The effect of aging and rhythmic temporal structure during encoding on recognition memory: An EEG Study

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Preface and Impact of Covid-19

I started the current project with in-depth learning of Electroencephalography (EEG) methodology, including how to use relevant software such as Brain Vision Recorder and E-Prime 3.0, and how to collect EEG data. In parallel to this I spent several of the initial months planning the experiment in detail and building the experimental task. This involved learning how to program using a coding language called E-basic and how to integrate this with EEG and computer hardware appropriately. I also prepared an extensive document to submit as a preregistration of the project to the Open Science Framework (OSF) platform (see https://osf.io/52vkr). This involved a thorough literature review in order to detail specific hypotheses and rationale, a detailed design plan, a rationale for the sample size, exclusion criteria and plans for pre-processing and final statistical analyses. Pre-registration increases openness, integrity, and reproducibility of scientific research, as all details are planned and specified prior to the commencement of data collection. Further, the pre-registration allowed me to fully understand both the context of the research, expected outcomes, and how to approach the analysis.

Following the necessary planning, set-up and pre-registration of the project, piloting and data collection commenced in early 2020. However, all testing at Middlesex University was stopped during the first national lockdown from March 2020, and at the time of writing in-person testing using EEG is still not permitted. As a result, only a small number of young participants were able to be tested before Covid-19 was declared a pandemic and all on-campus research experiments were consequently stopped. This made it impossible for me to complete the project as outlined in the pre-registration within the permitted timeframe of the MSc by Research. An attempt was made to build a suitable behavioural version of the experiment using an online platform for behavioural science (Gorilla Experiment Builder). However, it became evident that the software was unable to provide a reliable and acceptable consistency in the delivery of the precise timings in the rhythmic encoding condition. Ultimately, we decided against the online behavioural version given both the amount of work that had gone into planning and preparing the original EEG project and the limited time remaining on the MSc by Research. In consultation with my supervisors and the University, the decision was made to write my thesis as a proof-of-concept. The original planned project is described, but analysis is based on the small number of young adults that were tested. No older adults were tested. It is acknowledged that this is an underpowered study, and my interpretations are speculative. Nevertheless, as will be discussed, the project has produced very encouraging results and demonstrates the feasibility of the paradigm. This MSc has thus not only provided a proof-of-concept but also laid the foundations and analysis pipeline for the extended project.

Abstract

Aging deficits in memory have long been established in the literature, however, little has been done to investigate how environmental factors can be used to ameliorate age related declines in memory functioning. Recent research in recognition memory suggests that increased temporal expectancy during encoding can benefit recognition memory at retrieval in a younger adult sample. The current study aimed to investigate whether the benefit to recognition memory, and associated neural processes, observed in young adults is also evident in normal aging. Unfortunately, due to national restrictions affecting data collection, no older participants were able to be tested. As such, the current project resolved to provide a proof of concept to inform an investigation of the originally intended scope. Ten young participants (M age = 23.5; SD = 2.22) were exposed to pictures of everyday objects in 3 rhythmic and 3 arrhythmic encoding blocks, after which they performed a recognition memory test containing previously studied and new objects. A clear trend suggesting better memory following rhythmic encoding was observed, but no significant difference between conditions emerged. Furthermore, analysis of relevant ERP components uncovered no old/new effect in relation to the LPC or the LFE. Conversely, the FN400 displayed an old/new effect. Thus, the temporal manipulation did not result in significant differences in recognition, but it should be noted that the study is underpowered. However, participants did display a good ability to discriminate stimuli, and in addition RT differences between correct and incorrect recognition judgements and an FN400 old/new effect suggest that the paradigm is effective and sensitive to processing differences between conditions. Recognition could be detected by the FN400 in the present experiment. However, trends in recognition ability between temporal structures suggest that an insufficient sample size is likely to have caused the lacking significant temporal effects. As such, the paradigm is appropriate for extension including a larger sample size and the planned comparison of age groups.

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1.0 Introduction

1.1 Memory changes in normal Aging

Memory has been a key topic of scientific interest for many decades. As such, several independent distinctions of memory have been suggested. Relevant to the current project, explicit (declarative) memory is usually recognised to be conscious recollection of previously learned information (Schacter, 1987). There is ample research on the effect of cognitive aging on memory functions, suggesting a decreased explicit memory functioning in older age (Kausler, 1994; Light et al., 2000; Spaan et al., 2003). This has also been documented in a longitudinal study by Fleischman et al. (2004) who reported a progressive decline in explicit memory functions in older age. Additionally, similar results have been found in cross-sectional studies comparing younger individuals, usually between 18-30 years, to older adults, normally above 65 years of age (Craik, 1994; Burke & Light, 1981; Howe, 1988; Hultsch & Dixon, 1990; Craik & Schloerscheidt, 2011; Ward, 2018; Jelicic et al., 1996; Ward et al., 2017; Ward et al., 2015). These studies demonstrate significantly reduced memory, often assessed using tests of recall or recognition, in healthy older adults without dementia compared to young adults. As these findings suggest that decline in memory is expected even in normal aging, it is important to consider the implications this has on the gradually increasing age of the global population. Therefore, considering that memory decline in normal aging is well documented, it is important to investigate and consider potential approaches aiming to improve memory function in aging.

A range of different memory tasks have been used to investigate age-related changes in memory. Two of the most common include recall and recognition (Roediger, 1990). In a typical recognition task, stimuli (usually words or pictures of objects) are studied during an encoding phase prior to a test phase in which participants discriminate between previously studied (old) and new items. In similarity with recognition tasks, recall paradigms require participants to study a set of stimuli (often words). However, recall paradigms differ from recognition paradigms during retrieval as participants are asked to retrieve information without being re-exposed to the relevant stimuli. This is often done by either asking participants to freely recall stimuli without any further support (free recall) or recall information based on a given category (cued recall). Recall and recognition are argued to be differentially demanding in relation to cognitive load (Craik & McDowd, 1987). As such, Craik and McDowd (1987) argue that older individuals perform worse in recall as opposed to recognition tasks when compared to younger populations, due to an increased need of effort and self-initiated search of memory in recall. In addition, they argue that this difference is further amplified as recognition naturally provides retrieval cues functioning as environmental support to memory. Although some studies have reported non-significant age differences in recognition (Moscovitch & Winocur, 1992; Naveh-Benjamin & Craik, 1995), a large number of studies have produced reliable age differences in recognition (see Rhodes et al., 2019; Ward & Shanks, 2018, for reviews). Indeed, one very recent study using a large sample showed that an age difference in recognition memory is prevalent (Ward et al., 2020). In this latter study, a large lifespan sample was subjected to a range of different line drawings of everyday objects before being asked to indicate recognition of these images intermixed with unencountered stimuli during a separate test phase. They found that while recognition capabilities increased until mid-young adulthood (25-34 years of age), further aging predicted a decline in explicit recognition. This suggests that age differences in memory are due to a general mild decrease in cognitive functioning with age, and discrepancies between memory tasks are a function of the cognitive demands of the task. However, one must also consider the impact of encoding and whether it can be optimised to improve memory retrieval in older adults.

Encoding can be viewed as either incidental or intentional. This refers to whether an individual is consciously attempting to store information for subsequent retrieval, or whether this information is stored without this intent. Here, incidental learning refers to situations where individuals are unaware of the learning situation (e.g., without intent, being able to recall the speed limit on a road one has previously driven on). Conversely, intentional learning requires intent to learn information during encoding and is usually considered to be more effortful than incidental learning (Kontaxopoulou et al., 2017). According to a review conducted by Wagnon et al. (2019), age differences in explicit memory are most prevalent following intentional learning. Furthermore, following their investigation into age differences in free recall and recognition, Wagnon et al. (2019) continue to suggest that such age differences appear to be consistent between independent measures of memory (e.g., recall versus recognition). Troyer, Graves and Cullum (1994) argue that it is possible that such age differences in memory performance can be explained by older adults' reduced ability to engage in executive functions relating to organisation and elaboration during encoding. Although the effect of incidental encoding on age differences in memory is in need of further research, much scientific effort has been made to understand the developmental trajectory of intentional learning through the lifespan (Wagnon et al., 2019). Still, the discussed literature suggests an increased age difference following intentional learning due to the added cognitive demands caused by attempting to apply successful encoding strategies. This suggests a need to investigate how optimising encoding during intentional learning can help alleviate the magnitude of age differences in memory. As will be discussed in detail later, this project aimed to examine whether an incidental temporal encoding manipulation that has recently shown to improve memory in young adults is also beneficial to memory in older adults during intentional encoding of objects.

1.2 Recognition memory – what is the nature of the age-related deficit?

Responses on a standard recognition test are usually recorded as Hits ('old' judgements for studied items), Misses ('new' judgements for studied items), False Alarms (FA, 'old' judgements for unstudied items), and Correct Rejections (‘new’ judgements for unstudied items). Therefore, it is possible to further examine whether age differences in cognitive functioning disproportionally cause older individuals to commit more errors related to FAs or misses relative to younger populations. In other words, whether there are age differences in the bias to respond ‘old’ or ‘new’. As such, it could be possible to further infer specific aspects of the task that appear more demanding for older adults and attempt to tailor interventions to ease the cognitive load associated with these processes. Investigating age differences in recognition by using old, lure and distractor word-pairs, where lures contained one old and one new word, Isingrini et al. (1995) showed that older individuals generally produce more FAs than younger participants, and this is what drives the age difference. Specifically, they found that when subjected to lure word-pairs, older participants appear to produce more FAs than younger participants. Isingrini et al. (1995) suggest that this age difference is due to an increased cognitive load when tasked with differentiating between previously encountered stimuli that appear similar to lures, as opposed to being clearly distinct. This suggests that encoding stereotyped features is less demanding than encoding stimuli specific qualities and that when cognitive resources are lacking, it becomes more difficult to discriminate between lures and old stimuli.

The increased difficulty in differentiating between encoded stimuli and similar lures, when compared to discriminating between encoded and dissimilar unstudied stimuli, is widely discussed in the literature (e.g., Morcom, 2015). Common terms used when discussing this issue are recollection and familiarity. The former is argued to involve recollection of specific details of the prior encounter with the stimulus, such as contextual information, while the latter is thought to merely involve the feeling that the stimulus in question was encountered before in the absence of any specific detail about the encounter (Ward & Shanks, 2018; Wixted, 2007; Wixted & Stretch, 2004). There is ongoing debate regarding how familiarity and recollection relate to each other (Wixted & Mickes, 2010), however, it is thought that the recognition decisions can be made based on either process (Ward et al., 2017; Ward & Shanks, 2018). That is, the processes of recollection and familiarity can make independent contributions to recognition. Isingrini et al. (1995) argue that contemporary research supports the notion that older adults make recognition judgements based more on familiarity than on recollection (see also Ward et al., 2016). This supports the argument that older adults make more FAs on a typical recognition test as they are unable to retrieve accurate conscious recollections of presented stimuli. As such, FA recognition judgements when new test stimuli either resemble stimuli presented during encoding or stimuli that have been encountered prior to participation, triggering a feeling of familiarity but no explicit recollection.

As a possible explanation for reductions in recognition with age, it could be that intentional and unintentional recognition rely on differing processes. Bergström et al. (2016) investigated the neurocognitive mechanisms underlying intentional and unintentional recognition. Specifically, they subjected participants to 10 study-test cycles in a in memory Stroop paradigm. During each study phase, they randomly presented participants with 16 images and 16 words and asked them to rate the pleasantness of each. During recognition, participants were presented with 32 picture-word pairs with words superimposed over images. While counterbalancing the novelty combinations of picture-word pairs, participants were either asked to make intentional recognition judgements in relation to the words (Experiment 1) or images (Experiment 2). While intentional recognition involved an explicit recognition task, unintentional recognition was thought to occur when previously encountered stimuli appeared as distractors. Thus, processing differences during intentional and unintentional recognition was investigated by examining how Event Related Potential (ERP) components, signifying familiarity and recollection, were modulated by changes in the presence of old and new distractor and target stimuli. They found that while both intentionally and unintentionally recognized stimuli resulted in a frontally distributed early ERP positivity, the later parietal ERP positivity, argued to be associated with conscious recollection, was only observed for intentionally recognised stimuli. This provides direct evidence that separate processes are involved in intentional and unintentional recognition. The decline in the ability to engage in intentional recognition with age could therefore be due to a deficit in specific recollective processes, which appear to be dominant in intentional recognition. Using a near identical experimental paradigm to Bergström et al. (2016), Allen et al. (2020) examined age differences in intentional and unintentional recognition. In line with expectations, they observed that while age differences were less prevalent in unintentional recognition, the neurocognitive mechanisms that modulate intentional recognition are greatly affected by aging. While this research has primarily investigated differences in intentional and unintentional recognition, it provides important insights to the developmental trajectory and separation of processes affecting recognition memory throughout adulthood. Indeed, it suggests that the nature of the age-related deficit seen in recognition memory is primarily due to a decline in recollective abilities while familiarity-based processes are largely intact.

