Effects of typeface fluency on the hypothesised processes contributing to source recollection

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Abstract

Recollection accuracy can be significantly improved by producing written materials using hard-to-read (disfluent) fonts. Research suggest that these improvements are due to disfluency activating deeper levels of processing. While this 'disfluency effect' is well established, the cognitive mechanisms responsible are not yet understood. The present study involved 30 adults (71% female, mean age = 21.05, *SD* = 3.17), and examined the disfluency effect using EEG techniques to investigate familiarity and recollection; the two processes believed to be responsible for memory retrieval. The current study found no significant disfluency effects on the neurological correlates of familiarity (early frontal negative compenent; FN400) or recollection (late positive component; LPC) during the recall phase of a source memory task for information learned in fluent vs. disfluent typefaces. These findings bring into question whether familiarity and recollection provide an appropriate theoretical basis for the investigation of fluency and recollection. Furthermore, the current study also questions the correspondence between these two processes and specific ERP components may not be as straightforward as is generally believed. Therefore, it is suggested that future studies will be benefited by close monitoring of the theoretical assumptions which guide research.

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and, to the best of my knowledge, this thesis contains no material previously published except where due reference is made. I give permission for the digital version of this thesis to be made available on the web, via the University of Adelaide's digital thesis repository, the Library Search and through web search engines, unless permission has been granted by the School to restrict access for a period of time.

Signature: …………………..   Date: 16/11/2019

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1 Introduction

It has been established that the recollection of written information can be improved by using harder-to-read (disfluent) typefaces (Diemand-Yauman, Oppenheimer, & Vaughan, 2011). There are several different explanations for the disfluency effect on memory, each of which assumes that the feeling of difficulty evoked by the disfluent typeface functions as a metacognitive cue to change the cognitive processes involved. These changes may be an increase in analytic reasoning (Alter, Oppenheimer, Epley, & Eyre, 2007), a switch from ‘automatic’ to ‘conscious’ thought processes (Bottom, Gilovich, Griffin, & Kahneman, 2004) or an activation of ‘deeper levels of processing’ (Hertzog, Dunlosky, Robinson, & Kidder, 2003). Regardless of which of these explanations is correct, the robustness of the fluency effect on recollection raises the question as to which processes in the brain are being affected. The predominant model of recognition memory proposes that there are two processes at work: Familiarity and recollection. Electrophysiological studies of the brain have identified correlates for each of these processes, with successful recollection attempts showing stronger activation in frontal and left-parietal regions. While the brain activity associated with recollection is generally agreed upon, the effects of manipulating fluency on recollection processes are mostly unknown. The current study aims to address this by investigating the effect of typeface fluency on the neurological processes responsible for memory recall.

1.1 Fluency

Fluency refers to the feeling-of-ease experienced while performing a cognitive operation. Typically, cognitive tasks requiring more or less effort will have a corresponding feeling of disfluency or fluency, respectively. Popular models of fluency maintain that the amount of effort required to complete a cognitive task is determined by the difficulty of the cognitive content and the perceptual difficulty of the task (Wang, Li, Gao, & Guo, 2018).

1.1.1 Manipulating fluency. Every cognitive process that is available for conscious reflection can be described on a scale of difficulty and will have a corresponding level of fluency (Alter & Oppenheimer, 2009). Given the breadth of possible cognitive experiences, there are many ways in which fluency can be manipulated. In the case of written materials, the use of linguistic techniques such as rhyme or highly conventional grammatical structures has been shown to increase fluency (Lowrey, 1998). The fluency of written materials may also be manipulated by changing the perceptual qualities of the experience. Hansen et al. (2008) decreased the perceptual fluency in a visual discrimination task by reducing the contrast of the materials. Grey circles were presented against high or low contrast backgrounds, and it was found, perhaps unsurprisingly, that dark grey circles against a light background and light grey circles against a dark background were more easily perceived than grey circles against similar coloured backgrounds.

1.1.2 Metacognitive effects of fluency. Manipulating fluency has been demonstrated to affect a wide range of metacognitive judgements concerning the cognitive task in question. Reber et al.(1999) asked participants to judge the truth of statements presented in high and low fluency conditions. Statements were printed on cards against a white background in either high or low contrast colours. Participants were shown each card and asked to judge the truth of each statement. While statements in the low-contrast condition were judged at chance levels, those in the high-contrast condition were judged at levels significantly above chance, suggesting that fluency affects judgements of truth. Increased fluency has also been demonstrated to increase judgements of monetary value (Alter & Oppenheimer, 2007), judgements of liking (Reber & Schwarz, 1999) and judgements of familiarity (Whittlesea, 1993).

1.1.3 Why fluency effects metacognitive judgements. Given the variety of effects which may result from manipulations of fluency, researchers have sought an explanation as to why individuals interpret fluency differently in different situations. It is believed that individuals apply naïve theories in an attempt to explain the degree of fluency that they experience (Briñol, Petty, &

Tormala, 2005). For example, individuals tend to naively assume that previously seen pictures will be easier to process than new pictures, implying a belief that fluency indicates prior exposure. Naive theories are the result of learned associations between fluency and the outcomes of cognitive processes in different domains. Experiments have demonstrated that naïve theories can be subverted by offering individuals a different explanation of their experience of fluency. For example, Simmons and Nelson (2006) were able to demonstrate that individuals used fluency to guide their self-assessments of assertiveness. However, the effect was able to be mitigated by suggesting to participants that background music may be serving as a distraction, thereby replacing their initial naïve theory with an alternative theory unrelated to assertiveness.

1.1.4 Fluency and memory recall. Further research has explored the relationship between disfluency and memory recall. When disfluency is experienced during a learning event, participants are less confident that a future attempt at recalling the information will be successful (Alter et al., 2007). Despite this reduction in confidence, disfluency during learning *increases* the accuracy of later recollection attempts (Hirshman & Mulligan, 1991; Mulligan, 1996; Rhodes & Castel, 2008), referred to as the disfluency effect. The disfluency effect was examined by Diemand-Yauman, Oppenheimer and Vaughan (2011) in their Alien Task experiment where participants were instructed to memorise lists of physical features applying to several fictional alien species. These lists were presented in either an easy-to-read (fluent) or difficult-to-read (disfluent) typeface. After a 15-minute distraction task, participants were presented with each physical attribute, one at a time, and asked to identify the corresponding alien species. Accuracies for each condition were calculated. Participants in the fluent condition were able to correctly recall the required information for 72.8% of the questions, whereas participants in the disfluent condition were able to correctly recall the required information 86.5% of the time. The difference was statistically significant and demonstrated that the disfluency effect improved recall accuracy by 13.7%.

1.2 Memory Processes

Further investigation of the fluency effect requires a closer look at the cognitive processes responsible for memory retrieval. Though there is some contention as to the best model to account for memory retrieval, there is increasing empirical evidence and scholarly support for the dual-process model (For summary see: Slotnick, 2013; Yonelinas, 2002). The dual-process model of memory proposes that there are two main cognitive processes, familiarity and recollection, which contribute to memory retrieval (Mandler, 2008; Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010). Familiarity is thought to be a fast and automatic process which measures the strength of memory and allows a judgement to be made as to whether or not a stimulus has been previously encountered. As familiarity is a quantitative measurement of memory strength, it does not involve the recollection of any qualitative information (Migo, Mayes, & Montaldi, 2012). For example, when listening to the start of a song, feelings of familiarity may occur in the absence of any recollection of the artist, the song name, or the lyrics. Recollection is a slower, more effortful process which involves the retrieval and re-experiencing of a qualitative memory in order to retrieve its contents. Recollection is the retrieval of any qualitative information concerning a previous event, and as such, it involves the conscious re-experiencing of some aspect of memory (Nalbantian, Matthews, & McClelland, 2012). The difference between familiarity and recollection is clearly illustrated when considering the everyday experience of seeing a familiar face but being unable to recall a name or information about who the person is. In this situation, we are experiencing a sense of familiarity in the absence of recollection.

