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Investigating letter recognition in the brain by varying typeface: An event-related potential study

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ABSTRACT

We aimed to investigate the contributions of visual letter form and abstract letter identity to the time course of letter recognition, by manipulating the typeface (i.e. font) in which letters were presented. Twenty-six adult participants completed a modified one-back task, where letters where presented in easy-to-read typefaces (“fluent” letter stimuli) or difficult-to-read typefaces (“disfluent” letter stimuli). Task instructions necessitated that participant’s focus on letter identity not visual letter form. Electroencephalography was collected and event-related potentials (ERPs) were calculated relative to letter stimuli. It was found that typeface affected both early-mid (N1 amplitude and P2–N2 amplitude and latency) and late processing (450–600 ms), thereby including time points whereby it is theorised that abstract identity is extracted from visual letter form (that is, 300 ms post-stimulus). Visual features of the letter therefore affect its processing well beyond the currently theorised point at which abstract information is extracted; which could be explained by a feedback loop between abstract letter representations and lower-level visual form processing units, which is not included in current cognitive reading models.

1. Introduction

Reading words, by recognising groupings of letter forms as words with meaning, is an extremely complex task. There are a number of influential cognitive models of reading, such as the Interactive Activation Model (McClelland & Rumelhart, 1981), and refinements such as the Dual Route Cascaded Model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and the Multiple Readout Model (Grainger & Jacobs, 1996). All models include a similar hierarchical system, where basic feature perception feeds forward onto a letter-identity recognition processing level. This level incorporates a stage where letter meaning is abstracted from its visual features, referred to as an abstract letter unit (Coltheart et al., 2001) or abstract letter identity (Grainger & Jacobs, 1996). These early processing stages and the concept of the abstract letter unit have gone largely untested however (Chang, Furber, & Welbourne, 2012), with the vast majority of research focusing on whole-word reading (Finkbeiner & Coltheart, 2009). Our ability to accurately identify individual letters underpins our capacity to read words, yet we know very little about how the brain recognises letters.

Letter recognition involves a highly constrained visual pattern recognition system: constructing and identifying an abstract concept of a letter from basic visual features (Grainger, Rey, & Dufau, 2008). There appear to be abstract letter specific representations within the brain, predominantly within the left occipito-temporal cortex (Dehaene et al., 2004; Grainger et al., 2008). After a letter is presented, low-level visual feature processing is seen within the first 100 ms (ms) post-stimulus (i.e. the letter) which is unrelated to letter meaning (Madec, Rey, Dufau, Klein, & Grainger, 2012). High-level visual representations are activated around 120–180 ms post-stimulus, and this is the likely time where visual features are mapped on to letter representations (Carreiras, Perea, Gil-López, Abu Mallouh, & Salillas, 2013; Cornelissen, Tarkiainen, Helenius, & Salmelin, 2003; Madec et al., 2012; Petit, Midgley, Holcomb, & Grainger, 2006; Rey, Dufau, Massol, & Grainger, 2009; Wong, Gauthier, Woroch, Debuse, & Curran, 2005). This stage appears to be case-specific (i.e. upper or lower case), but insensitive to variation in type size (Carreiras et al., 2013; Petit et al., 2006). Processing stages around 220–300 ms appear to be more abstract and case-independent (Petit et al., 2006). This time window includes recurrent processing within occipital regions

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which contributes to the conscious identification of the letter by amplifying or sustaining activity (Madec et al., 2012). Activity after 300 ms post-stimulus has been reported to be task/response related (Madec et al., 2012) and therefore unrelated to visual letter form. However, findings from a recent priming experiment have suggested that the P3 component which peaks after 300 ms is modulated, to a small degree, by the visual similarity of letters (i.e. prime and target similarity) (Carreiras et al., 2013). Notably, although letter recognition is lateralised to the left hemisphere, there is evidence to suggest that the processing of letter visual form (typeface) is lateralised to the right hemisphere (Barton et al., 2010).

An interesting manipulation to test our current understanding of letter recognition in the brain is to manipulate the typeface in which letters are presented (the font, e.g. Arial, Freestyle Script, or Comic Sans), which would enable processing of visual letter form and letter meaning to be teased apart. According to the research above, typeface should not affect activity 300 ms post letter stimulus. There only appears one study manipulating typeface (of roman letters) in a letter recognition task (Wamain, Tallet, Zanone, & Longcamp, 2012). They reported that typeface influenced processing of letter stimuli around 100 ms and 500–600 ms but not at the N1/170 ERP component (Wamain et al., 2012). However, the task instructions had participants direct their attention to the typeface of the letters which would have shifted attention toward visual letter form not abstract letter meaning.

In a whole word study, Chauncey, Holcomb, and Grainger (2008) assessed masked repetition priming of whole words (i.e. rather than single letters) by varying typeface (Arial and Gigi fonts) and size. They found that typeface (but not size) affected the posterior N150, but not later components. The authors suggested that the N/P150 component reflected feature-level processing of word information; the timing corresponding with investigations of letter recognition, where visual features are mapped on to letter representations around 120 ms (Madec et al., 2012; Petit et al., 2006; Rey et al., 2009). However, it is unclear how applicable this finding is to single letter recognition.