1.3 Measures of Recognition Memory

1.3.1 Introspective Measures of Recognition Related Processing. Investigating memory processes that affect recognition, cognitive research has developed introspective measures aiming to identify when a decision is made based on recollection or familiarity. Serving as common examples of this, Tulving's (1985) ‘Remember/Know’ (RK) paradigm, further developed by Gardiner (1988), and the Receiver Operating Characteristic (ROC) recognition measure which collects recognition responses by using a 6 point confidence scale (Yonelinas & Parks, 2007; Yonelinas, 1999) are common in recognition tests. In relation to aging, both of these measures suggest that normal aging is associated with a decrement to recollection rather than familiarity processing (Koen & Yonelinas, 2016). However, while the six item confidence measure resembles the RK test in that recollection is more often made with higher confidence and accuracy than familiarity judgements (Rotello et al., 2004; Wixted & Mickes, 2010; Wixted & Stretch, 2004), they have been shown to decouple from each other (e.g., Gardiner & Java, 1990; Geraci et al., 2009; Rajaram, 1993; Rajaram et al., 2002). Indeed, these measures have been shown to be differentially affected by identical manipulations (Rajaram, 1993). To further complicate the matter, it appears that attempting to combine the measures to gain a more complex insight is ineffective as participants reportedly become confused and intermix their interpretation of the two questions, causing a lack of independency between the measures (Migo et al., 2012). Still, measurements such as d prime (d`) have been shown to decrease when binary yes-no responses are provided instead of confidence ratings (Juola et al., 2019), making confidence ratings favourable to provide participants with more nuanced response options. This is further supported by Ward et al. (2016), who suggest that this is the case if participants are strongly encouraged to use them. As such, confidence ratings are necessary as they provide participants with the ability to respond differently to qualitatively different memory experiences gaining a more accurate measure of recognition. However, it could be argued that more direct measures, such as provided by neuroscientific methodologies, circumventing the issues of introspection could render these methodologies obsolete in analysis by functioning as a more unbiased measure of recognition related processing. Indeed, more direct measures would provide better evidence for processing differences between manipulations such as differing age groups as observed differences would reflect less biased differences in neurological processing.

1.3.2 Direct Measures of Recognition Related Processing. Neuroscientific methods have the potential to shed further light on the underlying structures argued to be the basis of observed cognitive abilities. As discussed, there has been some debate regarding whether the qualitative experiences and behavioural outcome of a memory is the result of the strength of the memory signal, or whether different memory related abilities are the outcome of dissimilar neurological processes. In an fMRI study, Vilberg and Rugg (2007) aimed to investigate the notion that recognition outcomes are due to an unidimensional memory strength variable by using a modified RK test. Their results show that two differing brain regions are responsible for the processes of familiarity and recollection, indicating that these cognitive abilities are dissociated on a neural level. This is important, as it suggests that these processes are controlled differentially, and that interventions aiming to benefit one process might not affect the other.

Weidemann and Kahana (2016) propose that Reaction Time (RT) differences can account for much of the same information regarding reliance on familiarity and recollection during recognition, without the dependence on introspection by participants. However, although RT data can be valuable in understanding underlying processing differences, it lacks the clear distinctions that introspective measures provide. Conversely, Electroencephalography (EEG) research has identified ERP components that appear relevant to identifying brain processes of recollection and familiarity (see Rugg & Curran, 2007 for a review). As such, it is necessary to dissect the potential gain and limitations in such neuroscientific measures which are relevant to this investigation. Thus, neuroscientific measures could potentially provide both the benefit of introspective and RT data by avoiding introspection, while simultaneously identifying distinct neurological processes relevant to familiarity and recollection respectively.

In an ERP case study using a patient with bilateral hippocampal damage, Düzel et al. (2001) found that while recollective abilities and the parietal old/new effect was absent, the early frontal correlate of familiarity remained present. Their findings are further supported by Vargha-Khadem et al. (1997). Indeed, this suggests that whether an individual uses familiarity or recollection-based processes of recognition can be identified using ERP measures. Finally, a range of studies using EEG measures have been able to differentiate between recollection and familiarity processes reliably when no impairment is present (Curran, 2000, 2004; Düzel et al., 1997). There is some debate regarding what the ERP component FN400, here associated with familiarity, actually represents. Still, understanding how these processes, represented by differing ERP components, are differentially affected; might indeed improve the current theoretical understanding and practical areas of application in a more meaningful manner. As such, a more detailed discussion of relevant information relating to EEG memory research will follow later.

1.4 Time and Temporal Expectations in Memory Relevant Processing

Temporal expectation is generally referred to as the expectation of when an event will occur, such as the onset of a stimulus (Vangkilde et al., 2013). Temporal expectations occur frequently in our day to day lives and can be the product of an increased probability of an event occurring (also referred to as the hazard function, Janssen & Shadlen, 2005) or acquired temporal associations (such as the onset of a green or red light following an amber light at a traffic light stop). There is some previous research which has focused on how Inter Stimulus Intervals (ISIs) affect memory formation (Lichtenstein & Keren, 1979; Proctor, 1983; Watkins, 1985; Weaver, 1974). Much of this has focused on how stimulus processing during learning is influenced by ISIs. However, there are currently only a few studies that have investigated the impact of temporal expectations on long-term memory processing (e.g., Jones & Ward, 2019; Thavabalasingam et al., 2016). Still, even prior to these relatively recent studies on the differences in memory performance following temporal expectation manipulations, there is reason to believe that timing plays a very important role in memory formation. Tulving (1972) identifies time as an important factor in episodic memory, and the hippocampus, which has been identified as essential in episodic memory formation (Eichenbaum, 1999, 2001), has been associated with temporal information processing. In fact, identifying it as the processing of the passage of time, rodent studies have observed hippocampal activity during the interlude between two events (MacDonald et al., 2011; Pastalkova et al., 2008), with similar results observed in monkeys (Naya & Suzuki, 2011). More relevant to human capacities to process the passage of time, Barnett et al. (2014) investigated the hippocampal sensitivity to durations during event sequences in humans. They used a temporal match-mismatch paradigm in two experiments during functional neuroimaging and found that hippocampal activity is modulated by the temporal structure of events and intervals comprising a sequence. Furthermore, they found that when event or interval duration sequences were repeated, hippocampal activity was increased; indicating that the hippocampus, which is highly relevant for memory formation, integrates and utilises temporal information in the processing of stimuli. The increased hippocampal activity during the repetition of temporal structures suggests that durations and time structures can be learned and recognised to optimise processing at the neural level. If temporal structures are kept constant during encoding in memory paradigms, it might therefore be possible that memory related processing can benefit from this increased temporal predictability.

While little has been done to examine whether age-related decline in memory can be alleviated by optimising encoding, how information is encoded is likely to have an impact on subsequent information retrieval. Investigating the impact of encoding on later recognition in a sample of young adults, Thavabalasingam et al. (2016) found that recognition memory is improved if encoding occurs in a structured temporal framework. Specifically, they utilised a within-subjects design in which they asked participants to remember information (pictures of scenes) they later would be asked to recognise, while manipulating the regularity of the presentation of this information. In one condition a structured framework was created by presenting items after set interval durations that formed a mini sequence (i.e., 500 – 1000 – 2000 – 100msec). Conversely, intervals between stimuli in the temporally unstructured condition were random and did not follow any particular structure; however, the overall average interval length matched that of the structured condition. Recognition was greater in the temporally structured condition compared to the unstructured condition. Although Thavabalasingam et al. (2016) utilised a predictable structure as a temporal framework as opposed to rhythm, their findings strengthen the claim that a predictive temporal framework during encoding enhances subsequent recognition memory. As the temporal structure of information presentation during encoding appears to be relevant for one's ability to retrieve information, it is a viable question to ask whether the observed memory deficit in normal aging can be alleviated by improving encoding conditions through added temporal structure. Indeed, if age differences following a predictable encoding structure are smaller when compared to unpredictable encoding conditions, it would suggest that optimal encoding decreases the cognitive load during retrieval.

Presenting stimuli in a temporal structure during encoding appears to be beneficial for an individual's subsequent recognition. However, the underlying mechanisms for the memory benefit associated with rhythm are still unknown. In their review, Calderone et al. (2014) suggest that neural oscillations shape cognitive processes and that these oscillations entrain to external rhythmic stimuli to optimise processing of predictable events. Jones and Ward (2019) further suggest that neural processes differ depending on whether stimuli are presented rhythmically or arrhythmically. They manipulated rhythm by either presenting stimuli (pictures of everyday objects), intermixed with images of checkerboards, at fixed repeating intervals of 600ms (rhythmic condition) or at random intervals ranging from 70-1130ms (arrhythmic condition). Following encoding, they tested recognition memory by presenting all images from the prior encoding phase randomly dispersed between an equal number of novel images. Behavioural recognition was significantly greater in the rhythmic than the arrhythmic condition, and they also found that memory specific ERP components were differentially affected by temporal structure. The FN400 old/new effect was present for both rhythmically and arrhythmically encoded items, but a Late Positive Component (LPC) old/new effect was only observed for rhythmically encoding items, suggested greater/deeper encoding of these items. In relation to this, they argue that a rhythmic structure of stimuli presentation is beneficial for memory encoding that supports recognition. This indicates that, as previously suggested, recollective processes are more susceptible to manipulations during encoding and that temporal structures can be used to benefit subsequent recognition. It is noteworthy that it remains unknown whether it is the rhythmic condition that benefits memory, the arrhythmic condition that is detrimental to memory or whether a combination of effects present. Still, the experiment by Jones and Ward (2019) also emphasises the benefit of utilising EEG to better understand the neural processes responsible for an improved recognition memory following the application of a structured temporal framework during encoding. Indeed, it appears that it is mainly recollective abilities that are affected by the temporal manipulations.

1.4.1 The Impact of Attention on Memory. The argument that directing attention towards an event or fact is likely to benefit subsequent memory of that event or fact is likely to be considered uncontroversial. Craik et al. (1996) investigated the impact of dividing attention during both encoding and retrieval during free recall, cued recall and recognition paradigms. Relevant to recognition, they found that while retrieval success was not impacted if attention was divided during retrieval, dividing attention during encoding was associated with a significant decrease in recognition performance. This is further supported in a review by Chun and Turk-Browne (2007) who concluded that attentional and memory processes interact to benefit each other, although the enhancement of memory due to attention is more established than the reversal of the relationship. This is important, as it establishes that efficient attentional processing during encoding as essential to successful memory formation and subsequent retrieval. Although, as Chun and Turk-Browne (2007) suggest, there has been much work done to investigate the effect of divided and selective attention on memory, indicating that either process impacts memory formation, less work has been done to investigate how sustaining attention impacts memory. Indeed, it is possible that high temporal expectancy can benefit memory formation by allocating attentional focus to specific moments in time rather than sustained throughout encoding.

Based on this, attentional processing could function as a bottleneck to memory formation and, consequently, cause a benefit if demand is decreased. Predictive cues are generally observed to be effective at directing top-down controlled attention to improve behavioural responses. Early research suggests that using spatial cues can be beneficial for directing attention towards relevant locations (Posner, 1980). Similarly, directing attention towards task-relevant targets occurring at specific moments in time using temporal cues has been found to benefit subsequent behaviour on the given task. Specifically, such temporal orienting of attention is found to affect a range of tasks, such as speeding motor preparation and response times (Correa et al., 2004), in addition to enhancing the perceptual ability to discriminate and detect stimuli (Correa, Lupiáñez, et al., 2006; Correa, Sanabria, et al., 2006; Davranche et al., 2011; Rohenkohl et al., 2012). In a study investigating the influence of temporal predictability on attentional processing, Schmidt-Kassow et al. (2009) presented participants with auditory sequences that either appeared in one of two temporally predictable structures or in a temporally unpredictable structure. Asking participants to detect whether there were irregularities in a target sequence, Schmidt-Kassow et al. (2009) observed that temporal predictability was favourable to attentional processing in RT to auditory irregularities in target sequences. These results suggest that temporally predictable structures benefit processing, however, their methods largely rely on processing at motor levels, which might result in differing findings from studies that do not rely on RT to uncover processing differences.

Existing investigations examining the benefit to memory processing of temporal expectancy can still be considered recent, and there is much to be explored in this area. Still, as attention has been shown to be essential for successful memory encoding, it is likely that if temporal expectancy can improve attentional processing, a benefit to memory will be observed if this is utilised optimally during encoding. However, as RT investigations add additional levels of motor functioning, it could be argued that the influence of motor execution recorded through RT adds an additional factor. Recognising this, Correa et al. (2005) aimed to investigate whether manipulating attentional processing through temporal expectancy could affect perceptual processing, independent of processing at motor levels. They exposed participants to a temporal cue before a task where a target was displayed for 14 msec in one of two temporal locations between the rapid display of distractor stimuli. Following this, participants had to respond by indicating either which of two different targets had been displayed in one of the temporal locations or whether the trial presented a target or was a lure (i.e., no target). Their results showed that even when motor functioning did not contribute to performance, perceptual processing was shown to benefit from increased temporal predictability. As mentioned, these studies differ from the current investigation by investigating attentional processing rather than memory functioning. However, it illustrates that temporal predictability can modulate attentional processing. Given that attentional processes, especially during encoding, can impact memory formation, this is relevant to the current study, and suggests that temporal predictability during encoding might allow for an increased memory formation, as encoding appears less demanding on attentional processing.