1.2.1 Classes of memorised information. The categorisation of memory content as *item* information or *source* information is characteristic of modern memory research. Generally speaking, item information forms the specific, central object of information in memory (e.g. a word, number, picture or sound). In contrast, *source information* is the contextual information surrounding an item of memory. Source information may relate to the time and place where a memory was formed, whether the information was relayed through text or speech, or any other situational factor present during the initial encoding event (Johnson, Hashtroudi, & Lindsay, 1993). While the recollection of item information is the central process of memory, source information often provides the extra information that enables a memory to be usable in the context of daily life. Diemand-Yauman's Alien Task (2011) mentioned earlier involved presenting participants with the central *item* of memory (the alien attribute) and asking them to recall the *source* of information (the particular list). As such, the Alien Task is a test of source memory. The importance of source information is demonstrated when considering situations in which it is absent. For example, when we can remember someone's face but have no recollection of their name or where they had been encountered previously, we experience an uneasy feeling and will often dedicate great mental effort in trying to 'dig up' source information relating to that person. Source information also allows us to judge the reliability of item information (Johnson et al., 1993); e.g. recalling that information has been sourced from a peer-reviewed journal, as opposed to an internet forum, allows us to judge it as credible. The usefulness of item information may also be contingent on recalling relevant source information (Johnson et al., 1993); e.g. correctly remembering a phone number is useless if the identity of the person associated with it has been forgotten.

1.2.2 Relationship between source memory and familiarity/recollection. The retrieval of source information has been defined as a property and feature of recollection processes (Rugg, Schloerscheidt, & Mark, 1998; Yonelinas, 2002). Source information is a part of the qualitative information that may be retrieved from memory, and as such, it is necessarily reliant on the recollection process (Cansino, Hernández-Ramos, & Trejo-Morales, 2012; Curran, 2000; Mollison & Curran, 2012; Rugg & Curran, 2007). The near equivalence of source recognition and recollection has been noted as being so "almost by definition" (Mollison & Curran, 2012, p.2547). Correspondingly, familiarity processes have been closely associated with item recognition (Curran & Hancock, 2007; Hockley & Consoli, 1999).

The association between these memory processes and the classes of information that they are responsible for retrieving has been supported by behavioural evidence. Furthermore, behavioural studies testing both item and source memory under tightly controlled timing conditions provide evidence for the independence of familiarity and recollection processes. Hintzman and Caulton (1997) had participants undertake a series of learn/test blocks in which the learning phases of each block were identical: Participants were presented with 30 different words, one at a time, in either a visual (on a computer screen) or auditory (through headphones) mode. Two different test phases assessed item memory or source memory. In both test types, the time windows available for responses ranged from 100ms to 2000ms. The item memory test presented a mix of old (previously experienced) and new (not previously experienced) words and asked participants to identify them as either old or new. The source memory test presented participants with old items and asked them to identify whether they were learned visually or auditorily. During the shortest timeframe (100ms) participants performed at chance levels for both item and source memory tests as 100ms is insufficient time for memory processes to occur and so results in guessing. During the longest timeframe (2000ms) participants had ample time to make judgements of familiarity or to recall source information resulting in accurate judgements in both processes. The strength of the study was to determine the interceding times at which familiarity and recollection became adversely affected by time limitations. A comparison of average times found that the process of familiarity was substantially less than the process of recollection. This finding has been replicated reliably and demonstrates a dissociation between the two processes of familiarity and recollection (Hintzman & Caulton, 1997; Hintzman, Caulton, & Levitin, 1998; Hintzman & Curran, 1994; Reed, 1973).

Despite being dissociable, there is a variety of evidence suggesting that familiarity and recollection may both be involved in the recollection of source information. Hicks et al. (2002) used a remember/know (R/K) paradigm to examine the contribution of familiarity to source monitoring. The R/K paradigm is a testing paradigm in which participants are asked to identify old items as 'remembered' or 'known'. 'Remembering' entails the recollection of memory content, whereas 'knowing' requires only a sense of familiarity. The R/K paradigm relies on the belief that remember and know responses correspond with recollection and familiarity processes, respectively. Hicks et al. (2002) used a remember/know (R/K) paradigm to examine the contribution of familiarity to determine the source of a memory, otherwise called source monitoring.

1.2.3 Electrophysiological correlates of familiarity and recollection.

Electrophysiological studies of memory provide further evidence for the independent yet complementary roles of familiarity and recollection. While behavioural studies provide an indirect means of observing memory processes, brain imaging techniques allow us to observe the associated neurological processes directly. Electroencephalography (EEG) is a monitoring method in which an array of electrodes placed on the scalp measure minute changes in voltage resulting from electrical activity occurring within the brain. EEG is characterised by a high temporal resolution, making it useful for observing rapid processes involved in memory. However, the low spatial resolution of EEG means that the source of electrical signals can only be approximated. EEG studies of memory-related processes typically use event-related potential (ERP) studies to focus on EEG data recorded immediately following the presentation of a stimulus, during the short period in which the processes of familiarity and recollection occur.

There has been an ongoing effort in the field of neurological memory research to identify the ERP components which correspond with each component of the 2-process model. Typically, research of this type involves comparing ERPs for memory tasks which involve varying degrees of familiarity and recollection. Relying on previous behavioural research, tests of source memory involve only recollection processes (Yonelinas, 2002; Yonelinas et al., 2010), and tests of item memory involve both recollection and familiarity processes (Migo et al., 2012) The neurological effects of familiarity and recollection are then isolated by comparing ERPs recorded during item and source memory tasks. Using this approach, researchers have suggested that familiarity and recollection are correlated with independent ERP components (Curran & Hancock, 2007; Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Krumpe, Rosenstiel, & Spüler, 2019; Voss & Paller, 2009).

Familiarity has been associated with changes in mid-frontal brain activity occurring between 300-500ms after a stimulus is encountered. Curran and Hancock (2007) undertook research in which ERPs were recorded while participants observed novel and familiar faces. Differences in FN400 potentials were observed between the novel and familiar faces, regardless of whether further information could be recalled. This is referred to as the frontal old/new effect as it reliably distinguishes between old and new stimuli. Furthermore, the FN400 effect is greater in amplitude when old/new decisions are made with greater confidence (Curran, 2004; Woroch & Gonsalves, 2010).

Recollection has been associated with a late parietal ERP component (LPC) occurring between 500-800ms after stimulus onset (Curran, 2000; Woodruff, Hayama, & Rugg, 2006). The location of recollection processes in the parietal region is supported by brain imaging and human lesion studies (Davidson et al., 2008). Patients exhibiting damage to parietal brain regions as a result of a stroke were significantly impaired in their ability to recall previously memorised word pairs (Ben-Zvi, Soroker, & Levy, 2015). Furthermore, fMRI has demonstrated that activity in parietal regions during the successful recognition of a stimulus increases in proportion to the amount of related source information that can be recalled. EEG studies show that LPC potentials are greater in amplitude for successful recollection attempts as compared with unsuccessful recollection attempts (Wilding & Rugg, 1996). As confirmation of the findings of fMRI studies, the strength of the effect also varies with the amount of information that can be recalled (Mecklinger, Johansson, Parra, & Hanslmayr, 2007).

Experimental techniques using the established connection between ERP components and memory processes have been used to study a variety of factors affecting source memory. Aging has been demonstrated to affect familiarity and recollection at differing rates (Dulas, Newsome, & Duarte, 2011), resulting in source memory declining with age more rapidly than item memory. This effect was shown to be nullified when participants were instructed to use self-referential strategies to memorise stimuli.