Behavioural studies have demonstrated that typeface influences the feature detection of letters (Pelli et al., 2009; Sanocki, 1988) and effects perceptual speed, memory, perceived effort, attitude and the detection of deception from linguistic information (Bar & Neta, 2006; Diemand-Yauman, Oppenheimer, & Vaughan, 2011; Dreisbach & Fischer, 2011; Gauthier, Wong, Hayward, & Cheung, 2006; Jolicoeur, Snow, & Murry, 1987; Song & Schwarz, 2008a, 2008b). For example, Diemand-Yauman et al. (2011) reported that memory was better for descriptions of fictional alien species when they were presented in a disfluent (e.g. hard-to-read *italicised Bodoni*) as compared to a fluent (e.g. easy-to-read Arial) typeface.

We aimed to investigate letter recognition processes within the brain by varying the typeface in which letters were presented. By doing so, we sought to disentangle the processing of visual letter features and abstract letter meaning. There is no cognitive model which explicitly details how the same letter is recognised as the same letter if presented in a different typeface (Finkbeiner & Coltheart, 2009; Grainger et al., 2008). However, we are all aware that an ‘a’ is an ‘a’, regardless of the font it is presented in. We employed a one-back paradigm and based our selection of typeface from the typographic literature, where typefaces are placed on a fluency spectrum, and harder-to-read fonts are referred to as disfluent typefaces and easy-to-read fonts are referred to as fluent typefaces. We hypothesised that typeface fluency would affect ERP componentry prior to 300 ms. Further, we predicted that activity after 300 ms (corresponding to the letter being abstracted, with information unrelated to the typeface in which it was presented) would not differ between fluent and disfluent letter stimuli.

2. Methods

2.1. Participants

There were a total of 26 right-handed participants (5 male and 21 female), with a mean age of 24.01 years (SD = 9.71; range 19–59 years). Exclusion criteria were a history of psychological and psychiatric disorders (including those associated with language such as Specific Language Impairment and Dyslexia), unconsciousness, drug abuse, and visual disturbance not able to be corrected.

2.2. Experimental paradigm

The task was a modified one-back task in which participants were instructed to press a response button with one index finger when they saw the same letter twice in a row (i.e. a target stimulus), and another button with the other finger for non-repeats (i.e. an update stimulus). The buttons used to indicate stimuli identity were counterbalanced across participants. The target probability was 38%. Stimuli were presented for 500 ms and the inter-stimulus interval varied between 1250 and 1750 ms. The task was presented in two blocks, each lasting around 8 min ($n = 240$ stimuli per block), with a short break provided to participants between blocks. The stimulus train is illustrated in Fig. 1.

Different sets of letters were used for each trial block, one had the letters o, a, e and c, and the other f, l, t and I. These sets minimised inter-letter visual form differences (Grainger et al., 2008). There were four pseudo-randomised versions of each block, and block order was counterbalanced. Each block had half the letters presented in a fluent typeface (Arial or Times New Roman) and half in a disfluent typeface (Lucida Blackletter or Edwardian Script). The same font did not appear more than three times in a row, and target stimuli had an equal probability of being presented in a disfluent or fluent font. Letter aspect ratio (i.e. the internal ratio of each letter) was controlled over typefaces, as it is known that expert readers tune to aspect ratio but not to the other font changes (Gauthier et al., 2006). Letter aspect ratio is illustrated in Fig. 2, along with the four fonts employed in this experiment to vary typeface.

2.3. Psychophysiological recording and measures

Participants were seated in a darkened, sound attenuated room approximately 60 cm from the monitor that presented the stimuli. Electroencephalography (EEG) was recorded using a modified Quickcap (Compumedics Neuroscan, Charlotte, North Carolina, USA). Sixty-four silver/silver-chloride electrodes were arranged according to the 10–20 system (American Electroencephalographic Society, 1994). Reference was at the tip of the nose and ground at FPZ. Vertical and horizontal eye movements were recorded in bipolar channels with electrodes 1 cm above and below the left eye and from the outer canthus of each eye. Continuous EEG was recorded using a Synamps II amplifier (Compumedics Neuroscan) that sampled the analogue signal at 1000 Hz with an analogue bandpass filter between 0.1 and 100 Hz. Impedance at each electrode was reduced to below 5 KΩ at the start of the experiment. EEG data was edited using SCAN4.5 (Compumedics Neuroscan); data contaminated by excessive motor movement was removed, eye-blink artefact was removed using the ocular artefact reduction tool within SCAN4.5 and only trials involving a correct response were included in ERP averages. On average, 77% of trials were kept for ERP analysis.

Peak amplitude and latency measures were taken from the following ERP components of interest – posterior N1, occipital P2,