A neurological explanation of how cognitive demand is decreased through temporal expectation concerns the entrainment of brain oscillations that naturally occur during task relevant brain processes. In fact, entrainment is described as a process where at least two autonomous oscillators interact with each other by synchronising (Clayton et al., 2005). In relation to this, the Dynamic Attending Theory (DAT; Large & Jones, 1999) suggests that externally occurring rhythms entrain peaks of attentional focus giving a processing advantage to stimuli presented in line with the external rhythmic structure. The DAT does not restrict such a benefit to any specific oscillatory frequency, but a similar framework attributes this benefit to the firing of neurons being aligned through brain oscillations entraining to ongoing external rhythms (Arnal & Giraud, 2012; Calderone et al., 2014; Henry & Herrmann, 2014; Lakatos et al., 2013). Indeed, what has been referred to as temporal expectancy has demonstrated that external temporal regularities inherent in the presentation of stimuli, entrain attentional focus to match this external temporal rhythm, resulting in behavioural and perceptual advantages (Barnes & Jones, 2000; Jones & Boltz, 1989; Jones et al., 2002, 2006; Nobre & Rohenkohl, 2014). In fact, compared to more unstructured and less predictable temporal structures, it is regularly observed that individuals exhibit behavioural facilitation and enhanced sensory processing for stimuli presented in a temporally predictive manner (e.g., Jones et al., 2002, 2006; Lange, 2010; Mathewson et al., 2010; Olson & Chun, 2001; Rohenkohl et al., 2012; Rohenkohl & Nobre, 2011). This observed processing benefit for stimuli presented in a predictable as opposed to an unpredictable structure could result in a more robust memory formation if information is presented in a predictable temporal structure. However, assuming that the DAT is correct in that an externally imposed rhythm can cause an attentional processing benefit, it is still not given that memory specific processing can take advantage of this effect.

Still, the human brain appears to be proficient at perceiving regularities based on temporal aspects of experience. Specific to visually presented stimuli, temporal expectations through oscillatory entrainment in the visual cortex, have been shown to modulate perceptual processing of visual stimuli (Cravo et al., 2013). Although this still does not guarantee a benefit to memory if temporal expectancy is increased during encoding, it does suggest that a visually rhythmic encoding structure will provide optimal conditions for memory formation.

1.4.2 Processing Differences and the Utility of Predictability in Aging. Although cognitive processing can be made more successful by applying a beneficial temporal structure during task completion, normal aging is associated with a general decline in a range of cognitive processes. In particular, effortful memory related cognitive processing appears to become more difficult with age (Salthouse, 2010; Ward & Shanks, 2018). While some mental abilities such as vocabulary are suggested to strengthen during aging, it is regularly observed that other cognitive abilities such as processing speed and attention regulation decline with age (Harada et al., 2013). While age related abilities in attentional processing are primarily observed in cases where individuals have to exercise selective or divided attention, age deficits in processing speed usually have a more general impact and can affect a variety of other functions (Harada et al., 2013). This suggests that cognitive changes in aging are complex, and certain abilities, such as vocabulary, that favour experience, can even be positively impacted by aging. Of particular interest to memory research, an age-related decline in processing speed could explain age differences in memory performance when encoding or memory test conditions are temporally limiting. That is, if a decrease in processing speed is detrimental to performance during either memory encoding or retrieval, impaired performance in older compared to younger adults is expected.

It is not novel to claim that processing speed can affect memory performance and earlier research, such as that of Salthouse and Coon (1993), has claimed that a decrease in processing speed in aging accounts for much of the parallel decrease in memory performance. However, many cognitive assessments of processing speed and much of the literature on the development of processing speed in aging, rely on motor functioning in the execution of relevant tests.

However, as motor functioning is not directly relevant to the degree that memory processing operates, it could be possible that the deficit in memory attributable to a decline in processing speed is less prevalent than previously thought. As an example of where motor functioning might limit memory performance, measures such as RT differences and environments, where recall or recognition is time limited, is likely to reflect differences in motor functioning. Ebaid et al. (2017) used a range of measures to assess the development of processing time and differences in motor dexterity due to aging in adulthood. Specifically, they investigated motor functioning using a timed pegboard test where participants were required to move a peg between as many holes as possible using their dominant and non-dominant hands in independent trials, in addition to a bimanual trial. They also assessed processing speed using subtests of the Wechsler Adult Intelligence Scale 4th Edition (WAIS-IV), which are timed tests using pen and paper, and a modified inspection time task. The latter task varied the exposure time to relevant stimuli and asked participants to assess the stimuli post-exposure, to ensure that motor functioning did not impact results. They found that while there were significant differences between age groups in the pegboard task and the WAIS-IV sub-tests, no age differences were discovered in the modified inspection time task. Still, the significant age differences in the WAIS-IV subtests persisted after controlling for motor dexterity. As Ebaid et al. (2017) maintain, these results suggest that while age differences in processing speed are impactful in more complex cognitive tasks, age differences in less demanding tasks might reflect a decrease in motor dexterity rather than processing speed. When constructing paradigms intended to investigate age differences in cognition it is therefore essential that the impact of motor functioning on results are limited to a minimum.

One potential confounding issue in research investigating memory differences between older and younger age groups, is that younger adults appear to be better able to successfully exercise explicit strategies when they become aware of the cognitive demands and manipulations of a task (Mather & Carstensen, 2005). In their review, Mather and Carstensen (2005) specifically argued that young adults have a more prominent advantage in memory tasks that benefit from the generation and maintenance of internal strategies rather than memory tasks that only rely on external cues. Consequently, if awareness of the task relevant manipulations results in improved memory performance, such a benefit is likely to increase age differences with a skewed improvement in performance in younger adults. In investigations examining the effect of temporal manipulations during encoding on recognition memory in young adults, both Thavabalasingam et al. (2016) and Jones and Ward (2019) report relatively low occurrences of reported awareness of the temporal manipulations. Jones and Ward (2019) further explicitly state that scores between participants who were considered aware versus unaware appear largely similar. While recognition paradigms rely on external cues at retrieval (i.e., the presentation of a stimulus that the participant must judge as previously studied or new), these findings suggests that awareness of temporal manipulations does not introduce a strategy for young participants to further improve their performance. In other words, test awareness does not typically occur in the majority of participants, and for those who do become aware of the temporal manipulation, this is unlikely to have an impact on the outcome.

Any inability of older individuals to take advantage of a predictable temporal structure to benefit subsequent memory could arguably be due to a decline in the ability to temporally entrain attention. Using EEG while investigating age differences in the ability to temporally orient attention, Zanto et al. (2011) asked participants to complete one detection and two discrimination tasks. During the detection task, participants were asked to respond whenever a target appeared, while in the discrimination tasks, participants were asked to either respond to only one of two targets or to respond differentially depending on the presented target. Using the same cue paradigm across all three tasks, participants were given either a neutral, short or long predictive cue, where the neutral cue contained no predictive information regarding when the target would appear. Following this experiment, Zanto et al. (2011) argued that although younger individuals were able to utilise predictive cues to enhance performance, older adults showed no such ability irrespective of the task. Indeed, they suggested that the differences in neural activity between older and younger individuals indicate that only younger individuals cognitively used the temporal cue to improve performance, supporting their behavioural findings. This suggests that older individuals cannot take advantage of temporally predictive information, and as such would have no benefit of a temporally predictive structure during encoding to subsequent memory.

However, although Zanto et al. (2011) argue that the ability to utilise temporally predictive information to optimise attention declines with age, there are other studies that suggest the opposite. Chauvin et al. (2016) conducted an experiment investigating age differences in the ability to use temporally predictive information to enhance detection and discrimination abilities. Specifically, in two separate tasks, Chauvin et al. (2016) presented participants with either a valid or invalid temporally predictive cue. In one task they asked participants to make a keypress when they detected a target, while in the other task, they asked participants to discriminate whether a target appeared after a short or long interval amongst a stream of non-target stimulus. Using both blocked and trial-by-trial designs to vary between cues they observed that valid temporally predictive cues resulted in similar benefit to both young and older age groups in discrimination and detection tasks. In recent research, Droit-Volet et al. (2019) support Chauvin et al.'s (2016) argument that older individuals can memorise trained intervals equally as accurate compared to younger individuals. They illustrate that both younger and older adults display a similar capacity to react to temporally entrained stimuli. However, although they find that older adults are less proficient at reacting to stimuli appearing prior to what is expected, they do not investigate age related differences in RT in an arrhythmic condition. Although Chauvin et al. (2016) and Droit-Volet et al. (2019) contradict previous findings, such as those of Zanto et al. (2011), contemporary results suggest that age does not affect the cognitive capability to entrain to predictive stimuli. It is important that one acknowledges that there is some debate regarding whether the ability to orient attention temporally is preserved in aging. It is possible that the established benefit to memory of predictive structures during encoding does not extend to older populations if there is a parallel decline in temporal attention and memory. On the other hand, temporal prediction may provide a key benefit to memory in aging. As such, investigating whether the memory decline in normal aging can be ameliorated by employing a temporally predictive structure during encoding is viable.

1.5 EEG components of memory formation.

Memory formations are thought to be facilitated by modifications of neural circuits and synapses through plasticity (Martin et al., 2000). Furthermore, the synchronisation of action-potential timing across a selection of neurons is thought to favour the induction of neural plasticity (Markram, Lübke, Frotscher & Sakmann, 1997). Such synchronisation within populations of neurons can be recorded as oscillations of differing frequencies through EEG. Oscillation at the theta frequency (4Hz) is often associated with the favourable induction of neural plasticity relating to behavioural memory and, as such, is argued to be beneficial for memory encoding and retrieval (Buzsáki, 2002). This is supported by early animal studies, which argue that a time interval of approximately 200ms between stimuli is favourable for long-term potentiation within the hippocampal formation (Greenstein et al., 1988; Larson & Lynch, 1986). Contemporary research can be found to support that these findings are translatable to humans, as Clouter et al. (2017) maintain that theta-specific synchronisation mechanisms facilitate the formation of human episodic memory, while phase synchronisation across other frequencies appear unrelated to explicit memory formation. Nevertheless, there is on-going debate regarding whether human episodic memory can benefit from phase synchronisation outside the theta frequency during encoding. Jones and Ward (2019) argue that rhythmic temporal structure outside the theta frequency range also appears to benefit human memory formation. Applying both rhythmic and arrhythmic intervals during encoding, they found that an Inter Stimulus Interval (ISI) of 600ms enhanced recognition memory. Although Jones and Ward (2019) did not investigate differences in the benefit to recognition memory between theta and non-theta rhythmic conditions during encoding, their results suggest that a theta frequency during encoding is not necessary to benefit subsequent retrieval. This ongoing debate emphasises the need for further investigation into whether memory formation is affected by non-theta frequencies. Indeed, if the results of Jones and Ward (2019) are replicable, it would be grounds for optimism as it would suggest that the application of rhythm during encoding is more important than the frequency of the rhythm.

1.5.1 Recollection and Familiarity in EEG. As previously mentioned, there are individual ERP components that have been identified as highly relevant to memory functions. In relation to the previously discussed literature, FN400 is argued to be relevant for processes important for familiarity (Curran, 2000; Curran & Cleary, 2003; Curran & Doyle, 2011; Duarte et al., 2004; Emrah Düzel et al., 1997; Ecker et al., 2007; Rugg & Curran, 2007), while the parietal old/new effect, also known as the Late Positive Component (LPC), is claimed to be indicative of cognitive processes relevant for recollection (Allan et al., 1998; Curran, 1999, 2000; Curran & Cleary, 2003; Duarte et al., 2004; Griffin et al., 2013; Rugg & Curran, 2007; Voss et al., 2010; Woodruff et al., 2006). Although the notion that the LPC reflects recollection appears undisputed (Bader & Mecklinger, 2017), whether the FN400 old/new effect is reminiscent of familiarity appears to be more controversial (Bridger et al., 2012; Voss & Federmeier, 2011). Addressing the debate regarding the FN400 old/new effect, Voss & Federmeier (2011) presented participants with 200 target words in addition to one semantically related prime and one unrelated word. Half of the participants were first shown a target preceded by a semantically related prime before having the target word appear again after approximately 15-25 intervening targets, this time preceded by an unrelated word. The other half of the participants had the order of presentation relating to semantically related and unrelated words reversed. All participants were asked to make emotional valence decisions relating to the presented words, before indicating whether they believed the word was old (previously studied) or new. As a result of their experiment, Voss & Federmeier (2011) suggest that the semantic priming effects strongly modulated the FN400 while simultaneously having no effect on familiarity memory. This suggests that the FN400 is not functionally distinct from the N400. Indeed, it implies that familiarity recognition effects on the FN400 are actually due to contamination from conceptual priming.

As the claims made by Voss and Federmeier (2011) would have large implications on recognition related EEG studies, they have been subject to scrutiny. Indeed, Bridger et al. (2012) directly address their claim combating that the FN400 and N400 are functionally indistinguishable. In this, they maintain that the findings of Voss and Federmeier (2011) are due to several methodological flaws, causing issues such as conceptual priming contamination during recognition. Bridger et al. (2012) continue to argue that this is unlikely to have happened in other recognition studies as the design employed by Voss & Federmeier (2011) deviates notably from standard recognition paradigms by, for example, using shorter delays between encoding and testing. In addition, they claim that as participants were likely to be alerted to the semantic priming manipulation, leading to amplified N400 potentials when this expectancy was violated. Attempting to investigate the relationship between the N400 and FN400 old/new effect, Bridger et al. (2012) employed a design aimed at avoiding the confounds they identified in Voss and Federmeier (2011). Specifically, they exposed participants to 55 primed and 55 unprimed word pairs during a study and semantic priming phase, where they observed the established centro-parietal maximum identified as the N400 effect. Further following a longer unrelated filler task, they avoided semantic priming contamination by re-exposing participants to the 55 semantically unprimed words interspersed between 55 new words. Consequently, they observed a maximal ERP difference between correct old/new judgements over frontal sites. This suggests that, despite their remaining morphological similarity, the evidence implying a lacking functional distinction between the N400 and FN400 old/new effect is due to flawed methodological designs, such as in Voss and Federmeier, (2011). Indeed, they appear to be subject to confounds such as semantic contamination during recognition.