1.2.4 The effect of disfluency on familiarity and recollection. Knowledge of the relationship between memory processes and ERP components has also been widely used in studies investigating the effect of fluency at test on the processes of familiarity and recollection (Kurilla & Westerman, 2008; Rajaram, 1993). However, only a small number of studies have used this approach to study the effect of fluency as it is applied to stimuli during the learning phase (Li, Gao, Wang, & Guo, 2015). Additionally, investigations of the effects of fluency on familiarity and recollection have been limited to a narrow class of fluency manipulations. In the majority of cases, fluency has been modified using masked repetition priming (See: Alter & Oppenheimer, 2009; Kurilla & Gonsalves, 2012; Leynes & Zish, 2012). Li, Gao, Wang & Guo used masked repetition priming to investigate the effect of manipulating the fluency of pictures on subsequent memory processes. Increasing fluency resulted in a decrease in recall accuracy, which was also reflected in significant differences in LPC potentials. In a separate study, famous and non-famous names were presented as fluent and disfluent stimuli respectively. During learning, stimuli were presented visually or auditorily, and participants' ability to recall the sensory source of the stimuli was tested. The fluency produced by the familiarity of famous names was found to increase source recollection accuracy and was confirmed by observed changes in LPC potentials. While these findings provide preliminary insights into fluency and source memory, the effects of more common fluency effects, such as typeface fluency, remain unexamined.

1.3 The Current Study

Increasing perceptual disfluency during learning tasks has been shown to increase the accuracy of subsequent source memory tests (Alter, 2013; Besken, Solmaz, Karaca, & Atılgan, 2019; Diemand-Yauman et al., 2011; Seufert, Wagner, & Westphal, 2017; Weissgerber & Reinhard, 2017; Yue, Castel, & Bjork, 2013). Though studies have provided extensive behavioural evidence for the disfluency effect, investigations into the underlying memory processes responsible have been limited. In the present study, we examined source memory for lists of fictional alien attributes. Typefaces were varied as the experimental manipulation of fluency, and behavioural and electrophysiological responses during testing were recorded. The first aim of the present study was to reproduce the findings of earlier studies demonstrating the behavioural effects of typeface fluency. The second aim was to examine the ERP components corresponding to familiarity and recollection in an attempt to reveal the cognitive mechanisms responsible for the fluency effect on source memory.

Specifically, the present study hypothesised that:

Hypothesis 1: Recall accuracy will be higher for stimuli presented in a disfluent typeface, indicating a general disfluency effect on memory.

Hypothesis 2: The amplitude of FN400 potentials will be lower for successful source memory recollections, indicating differences in familiarity processes between successful and unsuccessful source recollections.

Hypothesis 3: The amplitude of LPC potentials will be lower for successful source memory recollections, indicating the increased role of recollection during successful source recollections.

Hypothesis 4: During successful recollection attempts, the amplitude and peak latency of FN400 potentials will be lower for disfluent typefaces, indicating the increased role of familiarity due to disfluency.

Hypothesis 5: During successful recollection attempts, the amplitude and peak latency of LPC potentials will be lower for disfluent typefaces, indicating the increased role of recollection due to disfluency.

2 Method

2.1 Participants

All participants were right-handed with normal or corrected-to-normal vision and hearing. Participants identified that they had no psychiatric, neurological or intellectual disorders, no history of drug addiction or abuse, and had not been unconscious for more than one minute, excluding anaesthesia. All participants identified English as their primary language. Participants were thirty-five undergraduate students from the University of Adelaide. Twenty-one took part for course credit as part of an undergraduate psychology course, and fourteen were respondents to recruitment materials posted publicly at the University of Adelaide. Recruitment materials were posters distributed through the Hughes Building at the University of Adelaide North Terrace Campus and numerous postings to university-related Facebook groups. 71.4% of participants were female (n = 25), and ages ranged from 18 to 34, with a mean age of 21.05 (SD = 3.17).

2.2 A Priori Analysis of Statistical Power

For the current study, an a priori power analysis was undertaken to determine the minimum sample size required to achieve a power of 0.8. The expected effect size ($d = 0.615$) was derived from the previous study on which the current study is based (Diemand-Yauman et al., 2011; Lenhard & Lenhard, 2016). Two-tailed alpha was set at 0.05 in G*power software (Faul, Erdfelder, Lang, & Buchner, 2007) and a sample size of 23 was returned.

2.3 Ethical Procedure

Participants read and signed a written form giving informed consent. Participants recruited through the university's research participation system received credit towards an undergraduate psychology course. Other participants received a $40 voucher as recompense for their time. Ethics approval was granted by the Human Research Ethics Committee at the University of Adelaide.

2.4 Materials

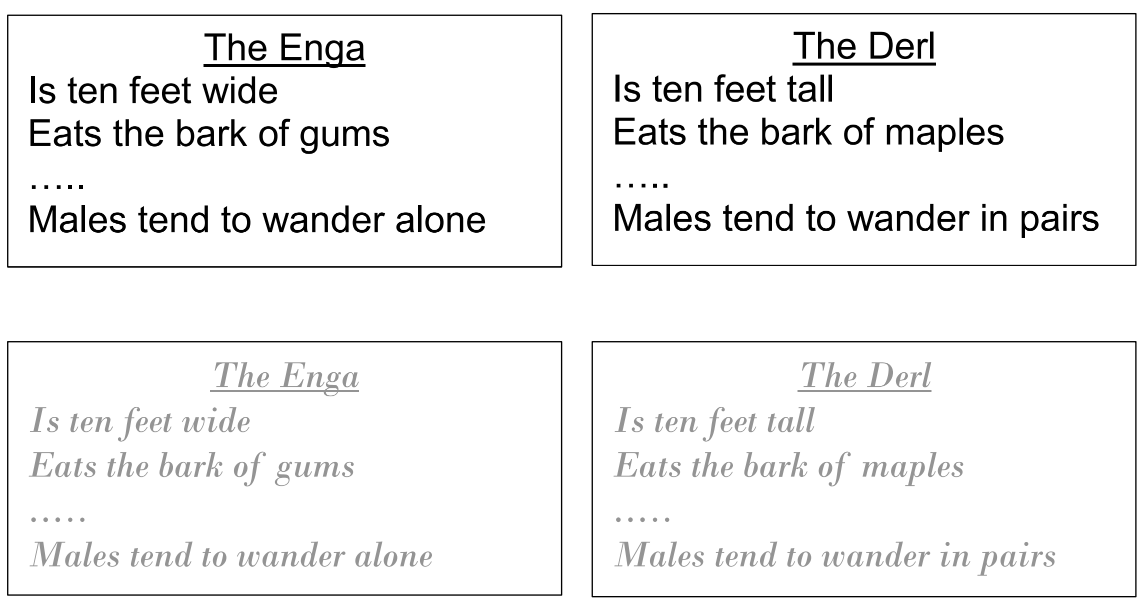
Learning stimuli were lists of attributes describing four fictional alien species (e.g. "Is five feet tall"). Descriptions of each attribute vary only by the final word of each sentence (see Figure 1). Each species had two lists of 7 attributes identical in content and varying only by typeface fluency, resulting in a total of 8 lists and 28 attributes (example species list shown in Figure 1). In the fluent condition, attributes were presented in 16pt Arial typeface. In the disfluent condition, attributes were presented in 16pt Bodoni MT 60% greyscale typeface.

Two different fifteen-minute distractor periods were used. Distractor Task 1 was the Embedded Figures Test (Witkin & Goodenough, 1971) and Distractor Task 2 was Raven's Progressive Matrices (Raven, 1996) followed by a 1-back memory test (Keage, Coussens, Kohler, Thiessen, & Churches, 2014). Though the primary purpose of these tasks was to prevent participants from using conscious memory consolidation strategies during the 15-minute delay between learning and test, the 1-back memory task was selected as it involves a manipulation of fluency similar to the main task. Participants are shown a series of single letters presented in either fluent or disfluent typefaces and asked to respond with a button-press when a letter is repeated. Accuracy levels then indicate the effects of fluency on letter perception (Keage, Coussens, Kohler, Thiessen, & Churches, 2014; Thiessen, Kohler, Churches, Coussens, & Keage, 2015).

