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Are all letters really processed equally and in parallel? Further evidence of a robust first letter advantage

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ABSTRACT

This present study examined accuracy and response latency of letter processing as a function of position within a horizontal array. In a series of 4 Experiments, target-strings were briefly (33 ms for Experiments 1 to 3, 83 ms for Experiment 4) displayed and both forward and backward masked. Participants then made a two alternative forced choice. The two alternative responses differed just in one element of the string, and position of mismatch was systematically manipulated. In Experiment 1, words of different lengths (from 3 to 6 letters) were presented in separate blocks. Across different lengths, there was a robust advantage in performance when the alternative response was different for the letter occurring at the first position, compared to when the difference occurred at any other position. Experiment 2 replicated this finding with the same materials used in Experiment 1, but with words of different lengths randomly intermixed within blocks. Experiment 3 provided evidence of the first position advantage with legal nonwords and strings of consonants, but did not provide any first position advantage for non-alphabetic symbols. The lack of a first position advantage for symbols was replicated in Experiment 4, where target-strings were displayed for a longer duration (83 ms). Taken together these results suggest that the first position advantage is a phenomenon that occurs specifically and selectively for letters, independent of lexical constraints. We argue that the results are consistent with models that assume a processing advantage for coding letters in the first position, and are inconsistent with the commonly held assumption in visual word recognition models that letters are equally processed in parallel independent of letter position.

1. Introduction

The computation of letter identity and localization within orthographic strings have been the focus of extensive experimental and modeling work (e.g., Adelman, 2011; Davis, 2010; Gomez, Ratcliff, & Perea, 2008; Whitney, 2001; for a review, see Grainger, 2008). Most models converge on the notion of parallel letter processing: information about the identity of all letters within a given word (or nonword) begins processing at the same time, independent of their location within the letter-array. This can be contrasted with more serial models (Whitney, 2001; see also Whitney & Cornelissen, 2008) in which there is a left-to-right processing scan, at least in left-to-right alphabetical languages.

Adelman, Marquis, and Sabatos-DeVito (2010) recently provided some intriguing evidence in favor of parallel letter-processing. In their experiment, four-letter words were briefly presented between both a forward and backward mask of hash marks (######). Participants were then presented with 2 alternatives, one corresponding to the target word and the other representing a distracter word for a forced choice recognition test. Critically, the target and the distracter differed by only one letter and the position of the mismatch between targets and distracters was manipulated across all four letter positions (e.g., *sung* and *lung* for a mismatch in the first position, *fish* and *fist* for a mismatch in fourth position). The duration of the target words' display was varied between participants, ranging from 12 to 54 ms in 6 ms increments, thus allowing one to track performance across stimulus duration. The rationale underlying this paradigm is straightforward: Serial accounts of letter processing claim that each letter takes 10 to 25 ms to be processed. If the serial account is correct, then performance should increase along a left to right trajectory as a function of the duration of the target display. In contrast, if a more parallel account is correct, there should be more of a step function, wherein all letters go above chance at a given duration. The results indicated that when the prime was displayed for 18 ms performance was at chance at all positions, whereas with a small increase of only 6 ms performance was significantly above chance for all letter positions. These data are most consistent with parallel processing in which information about all the letters in target-words become available after a given amount of time, irrespective of their location within the left-to-right horizontal sequence.

Although accuracy was significantly above chance in all positions at the 24 ms prime duration, a left-to-right decrement in accuracy was

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also observed in the Adelman et al. study. In other words, accuracy was higher when the mismatch was in first-position, and linearly decreased across the other positions, reaching its lowest level in fourth-position. Adelman et al. ascribed the horizontal decrease in accuracy to differences in the efficiency of information extraction as a function of letter-position, even though all letters are processed in parallel.

Differences in the detection of letters as a function of position within target strings have been investigated in several experimental paradigms. The most common paradigm involves participants simply reporting the identity of the probed letter instead of engaging in the forced choice of two words as in the Adelman et al. paradigm. The results from these letter detection studies typically indicate that performance is optimal at fixation and at end-letters (e.g., Merikle, Coltheart, & Lowe, 1971; Merikle, Lowe, & Coltheart, 1971; Mewhort & Campbell, 1978; Stevens & Grainger, 2003). Most notably, such a pattern holds only for stimuli made of letters (or digits). When target stimuli are made of non-alphanumeric characters (i.e., symbols such as %, /, -), the advantage for end-positions disappears, leaving higher accuracy only for the character at fixation (Mason, 1982; see also Hammond & Green, 1982; Mason & Katz, 1976).