Although Bridger et al. (2012) argue that the FN400 old/new effect is distinct from the N400 effect, the two components are, as mentioned, morphologically similar. Considering the active debate relating to the functional relationship of these components it is, therefore, viable to ask whether they share a brain network vital for both functions. Investigating the effect of a lesion in the Perirhinal Cortex (PRC), Bowles et al. (2016) maintain that both semantic knowledge representation and episodic familiarity is affected. However, Aly et al. (2011) found that patients with an intact PRC but with lateral Prefrontal Cortex (PFC) damage also had issues related to familiarity, specifically displaying an increased number of familiarity-based FAs. As suggested by Bader & Mecklinger (2017), this implies that while both familiarity and conceptual fluency related signals appear to generate in the PRC, familiarity based tasks require further processing in the PFC. This supports the notion that while conceptual fluency and familiarity depend on some shared networks, they are independent functions where the FN400 is more reflective of familiarity-based tasks while the N400 better reflects conceptual fluency.

While there is still some debate in the literature surrounding the FN400, the nature of the LPC old/new effect appears less controversial. The LPC effect has long been recognised as related to recognition memory as research has identified it by observing an increased and earlier effect over the parietal scalp, usually in the time interval 400-800ms when subjects are exposed to old, as opposed to new, words (Friedman & Johnson, 2000). Friedman and Johnson (2000) also suggest that the component has an asymmetrical distribution, being larger over left parietal electrode sites for verbal stimuli and that the component is associated with shorter RTs. Although they continue to mention that there have been some opposing observations in relation to the LPC old/new effect's relation to RT. More contemporary research, such as Jones and Ward (2019), further suggest that the LPC effect remains asymmetrically distributed across left parietal electrodes even when non-verbal stimuli is utilised as targets. Interestingly, the literature strongly supports that the parietal old/new effect is modulated by recollection, as it appears to be affected by whether participants successfully manage to retrieve source information and whether items are endorsed as known or remembered (Rugg & Curran, 2007). Furthermore, the component appears to be differentially affected depending on whether encoding can be considered structured or unstructured (Jones & Ward, 2019). Indeed, this latter point suggests that while recollection is present when encoding conditions are optimal, more difficult encoding conditions hinder recollective recognition. Still, it is yet unknown how the LPC old/new effect and recollection is affected due to structured and unstructured encoding in older populations.

If the LPC old/new effect is indicative of recollection, it would be expected that the magnitude of this parietal old/new effect could be used to predict the amount and quality of information that is retrieved by an individual. Investigating whether the LPC old/new effect indexes recollection in a graded manner, Wilding (2000) asked participants to indicate whether they recognised presented stimuli as old or whether they thought it was new before asking participants to make two different source judgements for items judged as old. While doing this, Wilding (2000) recorded EEG data to subsequently investigate differences in the LPC old/new effect and whether it modulated observed behaviour. The results indicated that the magnitude of the parietal old/new effect co-varied with the number of accurate source judgements. The fact that recollection appears to be reflected in a graded manner by the LPC old/new effect could be important in age investigations where recollection is argued to diminish. Indeed, as the late parietal old/new effect is observed to also be affected by temporal manipulations (Jones and Ward, 2019), this discovery makes it possible to infer the magnitude of the benefit that temporal structure during encoding can provide in differing age groups.

Not surprisingly, and as previously mentioned, recollection-based processes are thought to decrease with normal aging. Therefore, considering that the LPC effect, which is thought to be positively affected by a rhythmic as opposed to an arrhythmic structure during encoding in younger populations, one could quickly assume that older populations would show a similar, although reduced, effect. However, Murray et al. (2019) argue that while the LPC old/new effect still appears to reflect accurate recollection, they observed the effect as localised over inferior electrodes over the right as opposed to the left hemisphere in the older age group. This suggests that if an LPC old/new effect appears to be absent in older populations, potentially due to qualitative differences between older and younger populations. As such, remember judgements from older populations might still be representative of recollection even though a left inferior LPC old/new effect appears to be absent.

1.5.2 Memory Post-Processing and Monitoring in EEG. A third ERP component found to be relevant for recognition is the Late Frontal old/new Effect (LFE). Identifying it as starting at 800ms and potentially lasting until 2000ms post event, Goldmann et al. (2003) argue that the component is modulated by post-retrieval processes that are engaged when an individual encounters difficulty in making old/new discriminations of stimuli. More specifically, they argue that these post-retrieval processes appear to be present when neither a complete lack of recollection nor a clear recollection is present. This suggests that when lures are similar enough to trigger some recognition or when targets lack a sufficient recollection trace, individuals will engage in explicit attempts at deciding whether stimuli have been previously encountered. This, as opposed to stimuli which triggers a clear parietal response of recollection. However, studies such as that of Goldmann et al. (2003) tend to employ younger age samples making it difficult to translate these findings to an older population without further investigations.

Normal aging is associated with cognitive decline which can, as previously discussed, cause qualitative differences between age groups in how their cognitive functions operate. This makes it difficult to infer cognitive responses to recognition tasks in older age, based on younger age samples. Investigating differences in FN400, LPC and LFE between age groups during a recognition study, Wolk et al. (2009) support the notion that the LFE old/new increases as the FN400 and LPC attenuates with age. Of further interest, they did not only find a general effect where the FN400 and LPC decrease and LFE increase with age, but poorer preforming older adults showed a more prominent LFE effect than their better preforming peers. This supports the argument that the LFE is representative of increased explicit cognitive effort following a failed initial attempt to determine whether stimuli have been previously encountered. Consequently, it becomes an important component when investigating whether optimising encoding can benefit recognition memory in older adults, as decreased cognitive strain appears to be related to increased recognition accuracy.

Still, there is some debate regarding whether the LFE old/new effect is indicative of generic monitoring or decisional processes instead of processing specific to evaluating the outcome of episodic retrieval attempts. Hayama et al. (2008) conducted a study investigating whether this LFE old/new ERP component is symptomatic of specific or non-specific processing. In two experiments they asked participants to make semantic judgements both during study and testing and relating to both new and old items. They found that irrespective of when items were presented and whether they were considered old or new, right frontal effects reminiscent of the LFE were elicited whenever semantic judgements were required. This suggests that rather than being specific to outcome monitoring of episodic retrieval attempts, the LFE old/new ERP components is more indicative of a more general monitoring and decision process. Although the debate regarding the underlying process of the LFE can still be considered ongoing, it increases the need for caution when using the component in memory related EEG investigations. As an example, this seems relevant to experiments investigating source memory where the LFE is observed to be prominent (e.g,, Li et al., 2004). Still, it is likely to be useful in EEG investigations examining age differences in memory. For example, recognition paradigms that do not directly require participants to engage in semantic processing during retrieval will arguably only elicit an LFE effect when stimuli cannot be easily identified as either old or new. Thus, in aging, where recollective abilities are argued to be attenuated (e.g., Ward et al., 2020), the LFE is likely to be more prominent.

Interestingly, Wolk et al. (2009) found an attenuated LPC and FN400 old/new effect in older as compared to younger individuals. However, as already established, previous research suggests that familiarity-based processes remain largely unscathed in older age. Considering that the FN400 old/new effect is mainly associated with familiarity based processes, these observations appear to be contradicting. Wolk et al. (2009) suggest that such differences might appear due to differences in cognitive demand between incidental and intentional learning tasks, and that less attenuation is seen in older age following incidental when compared to intentional learning. Further explaining this argument, they suggest that since older individuals are less capable of engaging in successful intentional learning strategies, larger age differences occur following designs using intentional learning paradigms. This argument appears applicable to recollection-based processes associated with the LPC old/new effect as recollection is often argued to be weakened in older age. However, as established above, familiarity is argued to be less dependent on explicit learning strategies and should, therefore, be unaffected irrespective of whether learning occurs following incidental or intentional encoding. Indeed, this is supported by non-aging studies such as Jones and Ward (2019) who observed no significant difference in the FN400 old/new effect following temporally optimal contrasted with non-optimal encoding. Wolk et al. (2009) even suggest that their explanation is more applicable to LPC related findings. Considering the lack of a satisfactory explanation of why age differences in the FN400 old/new effect occurs, it is necessary to question whether Wolk et al. (2009) have committed a type one error. They conducted exploratory analyses on near-significant results, finding patterns in younger individuals which appear to be absent in older individuals. Specifically, they find a near-significant result following an ANOVA investigating the interaction between an old/new effect and age in the FN400. Still, they continue to determine that age differences are present as there is an old/new main effect of the FN400 in the younger age group which is lacking in the older age group. Although they appear to find trends by investigating their data this way, it is considered a questionable approach to analysis. As such it is difficult to determine that the FN400 old/new effect genuinely declines in aging without further investigations.

1.6 Summary

Past research has decisively shown that explicit memory decreases in normal aging, and the rate of decline has been shown to differ depending on processing demands. However, little has yet been done to attempt to ameliorate this memory decline. Both cognitive and neuroscientific measures agree that while familiarity-based processes are less impacted by aging and encoding manipulations, recollection processes are generally more affected by age and encoding environment. Indeed, previous research has shown that recognition memory can benefit from temporally predictive encoding conditions in younger adults. This benefit is likely due to such encoding conditions providing an attentional advantage for processing stimuli in temporally predictive conditions. Consequently, lowering the attentional demand during encoding can function as the attenuation of a cognitive bottleneck into recognition memory, allowing the production of recollective memories more easily. Although recollective cognitive functions are shown to decrease with age, the ability to entrain attention to temporally predictive information has been shown to remain largely intact in aging. As such, it is possible that a similar benefit to recognition memory will be observed in older populations by increasing temporal expectancy during encoding. That is, by removing the need to sustain attention outside temporally predictable points in time, the age-related memory deficit might be reduced.

1.7 Rationale for Pre-Registration

1.7.1 The Difference Between Predictions and Postdictions. Recently, it has been a growing concern that much of the scientific research within fields such as psychology and social science do not appear to replicate when independent groups of researchers attempt to do so. Nosek et al. (2018) address this issue when they discuss how prediction and postdiction affect the reliability of Null Hypothesis Significance Testing (NHST) differentially. Specifically, they suggest that a given *p*-value is diagnostic in relation to the confidence that can be placed upon an analytic result, following NHST, only when the hypothesis has been created by making predictions as opposed to postdictions. They illustrate this problem by explaining it as a garden of forking paths. Given that some significant results statistically will be type one errors, the probability of committing one is increased if one first attempts to find out where significant differences lie, and then commit to choices for how to analyse the data. Conversely, by first deciding on the analytic path before looking at the data, your chances of finding such a result are decreased and the probability of committing a type one error is equal to the stated *p* value, given that other methodological issues are not present. Indeed, logically, the probability of getting a type one error on one specific result is less than getting at least one in all possible comparisons in the dataset. Still, it is not uncommon to make multiple comparisons from one set of data, and although a pre-registration would make readers aware that this was intended, a pre-registration in itself is not sufficient to increase the replicability of research, if multiple comparisons have been made. As such, a preregistration ensures that researchers are indeed making predictions openly as opposed to postdictions, which is a requirement for the NHST to be of diagnostic value. Nevertheless, other factors might equally impact the replicability of conducted research.

1.7.2 The Issue with Multiple Comparisons. Although making predictions, as opposed to postdictions, is essential to maintain a diagnostic value when conducting the main analysis of a project, one could easily and credibly claim that actual predictions have been made, while simultaneously increasing the likelihood of a type one error. Spiegelhalter (2020) explains that significant results can almost be guaranteed, even when employing stringent criterions for which p values are considered to be indicative of significant differences, if a large number of multiple comparisons are made. An extreme example of this is Bennett et al. (2009), who conducted an experiment where they displayed a series of photographs depicting humans with a specified emotional valence to a dead adult salmon while recording fMRI. With a $p < 0.001$ criterion for significance, their analysis revealed that out of 8064 voxels, 16 voxels displayed a statistically significant response to the stimuli. They conclude that their results indicate a need to employ rigid controls for multiple comparisons to decrease the probability of claiming statistically significant differences, where there in reality are none. Spiegelhalter (2020) continue to suggest that using a simple Bonferroni correction will sufficiently lower the probability of conducting a type one error, due to multiple comparisons. It is feasible that design flaws, such as making multiple comparisons without sufficiently controlling for the increased probability of committing a type one error, is still contained in preregistered reports. However, a preregistration allows for more thorough scrutiny of such mistakes in conducted statistical analyses. The need to conduct research employing good project designs therefore neither starts, nor ends, with the need to preregister reports.