Stimuli used during the test phase were audio recordings of the twenty-eight learned stimuli and were presented using desktop speakers.

Figure 1

Examples of fluent and disfluent stimuli presented at learning. The typefaces are Arial and Bodoni MT 60% greyscale italic.



Note. Species are differentiated only by the final word in each descriptive sentence.

2.5 Visual Delivery of Stimuli

Visual stimuli and general experimental instructions were delivered via a 19" LG Flatron LCD Monitor (LG Electronics Inc., Korea) at 1680 x 1050 pixel resolution and 60Hz refresh rate.

Participants were positioned approximately 60cm from the monitor and instructed to maintain this distance as best as possible. Chair height was adjusted as necessary to maintain a consistent eye-level between participants. Stim2 software package was used to deliver the experiment (Compumedics Neuroscan, USA).

2.6 Auditory Delivery of Stimuli

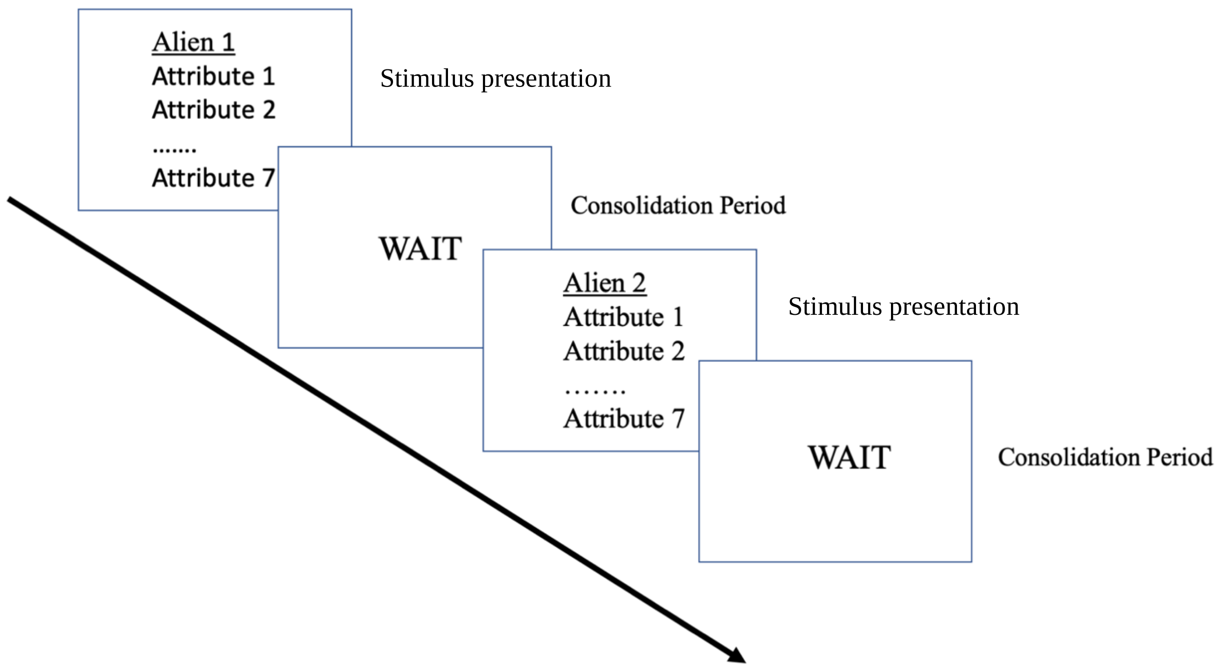
Stimuli were delivered during testing using a Compumedics StimAudio unit (Compumedics Neuroscan, USA). Analogue signals from the StimAudio unit were amplified and broadcast using a Juster SP-691 desktop speaker system (Juster Co. Ltd., Taiwan). The audio was recorded and stored in WAV format at 1411kbps data rate 44100 kHz sampling rate in stereo. Audio volume was tested and adjusted prior to data gathering and held constant for all participants.

2.7 Experimental Procedure

Participants were seated in a small test room, visually isolated from the wider lab and monitored using CCTV to ensure that instructions were being followed appropriately. The experiment began with a short audio introduction explaining the nature of the task and instructing the participants to effortfully memorise the stimuli. Participants then completed two experimental cycles consisting of one in the fluent condition and one in the disfluent condition, counterbalanced for order. Each experimental cycle consisted of a study phase, a fifteen-minute distraction period and a test phase. During the study phase, the first list was displayed for sixty seconds and removed for a thirty-second consolidation period; then the second list was displayed for sixty seconds and removed for a thirty-second consolidation period.

Figure 2

Stimulus train for the learning phase.



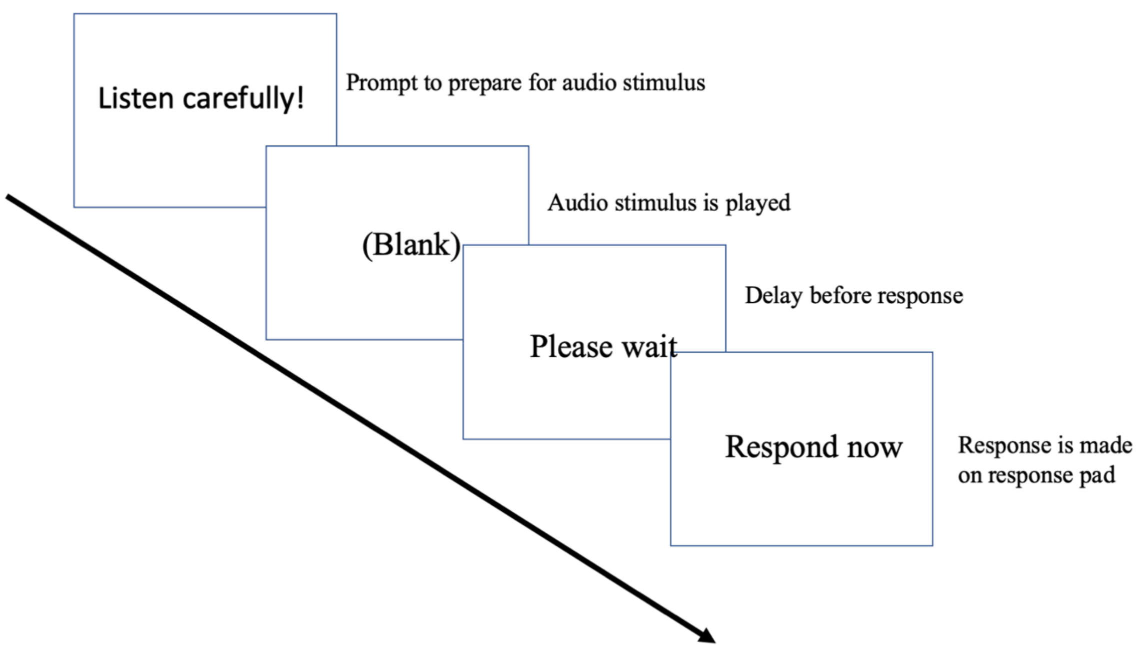
Following the learning phase, participants underwent one of the two fifteen-minute distraction tasks. Participants received each of the distraction tasks once only, and the delivery was counterbalanced for order.