This latter finding has been recently replicated and extended in a series of studies by Tydgat and Grainger (2009) (see also Chanceaux & Grainger, 2012; Grainger, Tydgat, & Isselé, 2010). In these studies, 5 character arrays were presented for 100 ms and both forward and backward masked. Across a variety of manipulations, Tydgat and Grainger found a consistent advantage in identifying letters and digits, but not symbols, occurring in the leftmost position of the array (first position advantage). In addition, they found that there was an advantage for the character occurring at fixation irrespective of the type of character (i.e., alphanumeric or non-alphanumeric characters). According to Tydgat and Grainger (2009), the first position advantage detected selectively for letters and digits but not for symbols suggests a mechanism optimized to process first position of letter/digit strings. Indeed there are a number of important constraints provided by the first letters. For example, letters occurring in the first position are more constraining for lexical identity compared to letters occurring in other positions (Clark & O'Regan, 1999; Grainger & Jacobs, 1993). In addition, letters in the initial position would be particularly important for mapping orthography to phonology, at least in models that posits a grapheme parser operating left-to-right (Perry, Ziegler, & Zorzi, 2007). Because of the functional utility of the first letter position, Tydgat and Grainger (2009) hypothesized that receptive fields are elongated to the left, in the direction of the leftmost position. Given the absence of any interfering character to the left of letters in first position (in left to right alphabetic reading languages), this left elongated shape of the detectors optimizes processing of the letters occurring in the initial position, readily explaining the consistent first position advantage detected across the different experiments (for further evidence and arguments, see also Chanceaux & Grainger, 2012; Grainger et al., 2010).

The primary aim of the present research is to investigate how accuracy in letter identification varies as a function of the location within the experimental paradigm used by Adelman et al. (2010). As noted, this paradigm involves a forced choice decision between two alternative words. This is somewhat different than the Tydgat and Grainger paradigm in which single letter, as opposed to word level, processing is emphasized. As such, the Adelman et al. paradigm may offer greater insight into how letters are differentially recognized in visual word recognition, i.e. where stimuli are real words and attention is directed to whole-word representations. Interestingly, Adelman et al. did not find evidence of a performance advantage of the letters presented at fixation, as obtained by the Tydgat and Grainger study, suggesting that the two paradigms are tapping different processes. Moreover, if the Tydgat and Grainger finding of an initial position advantage in letter processing extends to whole word processing then one should observe a similar pattern in the Adelman et al. whole word paradigm.

Although in Adelman et al.'s (2010) data accuracy was numerically higher in the first position (for similar results, see also Gomez et al., 2008), emphasis was placed on parallel processing across letters. Because of the importance regarding the special status of the first position within other paradigms (e.g., Merikle, Coltheart, et al., 1971; Merikle, Lowe, et al., 1971; Mewhort & Campbell, 1978; Tydgat & Grainger, 2009), we first attempt to replicate Adelman et al.'s pattern to further examine if one can provide evidence of an initial letter advantage in this paradigm. Given the constraints provided by the first letter to lexical identity, and given the hypothesis that letter-detectors are specifically adapted to capitalize on such a constraint by optimizing processing of initial letter (as hypothesized by Tydgat & Grainger, 2009), a first position advantage should be reliably detected. These data would suggest that there is a special status for word initial letter representations in lexical processing. Moreover, it is possible that there is a letter level serial processing mechanism in this paradigm, and if this were to be found then one might expect a more linear decrease in performance from left to right positions. As noted there was some tendency in the Adelman et al. data which was consistent with this possibility.

In our first study we examined words that ranged from 3 to 6 letters. We were particularly interested in whether the Adelman et al. results with only four letter words could be extended to other lengths. It is possible that one may find evidence for more parallel processing with shorter words and more serial processing with longer words. In the first experiment, length was blocked, so that individuals might tune the visual system to a particular visual angle. This is most consistent with the Adelman et al. and the Tydgat and Grainger studies in which only a single length was used. Finally, we measured both response latencies and accuracy in the present study, which extends previous studies that have most commonly focused on accuracy measures.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirty-two undergraduate students from Washington University in St. Louis participated in the experiment for course credit or compensation ($10). All were native English speakers and reported normal or corrected-to-normal vision.

2.1.2. Materials

Stimuli consisted of 3, 4, 5, and 6 letter words. For each letter-position within each length, 20 pairs of words were selected. Within each pair of words, the two words differed by only one letter at a given position (see Table 1, for examples of the pairs selected). This resulted in the selection of 360 pairs of words (20 pairs per position at each length). Due to an error in initial coding of the stimuli, the final materials resulted in 21 pairs for the third position in four- and five-letter words, 21 pairs for the fourth position in five-letter strings, 19 pairs for the first position of four-letter string, 19 for the second position of five-letter string and 19 for the fifth position of six-letter string. For all other positions within different lengths there were 20 pairs of words.

The two alternatives of the pairs were split into two different lists, for balancing and counterbalancing purposes, with one item serving as the target and the other item serving as the distracter for a given participant. For each length, within each position the lists were not statistically

Table 1
Examples of stimuli used in Experiments 1 and 2.

Position	Three-letter words	Four-letter words	Five-letter words	Six-letter words
1	hug–rug	zero–hero	cheat–wheat	wizard–lizard
2	toe–tie	ruin–rain	along–among	poison–prison
3	bug–bus	deny defy	coach–couch	riding–rising
4	–	fist–fish	floor–flour	strong–string
5	–	–	chair–chain	breach–breath
6	–	–	–	threat–thread