1.7.3 Open Science and Increased Replicability. Arguing that preregistered reports do not directly guarantee that studies will employ robust designs suggests that doing so provides little benefit beyond making it easier to identify that researchers in fact predicted as opposed to postdicted their hypotheses. However, the benefit arguably extends further. As Nosek et al. (2018) suggest, preregistration removes the influence of motivation to affect results in a certain manner, in addition to memory and reasoning biases. This renders results less prone to a range of potential human errors. In fact, there is some evidence to suggest that preregistered reports positively affect the ability to replicate results. Swaen et al. (2001) conducted a correlational study and found that *a priori* hypothesising is related to increased replicability. This in itself is not conclusively arguing that preregistration resolves all issues related to replicability, which would ensure that fields such as neuroscience and psychology remain relevant in improving the current understanding. However, it does provide some support for preregistration as a means to improve the utility of research.

1.7.4 Opening Science to Scrutiny. As established, promoting and using good research and statistical practices is essential to providing valuable knowledge, further informing the current understanding of a given scientific field. Still, as both Spiegelhalter (2020) and Nosek et al. (2018) suggest, it is not uncommon to see inadequate design, inappropriate assumptions, biased data and generally poor scientific practice. Furthermore, they also maintain that faults of this nature can easily be hidden, through omitting to report them in final reports. Although, it is possible to conduct perfectly valid research, which adequately acknowledges its faults, the opposite appears to be prevalent. Whether such faults occur by intention or through unconscious biases can be a topic of discussion, but these near invisible faults appear too often. However, by submitting a detailed preregistration to an independent party prior to conducting any research beyond a planning stage, one is able to properly scrutinise the quality of a project and investigate whether it has remained true to its initial plan. In addition, such preregistrations can encourage researchers to provide a timestamped update detailing why certain changes were made to the project. This ensures that other researchers are able to view a verified timeline of when and how changes were made, and how the project as a whole was conducted. This arguably allows others to better identify the impact of changes that were deemed necessary but could not be foreseen prior to a given stage. In addition, it allows others to better identify poor design, as it becomes more difficult to hide or omit in a final report. In conclusion, preregistration becomes a valuable tool in differentiating between when pre- and postdictions are made. In addition, it could arguably become vital in combating other poor scientific practices, such as making multiple comparisons without proper statistical control, by making it more transparent when substandard practices are employed.

1.8 Aims and Predictions

No prior study has investigated the effect of rhythmic encoding on memory in aging. Therefore, the current study aims to investigate whether the observed benefit to recognition memory as a function of rhythmic encoding in younger adults can be observed in older adults. The project was pre-registered on the OSF here: https://osf.io/52vkr. As has been reviewed, there is evidence that temporal function is preserved with age, and that the benefit of rhythm to memory occurs outside of conscious control (i.e., participants are generally unaware of temporal manipulations). Therefore, this leads to the prediction that rhythmic encoding will provide a benefit to memory in aging. More specifically, based on a wealth of evidence that recognition memory is reduced in older compared to younger adults, it is hypothesised that: (1) Younger individuals will show greater recognition (d prime) compared to older individuals (main effect of Age [young, older]). (2) rhythmic temporal structure will be associated with greater recognition (d prime) than arrhythmic temporal structure (main effect of Temporal Structure [rhythmic, arrhythmic]). This is predicted on the basis of prior evidence that rhythmic/structured presentation of information is associated with greater recognition than arrhythmic/unstructured presentation (see Jones & Ward, 2019). (3) There will be an interaction between Age and Temporal structure, with a smaller age difference in recognition (*d*`) in the rhythmic relative to the arrhythmic encoding condition (see Figure 1 for a visual illustration of behavioural predictions).

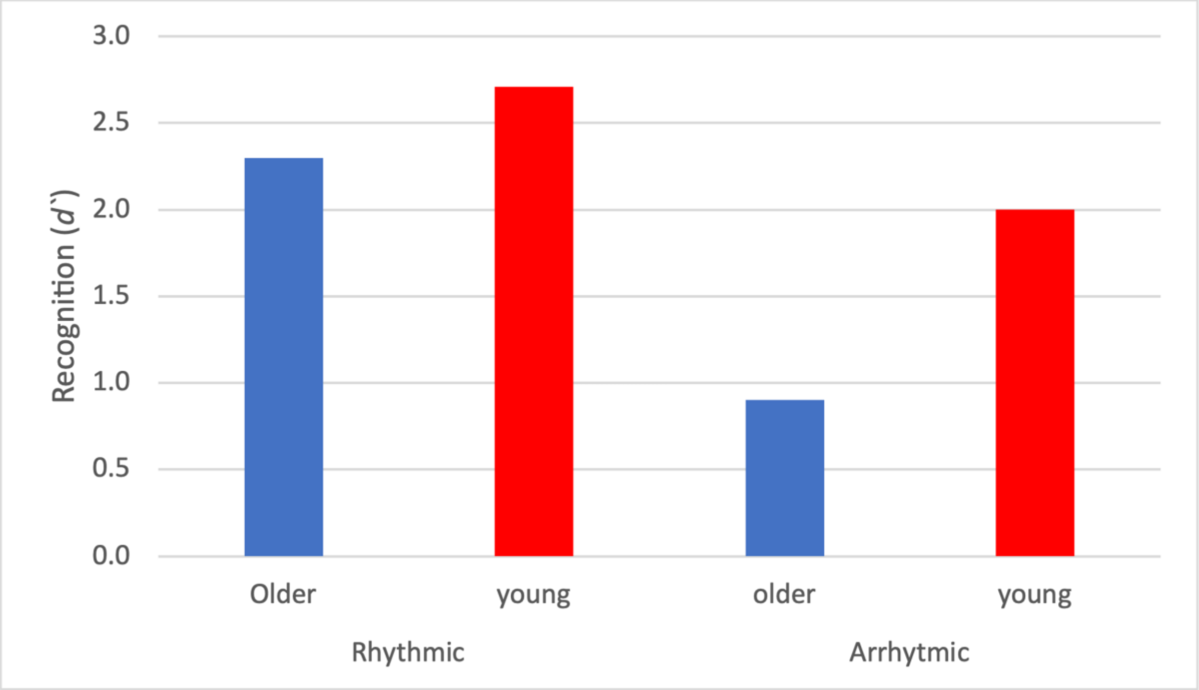

Figure 1. Predicted age differences in recognition (*d*`) following rhythmic and arrhythmic encoding.

The current study also aims to investigate these questions by utilising EEG through analysing ERPs to gain a better understanding of how these differences manifest at a neuronal level. Firstly, relating to the FN400 ERP component, (4) a main effect of Item (old/new) is predicted, (5) and a main effect of Age with a significantly greater effect in younger than older individuals. (6) Additionally, based on Jones and Ward (2019), no main effect of Temporal Structure is predicted. (7) Finally, it is hypothesised that no interaction between Age, Item (old/new) and Temporal Structure will occur. However, based on the observations of Wolk et al. (2009), an interaction between Age and Item is predicted with an attenuated effect of Item in older age.

Relevant to the LPC ERP component, (8) a main effect of Item with a higher positive amplitude for old compared to new items is expected. (9) In addition, a main effect of Age with a significantly attenuated effect in older when compared to younger individuals is expected. (10) Furthermore, it is predicted that a main effect of Temporal Structure, with a significant difference in amplitude in the rhythmic compared to the arrhythmic condition, will be observed. (11) Additionally, it is hypothesised that a significant interaction between Age, Temporal Structure and Item, with a significantly smaller age difference and a significantly larger old/new effect in the LPC in the rhythmic condition than the arrhythmic condition, will be revealed.

Regarding the final ERP component, the LFE old/new effect, (12) it is predicted that a significant main effect of Age with a greater effect in older than young adults will occur. It is difficult to make any further strong predictions due to lacking relevant literature. Still, (13) it is hypothesised that if the LFE effect is associated with overall worse memory based on encoding (rather than retrieval), then similar effects as outlined for the LPC regarding the main effect of Temporal Structure and (14) the interaction between Age and Temporal Structure are predicted. However, if the LFE is not affected by temporal prediction at encoding, then a main effect of Age but no main effect of Temporal Structure or an interaction effect between Age and Temporal Structure (rhythmic/arrhythmic) is expected.

2.0 Methods

2.1 Participants

Based on the behavioural analysis plan, an *a priori* power analysis using G*Power, was conducted to determine the necessary sample size for the current experiment (Faul et al., 2007). It is difficult to determine the level at which a decrease in recognition memory can be considered to have noticeably impacted daily functioning. Nevertheless, although there are no studies that have made the comparisons to those planned in the current study, Jones and Ward (2019) found an effect size of $d = 0.30$ in recognition between temporal conditions in their behavioural findings. Still, minor behavioural changes can be considered to be trivial as they are less impactful on daily life. As such, to power the sample for main effects in the behavioural analysis, a medium effect size, as outlined by Cohen (1988) was used ($f = .25$) in the power analysis. The probability of type two errors is generally given less attention than the probability of type one errors in the literature, and indeed, it is common to set power at .80 in *a priori* power analyses. However, as is becoming increasingly common, for the current study power was set at .95. With an a-error probability at .05 the power analysis determined a necessary sample size of 54 participants with 27 in the young group (18-30 years of age) and 27 in the older adult group (65+ years of age).

As inclusion criterions to the study, it was required that participants did not display and signs of dementia or photosensitive epilepsy, had normal or corrected vision and were fluent in English. Young participants (aged 18 to 26 years, M = 23.5, SD = 2.22) were sampled from the student population at Middlesex University, and older adults were due to be recruited from the University of the Third Age (U3A). However, as outlined in the Preface, due to UK Government restrictions implemented during the Covid-19 epidemic, data collection was stopped prematurely for an ongoing and indefinite period. At the time of writing, the UK is now in a third national lockdown and in person testing is still not permitted at Middlesex University. Consequently, only 10 younger participants were recruited to partake in the study, and no older participants. Of the 10 younger participants, one was excluded from the EEG analysis as their data became corrupted. Thus, the study collected behavioural data from 10 and EEG data from 9 participants. Of these 10 participants, 4 were male and 6 were female.

In addition to recording basic demographic data such as age, sex, and years of formal education, the current study also intended to collect background data to screen participants and potentially use as covariates in analyses. This included the Wechsler's Test of Adult Reading (WTAR, see appendix A, Wechsler, 2001) to assess premorbid intelligence, the Digit Symbol Substitution Test processing speed task of the WAIS-IV (see Appendix B, Wechsler, 2008) to assess processing speed (Table 1). As the study is focussed on normal aging, a key inclusion criterion was that participants do not have Mild Cognitive Impairment or dementia, hence it was planned to screen older participants using the Mini Mental State Exam (MMSE, see Appendix C, Folstein et al., 1975). Due to the absence of a sample of older participants, no MMSE data was collected. When prompted to specify whether they noticed any differences between blocks immediately following participation, 3 participants were considered to have become aware of the temporal manipulation during testing (see Procedure). The purpose of gauging awareness was to enable further analysis on aware versus unaware participants if sufficient number of participants allow, so the aware participants were not removed from analysis. All participants were awarded with a £20 gift voucher as a thank you for their time.

Table 1. Mean and Standard Deviation of Participants' data on Years of Education and performance on the WTAR and WAIS-IV Processing Speed Task.

	M (SD)
Years of Education	17.3 (3.47)
WTAR	43.8 (8.47)
WAIS-IV Digit Symbol Substitution subtest	75.8 (25.12)

Note: The WAIS-IV Digit Symbol Substitution subtest and the WTAR have maximum scores of 133 and 50, respectively.

2.2 Design

The behavioural experiment planned to use a mixed factorial design with a within-subjects factor Temporal Structure containing 2 levels (rhythmic and arrhythmic presentation of stimuli during encoding) and a quasi-independent between-subjects factor Age with 2 levels (young [aged 18 to 30 years] and older [aged 65 years of age and above] adults). As an outcome variable for the behavioural recognition data, the study used d prime scores (d` = z[hits] minus z[false alarms]).

As mentioned, only a small sample of young participants was able to be collected during this MSc by Research and this thesis therefore presents a proof-of-concept. Jones and Ward (2019) found an effect of a temporal structure on recognition in a sample with a mean age of 23.3 years. As the current study recruited a similar (albeit much smaller) sample of young adults, the study therefore provides an important opportunity to examine whether the results of Jones and Ward (2019) can be replicated. The design of the EEG aspect of the investigation also initially intended to utilise both the within-subjects variable Temporal Structure and the between-subjects variable Age, as well as the factor Item (Old vs New) as an additional within-subjects variable to investigate differences in amplitude at each component individually. However, as there is no older adult group, the design resulted in a 2x2 (Temporal Structure vs. Item) ANOVA for each component at the Fz(FN400), P3(LPC) and F2(LFE) electrodes.

2.3 Materials and stimuli

The experimental task was created in E-Prime 3 and includes 480 400 x 400 pixel grayscale images of familiar everyday objects (e.g., a car, a fork [see Figure 2]). The experiment was comprised of six blocks made up of an encoding and recognition test phase. Each of the six blocks contained a unique set of 40 images in the encoding phase. These images were reused in the recognition phase along with a new unique set of 40 previously unseen images, totalling 80 images per block. The 40 images in the encoding phase were randomly interspersed between 120 (400 x 400 pixel) checkerboard images, resulting in a ratio of three checkerboards per real object presented. A minimum of one checkerboard was displayed after every object, resulting in the remaining checkerboards being dispersed randomly throughout the encoding phase (see Figure 3 for an overview of the study paradigm). Each encoding phase also contained between two and six images of animals (varied in number to remain unpredictable) which functioned as target items that participants were asked to detect as quickly as possible through a spacebar keypress. Three additional checkerboards were added per animal. Images of animals were not presented in the test phase. Consequently, it is noteworthy that both the stimuli and the experimental task was the same as in Jones and Ward (2019) with the only difference being that the E-Prime 3 software, as opposed to MATLAB 2013a, was used to make and deliver the experimental task.