During the test phase, participants heard recordings of the stimuli and, following a 2000 ms interval, were asked to identify the source of each stimulus (i.e. alien list 1 or alien list 2). A 'get ready' symbol was displayed on the monitor for 2000ms indicating to participants that the next stimulus was about to begin. After the presentation of the stimulus, a 'wait' symbol was presented for 2000ms ensuring that there was minimal EEG interference from movement during the period of interest. Immediately after, a symbol was presented prompting participants to make their selection on the response keypad.

Each of the fourteen stimuli was heard four times in a pseudo-random order. Ordering was pseudo-random in order to avoid the excessive repetition of stimuli and to avoid more than four correct responses in a row requiring the pressing of the same response button. Participants received a total of 56 test items per study/test cycle and a total of 112 test items over the entire experiment.

Figure 3

Stimulus train for test phase.



Note. Sequence repeats for each of the 112 test cycles.

2.8 Behavioural Measures

2.8.1 Behavioural recording. Behavioural data were recorded alongside EEG data using the Compumedics StimAudio unit (Compumedics Neuroscan, USA). Participants responded with a 2-button response pad which was operated using left and right index fingers. The response pad was also used as a trigger for initiating learning and test phases by the instructors. Instructions regarding the correct use of the response pad were delivered verbally during the introduction to the task. To ensure the correct use of the response pad, three dummy tests were placed at the beginning of the first test block and were observed directly by instructors. Participants unsure of the use of the response pad were given guidance at this point before proceeding with the recorded section of the test.

2.8.2 Behavioural data analysis. Paired samples t-tests were used to compare the accuracy of responses in fluent and disfluent conditions to determine whether there was a behavioural effect for the fluency manipulation.

2.9 Electrophysiological Measures

2.9.1 EEG Recording. A modified Compumedics Quik-Cap paired with a Compumedics SynAmps RT amplifier (Compumedics Neuroscan, USA) recorded the EEG data, utilising the 10/20 electrode placement scheme (Homan, 2015). In addition to the standard 64 silver/silver chloride electrode placements, electrodes placed 1cm above and below the left eye and 1cm outside the canthi of both eyes recorded electrooculograms (EOG). During setup, impedances were decreased to less than 10kΩ. Data were recorded continuously and digitised at 1000 Hz. EEG activity was monitored in real-time by instructors and instances of excessive ‘popping’ or baseline drift were addressed during breaks in the experiment by adjusting the EEG cap or by re-establishing connections to below 10kΩ.

2.9.2 ERP components. Two components were selected for analysis, based on previous studies (Dulas et al., 2011; Li et al., 2015): a negative frontal component peaking at approximately 400ms post-stimulus (FN400) and a late positive component peaking at approximately 650-700ms. The FN400 component was selected in line with previous research suggesting its correlation with familiarity processes (Leynes, Bruett, Krizan, & Veloso, 2017). Similarly, the LPC component was selected as it has been widely attributed to recollection processes (Hannula, Federmeier, & Cohen, 2006). According to similar research already undertaken (Ekstrom, Copara, Isham, Wang, & Yonelinas, 2011; Finnigan, Humphreys, Dennis, & Geffen, 2002; Guo, Duan, Li, & Paller, 2006; Wang et al., 2018; Wang, Li, Gao, Xiao, & Guo, 2015), the FN400 component was examined by looking at a mid-frontal cluster of electrode sites (F3, Fz, F5, Fc3, Fcz, Fc4) from 300-500 ms and the LPC component was examined by looking at a left-parietal cluster of electrode sites (Cp3, Cpz, Cp4, P3, Pz, P4) from 500-800 ms.

2.9.3 EEG data processing. EEG data were processed and analysed using EEGLab Toolbox (Swartz Center for Computational Neuroscience, USA), ERPLab (Lopez-Calderon & Luck, 2014), Matlab R2018B (Mathworks, USA) and SPSS v.25 (IBM Corp., USA).

EEG data from each electrode were referenced to an electrode at the midpoint between Cz and Cpz. A 1Hz high-pass filter was then applied, and channels with high kurtosis or excessive baseline drift were rejected. Independent component analyses were then performed in order to identify unwanted sources of data present across multiple electrodes, such as saccades, EOG blink artifacts or muscle activity from the face and jaw. A high-pass filter was then reapplied at 0.2Hz, and bad components were removed. Channels were then re-referenced to mastoid electrodes, and a low-pass filter was applied at 25Hz. Signals were time-locked to the presentation of the stimulus and broken into 100 ms epochs. ERP epochs were set at 1000ms, and a pre-stimulus period of 200ms was used to determine the baseline from which post-stimulus amplitudes were measured. Channels were rejected where the fast average amplitude exceeded 100 mV and were reconstructed using spherical interpolation. Stimulus onset was defined as the beginning of the distinguishing final word of each attribute. For example, for the attribute “is five feet tall”, stimulus onset Artefact detection was performed on each the epochs, and average ERPs were calculated per participant for each fluency condition and correct/incorrect response. ERPs and topological maps were produced using EEGLab toolbox and ERPLab. Grand average amplitudes and peak latencies were calculated for each of these conditions, and this numerical data were then exported for further analysis using SPSS.

2.9.4 Numerical analysis of EEG data. Using SPSS, amplitude and latency data were checked for normality using the Shapiro-Wilk test. Paired sample t-tests were performed comparing the fluent and disfluent conditions. Primary and interactive effects between fluency and electrode cluster location were tested with 2-way repeated measure ANOVAs.

3 Results

3.1 Behavioural Results

Table 1 contains the raw proportion of responses for each fluency condition. Participants achieved a very high proportion of correct responses ($M = 0.984$, $SE = 0.043$). 61% of participants correctly identified all of the stimuli, and 90% achieved an accuracy proportion above 0.95. No incorrect responses were recorded. 1.6% of trials received no response ($M = 0.016$, $SE = 0.0076$). Distributions for both fluent and disfluent conditions were platykurtic and negatively skewed (fluent condition: $\kappa = 10.07$, $\gamma_1 = -3.19$; disfluent condition: $\kappa = 8.15$, $\gamma_1 = -3.19$).

Behavioural evidence for the fluency effect was investigated by comparing mean accuracies between the fluency conditions. No significant difference was found between mean proportion of correct responses between fluent and disfluent conditions ($t(30) = 1.56$, $p = .13$).

Table 1

Mean proportion of response type for fluent and disfluent conditions (reported as percentages with standard error in parentheses).

Condition	Correct	Incorrect	No Response
Fluent	98.8 (0.6)	0 (0)	1.2 (0.6)
Disfluent	98.0 (0.9)	0 (0)	2.0 (0.9)

3.1.1 1-back distractor task results. Participants achieved an average accuracy of 90% ($M = 0.90$, $SE = 1.67$). Results were skewed ($\gamma_1 = -0.919$) suggesting a ceiling effect. Prior research suggests that experiences of perceptual disfluency may be dependent on individual differences which are stable across different contexts (Alter & Oppenheimer, 2009). E.g. An individual may consistently experience higher than average levels of perceptual disfluency across multiple contexts and tasks. To look for stable variations in individual perceptions of fluency, a comparison was made between the accuracy of responses for the 1-back task and the main experiment. The relationship was found to be non-significant ($R = .05$, $n = 31$, $p = .776$).

3.2 Electrophysiological Results

EEG channels for all participants were initially assessed for excessive voltage fluctuations caused by non-neurological sources using a continuous process of kurtosis measurement. The data for 5 participants were rejected due to high kurtosis ($\kappa > 5$).

3.2.1 The general effect of fluency on subsequent source memory accuracy. Investigations of the fluency effect typically collapse ERPs across fluency conditions and compare ERPs for correct/incorrect source judgements and frontal/parietal electrode clusters with a 2-way ANOVA (Kurilla & Gonsalves, 2012; Li et al., 2015). Due to the extremely high proportion of correct responses, it was not possible to observe a primary memory effect of fluency for ERP amplitudes and latencies across response types as planned.

