentional biases might be characteristic of everyday reading, in the present work we chose to examine letter-level processing in conditions that were expected to minimize such biases as well as other higher-level influences on performance. This was done in order to better isolate purely bottom-up mechanisms involved in processing strings of letters, and to examine how such processing might differ for letter strings and non-letter strings, as predicted by the MRF hypothesis.

The present results nicely complement prior findings in favor of the MRF hypothesis, where it has been shown that visual hemi-field determines the first position advantage for letter strings but not for symbols or shapes. Thus, when strings are presented completely to the left or to the right of fixation, the first-letter advantage is only found in the left visual field, whereas the serial position functions for symbol stimuli are not affected by visual field (Chanceaux & Grainger, 2012). Furthermore, in studies manipulating the presence (and number) of flanking stimuli located to the left and to the right of a target stimulus, letter targets in the left visual field are more adversely affected by leftward flankers than rightward flankers, while this is not the case for symbols or shapes, and not the case for letters in the right visual field (Chanceaux et al., 2013, 2014; Grainger et al., 2010). Most important, with respect to the results of the present study, is the finding that reduced crowding for letter stimuli compared with symbol stimuli is found for horizontally aligned targets and flankers but not for vertically aligned arrays (Vejnovic & Zdravkovic, 2015).

Another key result is the finding that the first-letter advantage is determined by the nature of the script, as demonstrated by studies with Thai readers (Winskel et al., 2014; Winskel, Ratitamkul, & Perea, 2018). Thai is a language that is written with an alphabetic script without interword spaces, and for which the initial consonant of some spoken words can be preceded by a vowel in the written form of the word, and therefore occur in second position. Winskel et al. (2014) replicated the selective first-position advantage for Roman letters compared with symbols in English native speakers, but failed to find a difference between Thai letters and symbols in native speakers of Thai, where both types of stimuli and Roman letters showed a similar linear trend (best performance at position 1 and performance decreasing thereafter). Winskel et al. (2018) tested Thai readers with legal nonwords in Thai that differed in terms of the position of the initial consonant of the spoken form of the nonword, which was either at the first position of the written form (aligned) or the second position (non-aligned). These authors found that accuracy in discriminating the target nonword from a 1-letter different nonword was highest when the difference occurred at the first position in the string in the aligned nonwords, thus replicating Aschenbrenner et al.'s (2017) findings. However, with the non-aligned nonwords, accuracy was greatest when the difference occurred at the second position – a second-letter advantage (see Ktori & Pitchford (2008) for language-specific serial position functions in a letter search task). Results such as these demonstrate that higher-order information constrains letter-level processing in post-cued partial report, in line with the well-established word superiority effect (McClelland & Rumelhart, 1981; Reicher, 1969; Wheeler, 1970) and pseudoword superiority effect (Grainger & Jacobs, 1994; Jacobs & Grainger, 2005). Similarly, low-level influences on letter-string processing can be modulated by attentional mechanisms (Grainger, Dufau, et al., 2016), thus accounting for why there was some evidence for a first-letter advantage for vertically oriented strings in the present study.

Finally, the present findings dovetail nicely with important work aiming to isolate factors that impose limits on reading speed of vertically oriented English text, including marquee text as used in the present study (Yu, Legge, Wagoner, & Chung, 2014; Yu, Park, Gerold, & Legge, 2010). Yu et al. (2010) used a trigram (3-letter nonword) identification task in which the trigram position shifted either horizontally or vertically with respect to a central fixation point, depending on stimulus orientation. They found a strong correlation between trigram identification (their visual span measure) and reading speed. The work of Yu et al. (2014) further specified that increased crowding in marquee text was the single most important factor in determining the reduced visual span seen in this condition compared with horizontal text. Increased crowding is therefore likely to be the main factor causing the drop in performance in the vertical orientation condition for both letters and symbols in the present study, and changes in crowding specific to horizontally arranged letter strings the main cause of the greater first-position advantage seen in this condition.

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Conflict of interest

None.

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