Figure 2 Example of an image used as stimuli during the experiment.

2.4 Procedure:

The construction of the experimental paradigm involved constructing and implementing code responsible for tracking and backdating recognition decisions to images presented at encoding. This was done to make exploratory analysis of processing of items in the rhythmic and arrhythmic conditions at encoding possible at the analysis stage. Furthermore, dependent on both software and hardware, computers are limited in their ability to display stimuli on screen at exact specified times. As this could potentially limit the efficacy of a rhythmic temporal encoding condition, it was important to control and limit this delay as much as possible. By using secondary computer and an EEG light-diode attached to the middle of the 240Hz computer screen used in the experiment, it was possible to observe the display-rate delays down to a single millisecond. By condensing program-code to make computer processing more effective, this made it possible to ensure that the delay in display timings was consistently limited to one millisecond. Currently, this is the minimum response time that is available on commercially accessible computer displays, and as such deemed to be optimal as this delay was due to hardware, rather than software limitations.

Before participation, participants were informed that the approximate experiment length was two hours including setup and debrief. Upon arrival, participants were first asked to read the information sheet (see Appendix D) and sign a consent form (see Appendix E) before they were fitted an EEG cap and electrodes were attached (see EEG setup below). The experimental task contained six blocks, three rhythmic presentation timings during encoding and three with arrhythmic timings. The rhythmic and arrhythmic blocks were alternated. The recognition phase of each block remained structurally unchanged across both rhythmic and arrhythmic blocks. The image sets were counterbalanced with two image conditions, meaning that the image set presented as new and old were alternated between participants. Furthermore, blocks were presented in one of four possible block orders, labelling the block as Rhythmic and Arrhythmic 1 to 3. The first participant was presented with blocks starting from Rhythmic 1 through Arrhythmic 3, the second from Arrhythmic 1 through Rhythmic 3, the third from Rhythmic 3 through Arrhythmic 1 and the final version presented blocks from Arrhythmic 3 through Rhythmic 1. In a repeating pattern, the block order was alternated between each participant whilst the image condition changed after every fourth participant to ensure that all possible iterations were completed in turn. During encoding in each block, a central fixation cross was presented during the ISI. The duration of the fixation crosses was kept constant at 600 msec in the rhythmic condition and presented for a random interval between 70 – 1130 msec in the arrhythmic condition. (see Figure 3). These upper and lower limits for the fixation cross durations in the arrhythmic condition were based on Jones and Ward (2019), importantly the minimum and maximum durations are evenly distributed around a mean of 600msec, keeping the average trial duration constant at 600msec. As such, although items (images and checkerboards) were presented for precisely 600 msec in all blocks, item onset was predictable in the rhythmic condition and unpredictable in the arrhythmic condition.

In all encoding phases, participants were asked to detect animals as quickly as possible by making a spacebar keypress. They were informed that they would later be tested on their memory of the items shown in this phase. To encourage participants to closely attend to stimuli, they were presented with feedback on the number of correct and incorrect responses after each encoding task finished. Following the encoding phase, participants were asked to complete simple algorithmic problems for 30 seconds as a filler task. The final aspect of each block was the recognition phase. Here, the fixation crosses were displayed at a random interval between 70 – 1130msec to avoid any interference related to the expectation of event onset to affect EEG results (see figure 3b). Participants were further presented with individual items and asked to make a recognition judgement in relation to whether they believe that item was previously studied or new. Each object was displayed for 1000ms, before the instruction “Was this object shown in the last detection task?” and a response scale “6 = sure yes, 5 = think yes, 4 = guess yes, 3 = guess no, 2 = think no, 1 = sure no” was displayed alongside the image until the participant made a response. In the recognition phase, half of the objects were taken from the encoding phase immediately prior, and the other half were novel images. The purpose of using the response scale was to capture a broad range of old/new responses and minimise response bias, but responses 1-3 indicating a new image response and 4-6 indicating an old image response were collapsed respectively for analysis. Participants were made aware that half of the items in the test phase were previously studied and asked to use the full range of response options. EEG was recorded from 64 locations on the scalp throughout the experiment. Immediately following the completion of the experiment, participants completed a brief questionnaire to gauge their awareness of the temporal manipulation (see Appendix F), participants who correctly identified the temporal manipulations were further asked whether awareness occurred following or during completion of the task. Following this, participants completed the WTAR, which requires participants to read aloud 50 uncommon English words. In addition, they completed the WAIS-IV processing speed subtest, which requires participants to complete as much of a grid of symbols associated with numbers as they can in two minutes. Once these tests were finished, they received a debrief form (see Appendix G) and their £20 reward.

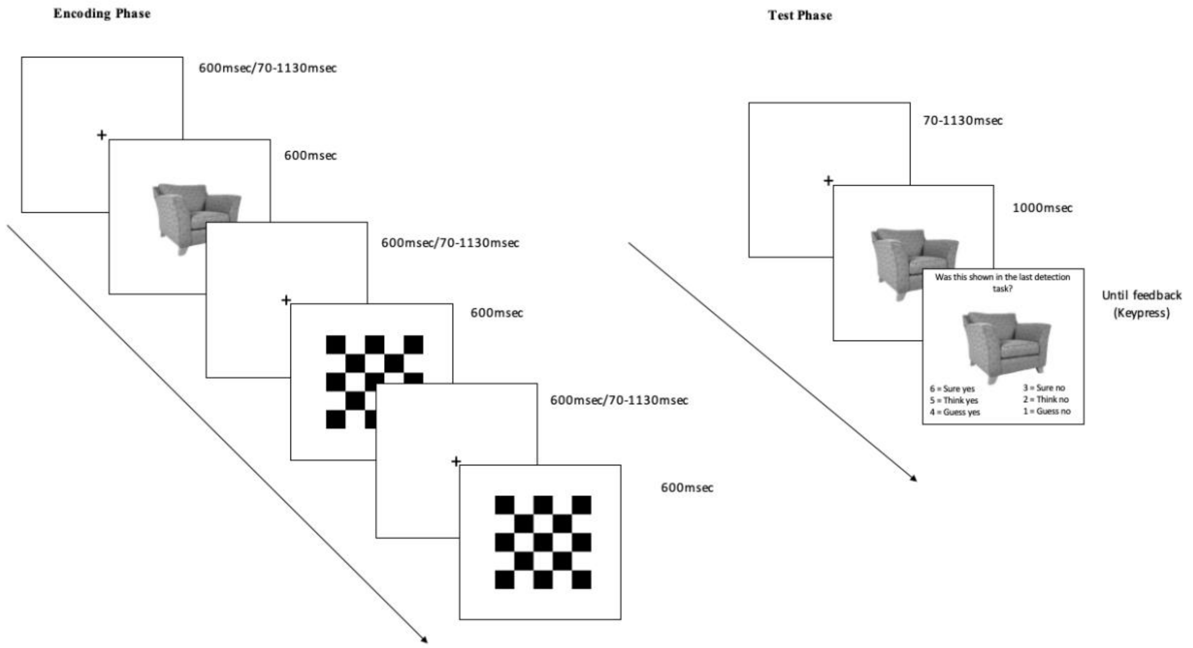

Figure 3 Left (Encoding Phase): an overview of the experimental paradigm during the encoding phase with either a random (arrhythmic) or fixed (rhythmic) duration fixation cross (ISI) preceding each display of checkerboard or image. **Right (Test Phase)**: an overview of the experimental paradigm during the recognition phase with a random duration fixation cross

preceding a 1000 msec display of an old/new object followed by a recognition response options.

2.5 EEG Pre-analysis and Analyses

2.5.1 EEG Pre-processing. The Brain Vision actiCHamp Plus amplifier was employed during recording and a sampling rate of 1000Hz was used throughout EEG data collection. All filters were applied offline and pre-processing of the EEG data was conducted in Brain Vision Analyzer 2 (BVA). Bad channels were topographically interpolated on a participant-by-participant basis. However, channels that were to be included in the analysis, i.e. Fz, F2, P3, PO7 or PO8, were not interpolated. A second-order Butterworth zero-phase bandpass filter with a high cut-off of 40Hz and low cut-off of 0.1Hz with a 50Hz zero-phase notch filter was applied to each participant's continuous data. An average of all 64 electrodes was used to re-reference the data offline. Using independent component analysis in BVA, ocular correction was conducted in a semi-automatic mode. ERPs at encoding were epoched into 900-msec segments, ranging from 100 msec pre-stimulus onset to 800 msec post-stimulus onset. At retrieval a 1100-msec epoch was used with 100-msec before and 1000-msec after stimulus onset. A 100-msec baseline correction was performed on each ERP. This was done by subtracting the mean voltage in the 100msec pre-stimulus onset interval from the ERP at every voltage point (1/msec). Artifact rejection was performed on all channels excluding segments with amplitudes of ±100 μV.

2.5.2 ERP Analysis Plan. For the EEG recognition task analysis, average ERPs was computed for each participant in each of the temporal conditions, separately for hits, misses, correct rejections, and false alarms. Comparisons for all components were made using mean amplitudes for hits (old) and correct rejections (new). This was done at the midfrontal electrode Fz in the 300–500 msec interval for the FN400 and at the left parietal electrode P3 in the 500–

800 msec and 800-1000 msec interval for the LPC. In addition, mean amplitudes were compared for hits (old) and correct rejections (new) at midfrontal electrode F2 in the 800-1000msec interval for the LFE. For the FN400 and LPC, the electrode choice and time intervals were based upon well-established literature (for a review, see Rugg & Curran, 2007) and were the same as both Bergström et al. (2016) and Jones and Ward (2019). The LFE has been reported across different time intervals lasting longer than the FN400 and LPC. In the current study, the selection of time interval for the LFE component was based on Wolk et al. (2009) who suggested that the LFE can last for up to 1000msec post-stimulus, although it has also been mentioned as lasting longer (e.g., Curran et al., 2001). It is noteworthy for the current study that Wolk et al. (2009) maintain that age differences became more evident after 800msec. In addition, the LFE is reported to be preferentially associated with the right frontal area of the brain, such as in Wolk et al. (2009); consequently, the F2 electrode was chosen to investigate the LFE component.

2.5.3 Phase-Locking Factor Analysis Plan. The following steps were outlined in the preregistration and were planned to primarily investigate the differences in coherence of the relevant phase angle of EEG oscillations in different age groups across trials. However, as an age comparison was not possible the analysis has not been conducted in the present thesis. The description of this planned analysis has been included for transparency, and it is our intention to conduct this analysis when the project can eventually be completed in the future (not as part of this MSc by Research). The Phase-Locking Factor (PLF) analysis on the encoding data will involve segmenting the EEG data into 2000-msec segments, with 1000-msec prior to and 1000-msec post-stimulus onset. This data will be segmented separately for objects and checkerboards in the rhythmic and arrhythmic conditions. The following pre-processing steps will be identical to those described in relation to the ERP analysis: filtering, re-referencing, independent component analysis correction and topographical interpolation. Using a 100-msec pre-stimulus as baseline correction, artifact rejection will be performed on all channels, excluding segments with amplitudes of ±100 μV in the -200- to 600-msec time interval. Rejected segments will be further marked as bad segments before markers are reimported to perform an analysis on non-baseline-corrected data. A complex Morlet wavelets (Morlet parameter c = 3) analysis will be conducted on each segment, and one layer will be transformed with a central frequency of 1.67Hz (1.21-2.13Hz). PLF across trials will be computed for each time point for electrodes P07 and P08. This electrode choice is based on what was used in Jones and Ward (2019) to investigate phase-locking visual stimuli. An average value will be computed 200 msec before stimulus onset to be used for analysis in order to avoid stimulus onset artifacts (Notbohm & Herrmann, 2016). Finally, the PLF will be submitted to a 2x2x2x2 repeated-measures ANOVA with Age (old, young), Temporal structure (rhythmic, arrhythmic), Object type (objects, checkerboards) and Electrode (P07, P08) as manipulated variables.

3.0 Results

The current study employed an alpha level of .05 in all statistical tests, however, a Bonferroni correction was applied when multiple comparisons were made. Cohen's *d* effect sizes are reported for *t* tests, and partial eta square for ANOVA effects. Furthermore, all *t* tests were two-tailed. Data was collapsed across blocks except for in analyses where block order was made relevant. Subsequently, data was entered into JASP which served as the software in which statistical analyses were conducted.

3.1 Behavioural Results

3.1.1 Detection task. During the detection task, the number of correctly detected targets (animals) and their associated RT in addition to the number of erroneous keypresses when targets were not presented were recorded. This data was then further collapsed across the rhythmic and arrhythmic temporal structures (see Table 2). There was no significant difference between temporal conditions in relation to correct detection of targets ($t(9) = 1.51$, $p = .164$, $d = -0.48$) and the associated detection RT ($t(9) = -0.19$, $p = .854$, $d = -0.06$). However, participants made significantly fewer erroneous keypresses in the arrhythmic compared to the rhythmic condition ($t(9) = 5.80$, $p < .001$, $d = 1.84$).

Table 2. Detection Task performance collapsed across the rhythmic and arrhythmic conditions.