3.2.2 Effect of fluency on FN400 and LPC old/new effects. ERPs to fluent and disfluent learning conditions for frontal and parietal electrode clusters are shown in Figure 4. Maps illustrating neurological activity across the scalp for fluent and disfluent stimuli during the early and late components are shown in Figure 5. We analysed ERP responses to assess whether manipulations of fluency at learning influenced old/new effects. Average amplitudes and peak latencies were calculated for frontal and parietal electrode clusters for periods corresponding with FN400 (300-500ms) and LPC (500-800ms) components.

Figure 4

Frontal and Parietal ERPs to correct responses.

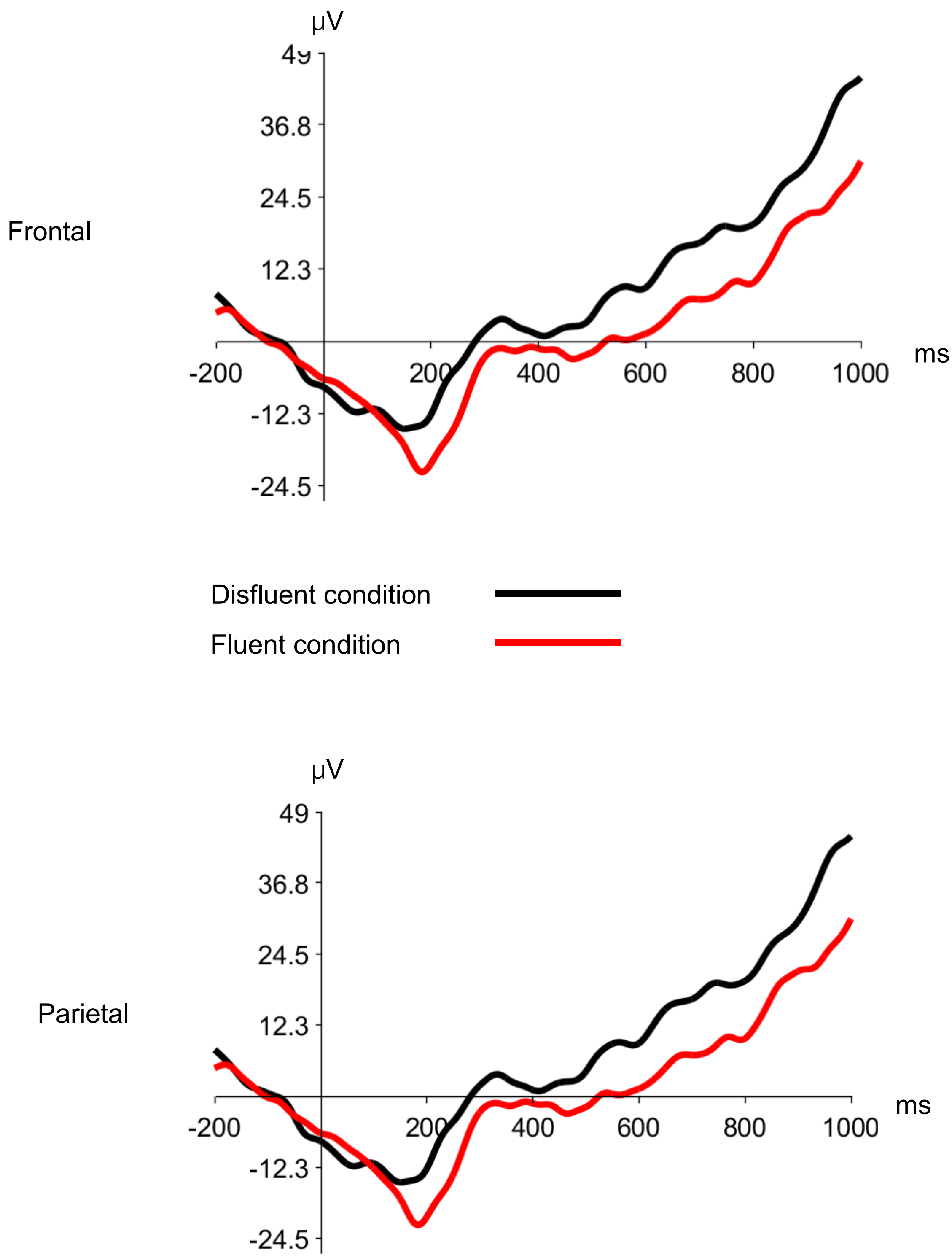
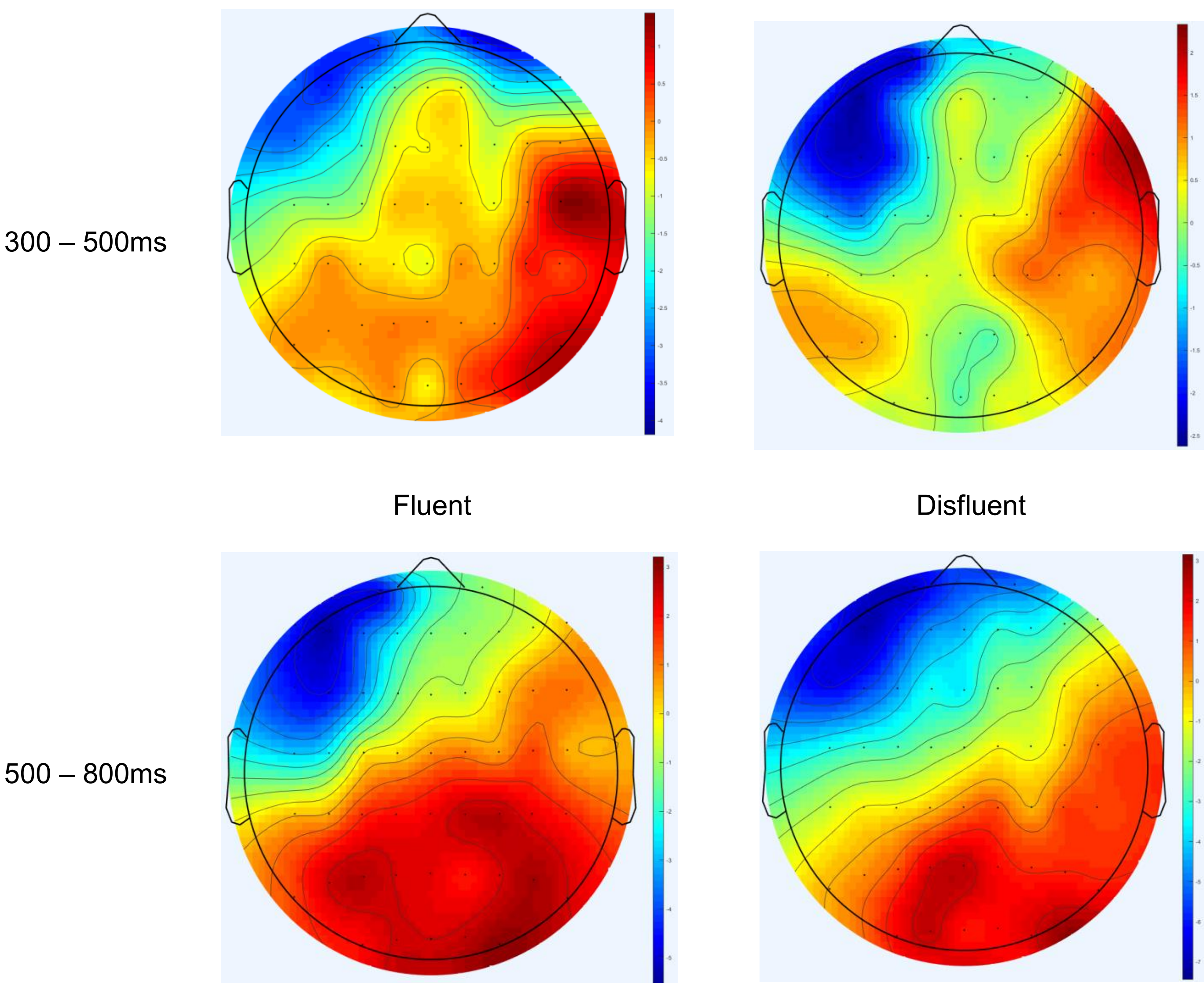


Figure 5

Topological map of grand averaged activity for fluent and disfluent stimuli during early and late components.