	Rhythmic M (SD)	Arrhythmic M (SD)	
Correct detection of targets (%)	91.19 (13.57)	93.67 (12.39)	ns
Erroneous keypresses (%)	0.64 (0.35)	0.01 (0.01)	$p < .001$
RT (Correct)	519.08 (90.03)	524.33 (109.66)	ns

3.1.2 Recognition task. In each block in the recognition phase; responses 1-3 were coded as a ‘no’ (new-item) response while 4-6 responses were collapsed into a ‘yes’ (old-item) response. See Table 3 for proportion of hits, false alarms, misses (‘no’ responses to old items) and correct rejections (‘no’ responses to new items) and Figure 4 for an overview of recognition (*d*`) collapsed across temporal conditions. d` was calculated as the z-transformed hit rate (proportion of old items correctly judged as old) minus the z-transformed false-alarm rate (proportion of new items incorrectly judged as old) (Ward et al., 2020). As a z transform of either 0 or 1 reaches infinity, d` cannot be properly calculated with a z transform for hits or false alarms with either of these values. Therefore, a correction suggested in the literature such as in Snodgrass & Corwin (1988), was applied to participants with ceiling effects prior to calculating d`:

$$\text{Hit rate} = (n \text{ Hits} + 0.5) / (n \text{ old} + 1);$$

$$\text{FA rate} = (n \text{ FAs} + 0.5) / (n \text{ new} + 1)$$

In this correction, '*n*' represents the total number of trials relevant for the stimulus in question. Thus, this procedure serves to make the calculation of d` possible while simultaneously reducing the statistical bias in the estimation of d`. Indeed, as Macmillan and Kaplan (1985) suggest, this correction takes into consideration the number of trials the ceiling effect results from, thus a perfect score following 40 trials is given a higher d` value than the same result following only 5 trials.

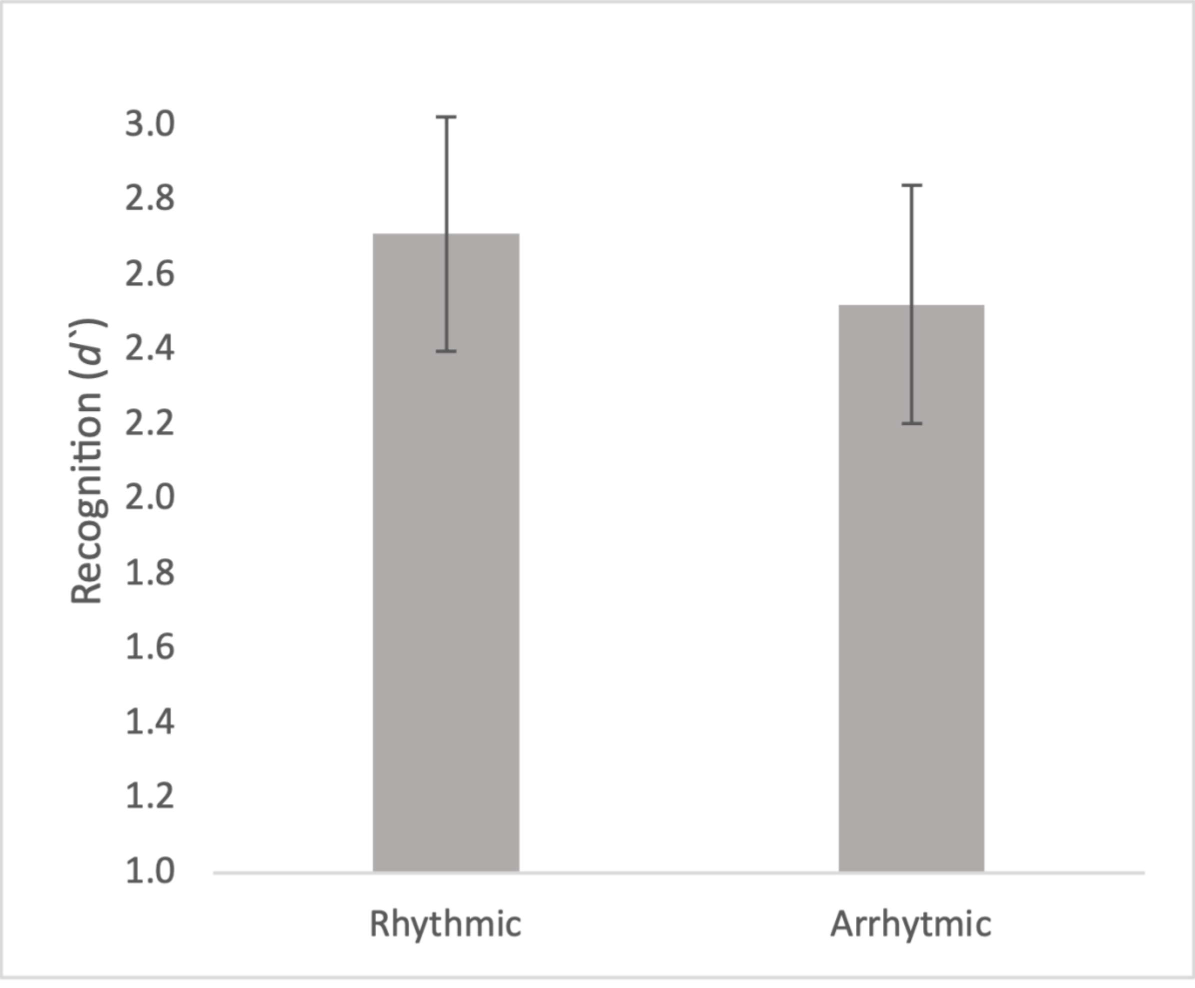

Figure 4. Recognition (d') for the rhythmic and arrhythmic temporal conditions collapsed across blocks. Error bars indicate the standard error of the mean.

Collapsing temporal conditions across blocks, recognition in both the rhythmic ($t(9) = 8.62$, $p < .001$, $d = 2.73$) and arrhythmic ($t(9) = 7.53$, $p < .001$, $d = 2.40$) temporal conditions differed significantly from chance. This suggests that the task functioned as expected and was able to yield above chance recognition in participants. However, despite the numerically greater recognition in the rhythmic than the arrhythmic condition, recognition did not differ significantly between the rhythmic (M = 2.71, SD = 0.99) and the arrhythmic (M = 2.62, SD = 1.09) temporal conditions ($t(9) = 0.61$, $p = .555$, $d = 0.19$). A repeated measures ANOVA was conducted to investigate possible variations in recognition accuracy across blocks. This indicated no significant main effect of block (F(5, 40) = 1.17, $p = .339$, $\eta_p^2 = 0.13$). and no significant main effect of the counterbalanced order of blocks (F(1, 8) = 0.03, $p = .859$, $\eta_p^2 = 0.004$), in addition to no significant interaction (F(1, 40) = 1.06, $p = .399$, $\eta_p^2 = 0.12$). Therefore, recognition did not vary significantly as a function of the temporal manipulation nor the order of blocks.

Table 3. Top: proportion of Hits, Misses, False Alarms and Correct Rejections for both temporal conditions. Bottom: Associated RTs for each recognition response type in both temporal conditions.

	Rhythmic M (SD)	Arrhythmic M (SD)
Hits	0.89 (0.10)	0.87 (0.13)
Misses	0.11 (0.10)	0.13 (0.14)
False Alarms	0.14 (0.16)	0.14 (0.15)
Correct Rejections	0.86 (0.16)	0.86 (0.15)
RT Hits	885 (894)	769 (598)
RT Misses	1479 (1058)	2260 (1447)
RT False Alarms	2473 (1367)	2611 (1748)
RT Correct Rejections	1150 (1135)	1100 (1163)

Across all blocks, the mean RTs for recognition judgements did not differ in the rhythmic (M= 1443msec; SD = 1044msec) and arrhythmic (M = 1638msec; SD = 1094msec) temporal conditions ($t(9) = -1.47$, $p = .176$, d = -0.47). Furthermore, RTs were analysed using a repeated measures ANOVA for each temporal condition according to whether recognition responses were hits, misses, false alarms or correct rejections (see Table 2). This analysis uncovered a significant main effect for both the rhythmic condition (F(3, 24) = 12.40, $p < .001$, $\eta_p^2 = 0.61$) and the arrhythmic condition (F(3, 24) = 10.04, $p < .001$, $\eta_p^2 = 0.56$). RT results were similar for both temporal conditions with hits being significantly faster than false alarms and misses while correct rejections being significantly faster than false alarms (all *t*'s > 3, *p*'s < .008). No other comparisons returned a significant result after a Bonferroni correction of .008 was applied.

To investigate the impact of test-awareness during encoding, comparisons were made between participants considered aware and unaware. A 2x2 ANOVA revealed no significant difference between the three aware (*M* = 3.28, *SD* = 0.61) and seven unaware (*M* = 2.40, *SD* = 1.11) participants in d` (*F*(1, 8) = 1.67, *p* = .232). In addition, no significant interaction between test awareness and temporal condition was uncovered in d` (*F*(1, 8) = 1.19, *p* = .307).

3.2 EEG Results

3.2.1 FN400 Analysis. Following an ANOVA investigating the differences in the FN400 component due to Temporal Structure and Item, it was uncovered that there was a significant effect of Item with a higher positive amplitude in the old item condition (F(1, 8) = 12.362, $p = .008$, $\eta_p^2 = .607$) (see Figure 5). However, the analysis revealed no significant effect of Temporal Structure (F(1, 8) = 0.170, $p = .691$, $\eta_p^2 = .021$) and no significant interaction between Item and Temporal Structure (F(1, 8) = 1.851, $p = 211$, $\eta_p^2 = .188$) on the FN400 component.

3.2.2 LPC Analysis. Relating to the LPC component, an ANOVA revealed a significant effect of Temporal Structure (F(1, 8) = 5.932, $p = .041$, $\eta_p^2 = .426$) with a higher positive amplitude in the arrhythmic temporal condition. Conversely, no significant differences on the LPC component were found due to Item (F(1, 8) = 2.138, $p = .182$, $\eta_p^2 = .211$) and no significant interaction effect on the LPC component between Item and Temporal Condition was uncovered (F(1, 8) = 0.302, p = .598, η_p^2 = .036).

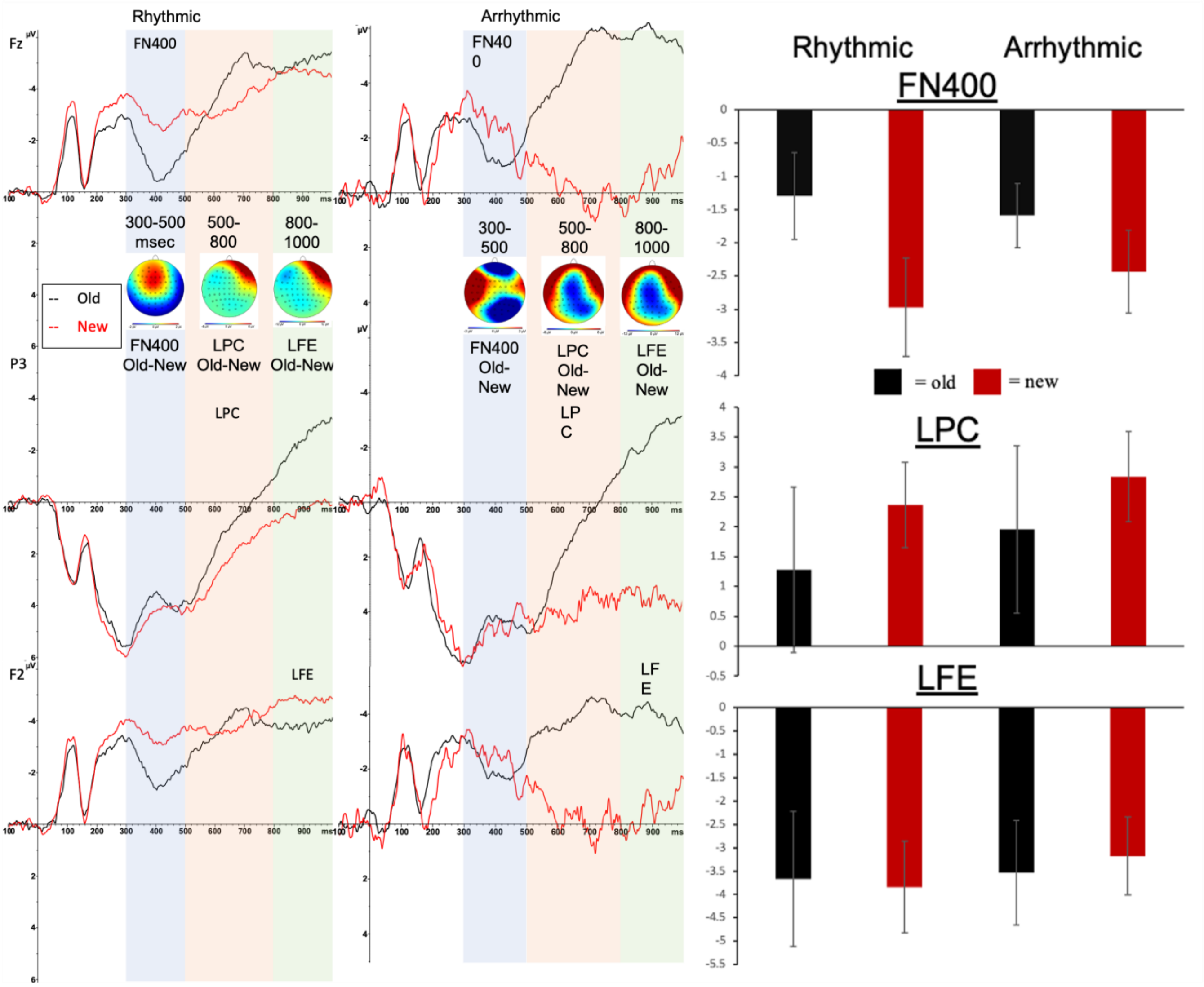

Figure 5. Left: Grand-averaged ERP waveforms for new/correct rejection (red) and old/hits (black) items during recognition testing. ERP waveforms are further divided by items presented during arrhythmically and rhythmically presented encoding. X-axis represents time with 0 msec representing event onset, while the Y-axis displays ERP amplitude (µV). The top ERP waveform shows Fz-electrodes relevant to the FN400 analysis in the 300-500 msec interval (blue shaded area). The middle ERP waveform displays P3 electrodes used in the analysis of the LPC component in the 500-800 msec time interval (pink shaded area). The bottom ERP waveform shows F2 electrodes included in the LFE analysis in the 800-1000msec time interval (green shaded area). **Right (top):** Averaged ERP amplitudes at the Fz electrode in the 300-500msec interval for new (red) and old (black) trials. **Right (middle):** Averaged ERP

amplitudes at the P3 electrode in the 500-800msec interval for new (red) and old (black) trials. **Right (bottom):** Averaged ERP amplitudes at the F2 electrode in the 800-1000msec interval for new (red) and old (black) trials.