3.2.3 300 – 500 ms. Paired sample t-tests were performed to compare the mean amplitudes of fluent and disfluent ERPs for frontal and parietal electrode clusters. No significant difference was found for frontal ($t(29) = 0.713$, $p = .418$) or parietal ($t(29) = 0.255$, $p = .718$) clusters. A 2-way ANOVA revealed no significant main effect for fluency condition ($F(1,29) = 0.368$, $p = .548$, MSE = 2.85) or interactions between electrode clusters and fluency conditions ($F(1,29) = 0.470$, $p = .498$, $MSE = 0.661$).

Statistical analyses of peak latencies for the early component revealed no significant fluency effects. Paired sample t-tests revealed no significant difference in latency for the early component in frontal ($t(29) = 0.461$, $p = .648$) or parietal ($t(29) = 0.037$, $p = .970$) electrode clusters. 2-way ANOVA indicated non-significant relationships between fluency conditions and peak latency for the early component ($F(1,29) = 0.095$, $p = .760$, $MSE = 82.36$), and no significant interaction between electrode cluster and fluency ($F(1,29) = 0.086$, $p = .772$, $MSE = 56.38$).

3.2.4 500 - 800 ms. Equivalent tests were undertaken for ERPs measured from 500 – 800ms. No significant differences were found for frontal ($t(29) = 1.61$, $p = .118$) or parietal ($t(29)$ = 1.386, $p = .176$) electrode clusters. No significant main effects for fluency ($F(1,29) = 0.095$, $p = .759$, $MSE = 70.60$) or interactions between electrode clusters and fluency conditions ($F(1,29) = 0.086$, p = 771 $MSE = 48.32$).

No significant relationships between peak latencies were found in the late component. Differences between fluent and disfluent latencies were found to be non-significant for frontal ($t(29)$ = 1.536, $p = .135$) and parietal ($t(29) = 0.537$, $p = .595$) electrode clusters. A 2-way ANOVA revealed no primary effects for fluency ($F(1,29) = 1.169$, $p = .287$, $MSE = 6169.03$) or interactional effects for fluency and electrode cluster ($F(1,29) = 1.584$, $p = .217$, $MSE = 1214.42$).

4 Discussion

4.1 Summary of Overall Findings

The present study aimed to explore the behavioural and electrophysiological effects of manipulating typeface fluency during a source recollection task. A strong ceiling effect was encountered due to the ease of the memory task which prevented some of the planned analyses. However, there were sufficient data to investigate the ERP effects for successful recollection events. Typeface fluency was found to have a non-significant effect on the subsequent recollection of source information. Analyses of the collected ERP data were performed in line with the 2-process model of memory to identify possible effects of typeface fluency on the processes of familiarity and recollection. No significant effect of fluency on familiarity was found when comparing amplitudes and peak latencies in the corresponding period of 300 - 500 ms post-stimulus. Neither were there any interactional effects found in this period to suggest any relationship between frontal/parietal electrode clusters and fluent/disfluent typefaces.

Additionally, no significant effects of typeface fluency were discovered during the ERP correlate of recollection. Comparisons of mean amplitudes and peak latencies between fluency conditions revealed no significant effects. A 2-way ANOVA testing primary and interactional effects of frontal/parietal electrode clusters and fluent/disfluent typefaces also revealed no significant effects. Although no significant effects were found, the results of the present study suggest several theoretical and empirical limitations of the research to date.

4.2 Behavioural Limitations.

Hypotheses 1, 2, and 3 were not able to be tested as incorrect recollection attempts did not occur. As such, it was not possible to observe the disfluency effect on memory. The proportion of correct responses was expected to be above 0.5 due to the binary response choices and chance.

However, accuracies of 98.4% in combination with highly skewed data strongly suggest the presence of a ceiling effect. These findings demonstrate a limitation of the experimental design. The original experiment, as conducted by Diemand-Yaumann et al. (2011), required participants to memorise the attributes of three alien species. For the current experiment, this was reduced to two alien species as the difference in modes between learning (visual) and test (auditory) was expected to increase the difficulty of the task and reduce memory accuracy. This decision was further supported by the results of a short pilot study in which the mean accuracy observed was 81.4. Future research could address these problems by adjusting the difficulty of the memory task to ensure normally distributed results are collected for correct and incorrect source judgements.

Despite this limitation, it is still possible to use ERP data from successful attempts that were recorded to examine the neurological mechanisms which contribute to the disfluency effect. Additionally, the inclusion of previously unseen stimuli during the test phase would enable secondary analyses of old/new effects that could provide complementary evidence if any effects were found (see: Hintzman et al., 1998; Migo et al., 2006, 2012)

4.3 Discussion of Findings

Hypothesis 4 predicted that the amplitude and peak latency of the FN400 component would be lower for disfluent typefaces during successful recollection attempts. Comparisons of mean differences between fluent and disfluent ERPs during the FN400 time period revealed no significant differences in amplitude or latency. Potential explanations for the absence of an observable effect on familiarity and the FN400 component include underpowering of the study and several possible theoretical shortcomings.

4.3.1 Post-hoc power analysis. Limited statistical power may have contributed to the non-significance of the statistical findings in the current study. G*power software (Faul et al., 2007) was used to perform a posthoc power analysis of the primary analysis comparing the mean amplitudes across fluency conditions. The minimum effect size found for the comparison of mean amplitudes between the fluent and disfluent conditions for correct responses (d = -0.24) resulted in a power of 0.09. A power of .09 suggests that the number of participants may be insufficient to detect amplitude changes due to fluency. A further a priori power analysis suggests that a sample size of 138 would increase the power of the study to 0.8. However, the low power suggested by the posthoc analysis is likely caused in part by the low difficulty of the memory task; If the difficulty were increased it would be reasonable to expect a corresponding increase in effect size and statistical power.

4.3.2 Source recollection may not be supported by familiarity processes in all contexts. Fluency manipulations at learning did not affect the amplitudes or peak latencies of the neural correlate of familiarity (FN400). Despite the general agreement in the literature of the relationship between familiarity and source recollection, the absence of change may indicate that familiarity, which is associated with the FN400 component, may not always contribute to source recollection. Though there is much evidence to suggest that there are many contexts in which familiarity processes support source recollection, it has been suggested that conditions during encoding may affect the degree to which it operates (Mollison & Curran, 2012; Quamme, Frederick, Kroll, Yonelinas, & Dobbins, 2002). Montaldi and Mayes (2010) demonstrated that familiarity processes operated only when participants were instructed to effortfully associate item and source information by being encouraged to use mnemonics when memorising stimuli. In the present study, the high levels of recall accuracy observed may be an indication that little effort was required during the memorisation process at learning. Consequently, familiarity processes may not have been operating due to the ease of the task. In addition to future research involving more difficult tasks, it may be useful to study familiarity processes across different classes of source information such as modal, temporal, spatial or ordinal information in order to identify the specific function of familiarity in source recollection.

4.3.3 Familiarity may not be associated with FN400 component. The absence of observable effects may indicate that there is not a reliable correlation between familiarity and FN400 potentials. While it is widely agreed that familiarity is indexed by changes in FN400 potentials (for reviews see: Joordens & Hockley, 2000; Yonelinas, 2002; Yonelinas et al., 2010), researchers have pointed to specific conditions in which the relationship is not guaranteed. Lucas, Voss and Paller (2010) dispute the association of FN400 effects with familiarity and perceptual fluency. They argue that methodological problems with previous research have caused a confounding of perceptual fluency with conceptual fluency (Bruett & Leynes, 2015; Stenberg, Johansson, Hellman, & Rosén, 2010). If this is the case, FN400 potentials would not be influenced by perceptual manipulations such as typeface fluency, as demonstrated by the current study. Alternatively, Paller et al. (2012) criticise the methodology that has been used to connect FN400 potentials with familiarity. They point out that in much of the research, claims of the presence of familiarity are often made through reverse inference from the observation of FN400 effects. Instead, it is suggested that FN400 effects may be more accurately associated with implicit memory.

4.3.4 2-process model of memory may not be appropriate. There is extensive behavioural and neurological data which supports the 2-process model of memory. Behavioural studies indicate that recognition memory is supported by two dissociable processes which occur at two distinctly different times (Anderson, James, & Kirwan, 2016). Neurological data has also provided support for the 2-process model of memory (for summary see: Yonelinas et al., 2010).

Despite this evidence, there are competing explanations which could account for the data collected in the current study. For example, Hayes, Dunn, Joubert and Taylor (2017) examined the development of recognition memory from 6 years of age to adulthood. Using statistical modelling, they demonstrated that the changes observed throughout cognitive development could be accounted for with a single factor, suggesting that a single process is responsible for recognition memory. The 2-process model of memory has also not been successfully modelled computationally, unlike single process models which can account for a large body of behavioural data (Clark & Gronlund, 1996).

4.3.5 LPC component may not reliably index recollection processes. Hypothesis 6 predicted that ERPs for successful recollection attempts would exhibit lower amplitudes and peak latencies than unsuccessful recollection attempts. A comparison of mean amplitudes and latencies revealed non-significant effects, in contrast to Hypothesis 5. Though there is substantial evidence supporting the association of the LPC component with source recollection processes (Skinner & Fernandes, 2007; Yu, Johnson, & Rugg, 2012), the relationship has been qualified by some researchers. Addante, Ranganath, & Yonelinas (2012) performed a source recollection test while recording judgements of confidence and showed that the LPC predicted source recollection accuracy only when judgements of confidence are high. Changes to LPC potentials were not observable between unsuccessful and low-confidence, successful recollection attempts, suggesting that in some cases LPC potentials may index confidence and not recollection.

4.4 Methodological Limitations and Future Research

4.4.1 Fluency effects may be reduced or nullified across sensory modalities. There are several possible limitations of the present study beyond those already discussed. For the present study, the modality of stimuli changed between learning (visual stimuli) and test (auditory stimuli). Empirical evidence suggests that changes in modality between learning and test may attenuate the effect of fluency (Masson & MacLeod, 2002). Miller et al. (2008) suggest that familiarity processes are reliant on the direct matching of perceptual features between stimuli. When stimuli are presented in different perceptual modes, direct comparisons are not possible, and consequently, the familiarity effect of fluency is precluded. Therefore, the different modes of stimuli between learning and test in the present study may have nullified the fluency effect.

Future research may address this limitation by using the same stimuli modes in both learning and test phases, though further problems would be created in doing so. For instance, the methodological strength of the present study results from the independent variable, fluency, being manipulated only during the learning phase. If the experiment were modified as suggested, and identical stimuli were using during learning and test, fluency would vary at both stages. An analysis of the data would require the memory effects of fluency (produced at learning) being separated from the perceptual effects of fluency (produced at test).

4.4.2 Test stimuli may be inappropriate for ERP measurements. In the present study, stimuli were descriptive sentences of three to seven words with durations of up to 3200ms. This presents some problems when considering the specificity required for analysing electrophysiological data using ERP techniques.

Firstly, the content of the stimulus sentence may have produced overlap confounds (Luck, 2014). For the ERP analyses, stimulus onset was defined as the beginning of the differentiating word in each sentence. For instance, where the stimulus pair was “Is five feet tall” and “Is five feet wide”, stimulus onset was defined as the beginning of “tall” and “wide” respectively. It is unclear whether the memory processes which we wish to observe occur exclusively during this final word, or whether overlap confounds are being produced by memory responses to the earlier section of the sentence. This limitation would be addressed by implementing the prior suggestion that visual stimuli be used during both learning and test phases.

Secondly, the length of the stimulus may prevent a well-defined stimulus onset from being chosen. Single syllable words are typically selected for use as stimuli in ERP experiments investigating auditory word perception (Luck, 2014; Phillips, Klein, Mercier, & de Boysson, 2006). The short duration of single-syllable words ensures that the content of the stimulus is delivered as rapidly as possible, and the subsequent neurological processes begin at a predictable and consistent time. The inclusion of two-syllable words in the present study may have resulted in variations in the onset of memory processes.

4.4.3 Implications of memory research. The findings of the current study did not support the predominant theories which seek to explain memory recall, fluency and the relationship describing their interaction. While the non-significant findings of the current study may have been the result of a lack of statistical power, the findings may also be indicative of broader factors within memory research. For instance, though there are a dominant set of theories that pervade much of the literature and research, there are data which contradict these theories in ways which can be systematically reproduced. Recollection is reliably improved when an individual's naïve theories interpret disfluency as an increase in cognitive difficulty (Thomas & Morwitz, 2009). However, this effect can be reversed by verbally offering an alternate interpretation.

Similarly, the 2-process model of memory has been demonstrated to successfully account for data gathered across behavioural, electrophysiological and neuroanatomical domains, yet it is unable to explain the trends observed in large sets of behavioural data; the same data which is explained by a more parsimonious 1-process model of memory. The uncertain foundations of much fluency and memory research, and the highly context-sensitive nature of memory effects is often noted by researchers (Meyer et al., 2015; Rummer, Schweppe, & Schwede, 2016; Xie, Zhou, & Liu, 2018; Yue et al., 2013). The contradictions and qualifications which are prevalent in memory research indicate a need for future research to clarify the conceptual basis of the field carefully.

There are, potentially, many practical benefits in developing an accurate account of the mechanisms which govern recollection, fluency and the factors which govern them. The possibility that typeface fluency manipulations may increase recollection has resulted in the rapid growth of fluency research in memory. This growth is, in part, an acknowledgement that a simple, low-cost intervention such as changing the typeface of educational materials would have overwhelmingly positive real-world implications. This interest has been mirrored in the general public and mainstream media, as is evidenced by trends in related search terms and extensive media coverage of purpose-built typefaces. For instance, RMIT Univerity's memory enhancing 'Sans Forgetica' typeface (Harris, 2018) and typefaces designed to counteract common symptoms of dyslexia (Rello & Baeza-Yates, 2016).

4.5 Conclusion

The present study aims to investigate the effect of typeface disfluency by observing changes in the underlying cognitive mechanisms as predicted by the 2-process model of memory. ERP analyses of brain activity during recollection reveal no significant effects of fluency manipulations during learning. A ceiling effect in the behavioural results of the experiment limits the scope of the possible analyses, and a posthoc power analysis suggests that any future research will require substantially larger sample sizes in addition to addressing the limitations of the paradigm used here. The findings of the present study are a contribution to existing areas of research which question the empirical validity of several key theories in memory and fluency research. It is currently unclear as to whether the 2-process model of memory provides an appropriate basis for investigations of fluency.

Despite the current uncertainty in the field, pursuing a comprehensive theory to explain the memory effects of fluency is justified by the potential for real-world applications in education and the dissemination of written information more generally. Progress is being made, and future studies will be benefited by close monitoring of the theoretical assumptions which guide research.

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