3.2.3 LFE Analysis. Finally, investigating differences due to manipulated variables on the LFE component, an ANOVA uncovered no significant differences due to Temporal Structure ($F(1, 8) = 0.375$, $p = .557$, $\eta_p^2 = .045$), no significant differences due to Item ($F(1, 8) = 2.714$, $p = .138$, $\eta_p^2 = .253$) and no significant interaction effect between Temporal Structure and Item on the LFE component ($F(1, 8) = 0.57$, $p = .817$, $\eta_p^2 = .007$).

4.0 Discussion

4.1. Current Implications

The current study initially intended to extend upon the results of Jones and Ward (2019), to investigate whether temporal structure during encoding can improve subsequent recognition in older adults, helping to ameliorate the typical memory decline seen in normal aging. Furthermore, it aimed to examine the underlying neural processes using EEG, to shed light on potential differences in processing of items in rhythmic versus arrhythmic conditions by specifically looking at the LFE component, as well as two EEG components common to recognition, the FN400 and LPC. As previously discussed, however, data collection was unfortunately cut short due to imposed restrictions following the Covid-19 pandemic. As such, the presented thesis is a proof-of-concept supplying a tested and finished experimental task and an analysis pipeline to be used in the future completion of the originally planned version of the project including the required full samples of young and older adults. Regardless, it is important to remain aware that, due to the mentioned difficulties relating to data collection, this is an underpowered study. Consequently, the provided interpretations of null-effects should be considered speculatory, as sufficient data to provide reasonably confident claims of their prevalence is lacking. Relating to this, the current study analysed the data based on a preregistered pipeline. However, in hindsight, it would have been beneficial to include a Bayes factor analysis (Dienes, 2014) in this analysis-pipeline, as this would make the current findings more credible.

Relating to behavioural predictions, the current study failed to support the prediction that a rhythmic temporal structure, compared to an arrhythmic temporal structure, during encoding would result in greater subsequent recognition of presented stimuli. Nevertheless, a numerical trend with greater recognition in the rhythmic than the arrhythmic condition was observed, an effect that could become significant with adequate power. The lack of significant difference in recognition in the rhythmic and arrhythmic conditions does not appear to be due to a relatively high proportion of test aware participants, as there were no evident differences in performance between aware and unaware participants. Conversely and as expected, the EEG analysis revealed a significant old/new effect in the FN400 component with a larger positive amplitude for old items when compared to new, thus, replicating well established effects (Curran, 1999, 2000; Curran & Cleary, 2003; Duarte et al., 2004; E. Düzel et al., 2001; Rugg & Curran, 2007). Notably, there was no observed old/new effect in the LPC in either the rhythmic or arrhythmic conditions. However, a difference in the LPC at recognition was discovered due to temporal structure. In the final component, LFE, there was no uncovered old/new effect and no effect due to temporal structure. Similarly, the analysis uncovered no significant interaction between these two conditions on the LFE.

4.2 Assessment of the Current Behavioural Paradigm.

4.2.1 Task Length and Cognitive Fatigue. The completion time of the experimental task varied depending on each participant as they, to a degree, controlled the progression speed during the recognition phase and the length of breaks between blocks. However, participation took roughly 2 hours. This is of concern as experiments of similar lengths have observed cognitive fatigue due to the attentional and general cognitive demands placed upon participants, which has significantly impacted findings (van der Linden & Eling, 2006). Nevertheless, this is unlikely to have impacted the current results as there were no observed differences in recognition accuracy across either rhythmic or arrhythmic blocks or any prevalent differences between counterbalancing orders. This, viewed in unison with the observed general high ability to discriminate between new and old stimuli, suggests that if any cognitive or attentional fatigue did occur, it was not sufficient to impact the current results. For the current study this provides promise as it suggests that the paradigm is effective in examining recognition and that this ability is retained throughout the experiment.

Although no attentional or other relevant cognitive fatigue appears to have occurred in a young sample, it cannot be certain that this will apply to older age groups while using the current paradigm. Indeed, Wascher and Getzmann (2014) have shown that it is possible that a paradigm elicits no evident attentional deficit due to mental fatigue in a younger sample, while the same paradigm causes amplifications in age-related attentional deficits, due to mental fatigue if applied to an older sample. They argue that this is due to an inability to engage in task specific adaptions as time on task increases, which is further attributed to an increased age-related decline in executive functioning. It is difficult to speculate in whether this would become an issue when extending the current paradigm, to investigate the impact of temporal structure on age-related differences in recognition. Nonetheless, it arguably remains important that such an investigation is conducted. Indeed, to date, there exists no evidence that can settle whether the temporal structure during encoding provides a benefit that allows older individuals to overcome the effects of such age-related cognitive deficits.

4.2.2 Lacking Temporal Effect on Behavioural Recognition. The effects unveiled in the results of the current study failed to fully replicate the reviewed literature. Relating to the most noteworthy current behavioural results, this differs from the significant differences uncovered by both Jones and Ward (2019) and Thavabalasingam et al. (2016), who argue that being able to either automatically or voluntarily predict the onset of stimuli is beneficial for subsequent recognition and retention of information. However, having reviewed the literature, it is important to note that it is uncommon for experiments investigating the effects of temporal expectations on cognitive functions to employ only 10 participants (e.g. Correa & Nobre, 2008; Jones & Boltz, 1989; Rohenkohl et al., 2012). As such, it is important to also consider how the trends in the current data relate to previous findings, as it is reasonable to question whether a lack of significant results might be due to insufficient power in the present sample size.

Concerning the current main behavioural analysis regarding differences in recognition between temporal structures, despite a non-significant result, it is evident that the trend suggests a higher level of recognition in the rhythmic when compared to the arrhythmic temporal condition (see Figure 4). Viewing this trend in context with the results of Jones and Ward (2019) and Thavabalasingam et al. (2016), it is still more feasible that there is a benefit to recognition memory, by encoding stimuli in a rhythmic structure, compared to an arrhythmic structure than that no such benefit is present. Conversely, there is still some utility in understanding that this effect is not large enough to be reliably uncovered with a small sample size, such as the current one.

Even though the current study is clearly limited, due to low power, in its ability to uncover a difference in recognition memory as a function of temporal structure, it is useful to consider why such an effect is lacking if it is not due to insufficient sample size power. The current study, like that of Jones and Ward (2019), employed a rhythmic structure which predictably alternated between fixation points and stimuli for 600ms each. This rhythm closely resembles oscillations at the delta (1.7 Hz) frequency. In a review of the literature on human memory modulation via brain oscillation entrainment, Hanslmayr et al. (2019) mentions that while oscillations at the delta frequency have been linked to memory processes, oscillations at the theta (4 Hz) and gamma (40 Hz) bands have a stronger evidence base. Indeed, Wang et al. (2018) support the notion that theta oscillations serve a specific function in memory formation. Specifically, they investigated whether synchronised as opposed to offset video luminance and audio volume modulation both, oscillating at theta frequency, benefitted subsequent episodic memory. Their findings suggested that decreased theta band phase differences between modalities benefitted performance on subsequent memory tests. This supports the review by Hanslmayr et al. (2019) in their claim that entrainment of brain oscillations at the theta band frequency is indeed beneficial for memory processes. Still, it does not discount the influence of similar entrainment at the delta band frequency. While using similar methods to that of Wang et al. (2018), Clouter et al. (2017) examined whether a memory benefit due to synchronised multi-sensory rhythmic stimulation could be observed across a range of differing frequency bands, including both the theta and delta bands. In this investigation, they observed that such benefits did not appear to occur outside of theta phase synchronisation. As such, it might be that synchronisation outside of the theta frequency band, which Jacobs (2014) identify as the intrinsic frequency of the Hippocampus, is not beneficial for human memory formation. In fact, this suggests that entrainment at the delta frequency does not modulate memory performance, which might help explain the lacking benefit of rhythmic encoding in the current study.

A potentially important distinction between Wang et al. (2018) and Clouter et al. (2017) and that of the current study and Jones and Ward (2019), is that the current and latter study did not synchronise multi-sensory input at a certain frequency to attempt to modulate subsequent memory. Rather, they relied solely on visually entrained rhythms to investigate their benefit to recognition memory. This is important, as learning associations between unrelated stimuli is greatly dependent on the hippocampus (Eichenbaum & Cohen, 2004; Gonzalo et al., 2000; Staresina & Davachi, 2009). Jones and Ward (2019) and the current study did not depend on participants learning such unrelated stimuli associations to construct the rhythmic encoding environment. Considering that studies such as Thavabalasingam et al. (2016), Jones and Ward (2019) and the current investigation rather made the structured encoding environment inherent to the relevant stimuli, this might be of importance. In fact, it is possible that as a rhythmic structure becomes less dependent on making associations between differing sensory input, the importance of entrainment at the theta band decreases in relevancy, compared to other frequency bands. This suggests that the cause for the differing findings between these different studies can potentially be allocated to differing methods. Still, this debate is unlikely to be fully settled at this argument, as recent evidence suggests that multi-sensory rhythmic synchronisations can be beneficial to memory formations even outside the theta frequency band (Hickey et al., 2020). Regardless, these discrepancies indicate that the frequencies at which human memory formation can be modulated by the entrainment of brain oscillation to external stimuli is more complicated than first thought. Although the current trend supports Jones and Ward (2019), an extension including age groups is therefore beneficial to gain a better understanding of how these neural processes develop throughout the human lifespan, as this remains unexplored.

4.2.3 Differences in Erroneous Keypresses. Although it was not the primary area of investigation for the current experiment, an interesting, but unexpected, finding regarding erroneous keypresses during encoding occurred. Specifically, this suggests that there are more erroneous animal detection keypresses in the rhythmic temporal condition. Intuitively, this raises a question concerning why a rhythmic presentation of stimuli causes a higher level of errors when compared to an arrhythmic structure. As a potential explanation, it is possible that the rhythmic encoding structure caused a higher-level motor preparation with an increased expectancy to execute the task at stimulus onset. In support of this, Kunert and Jongman (2017) conducted an experiment where participants had to discriminate true words from pseudowords, which appears either in or out of synchrony with an auditory rhythm. Participants displayed an increased RT ability in discriminating words that appeared in synchrony with the auditory rhythm but failed to display any subsequent difference in memory between in and out of synchrony words. This suggests that it could be that the rhythmic temporal structure, functioning as a cue to the stimulus onset, also allows for the temporal orientation of motor preparation, which results in a higher level of erroneous keypresses, as motor-inhibition becomes more difficult. Arguably, such motor preparation does not occur in an arrhythmic structure as the stimuli onset is more unpredictable, thus, resulting in less erroneous keypresses, as the need for motor inhibition if non-target stimuli appear is less prevalent. It is noteworthy, however, that it is the low number of errors during arrhythmic encoding that deviates from the expected amount. This can be argued, due to similarities between the analyses conducted between Jones and Ward (2019), who did not find differences in erroneous keypresses due to temporal conditions, and the current study. Although the above explanation is plausible, it remains unknown what caused the discrepancy in the number of erroneous keypresses between manipulations in the current study. Nonetheless, the percent of erroneous keypresses remains low in both temporal conditions.

4.2.4 Reflection of Processing Differences in Reaction Time. In similarity with Jones and Ward (2019), the current study did observe that correct discrimination of stimuli was associated with faster RTs. However, recognition judgement RT has previously been shown not to differ between temporal encoding conditions (Thavabalasingam et al., 2016). Thus, if a rhythmic temporal condition is beneficial to subsequent recognition, one would expect to see a higher degree of correct recognition responses following a rhythmic encoding but not necessarily RT differences between temporal encoding conditions when controlling for type or response (Hit, Miss, FA, CR). In addition, correct memory judgements are generally associated with quicker RT due to an ease in processing compared to stimuli that a participant fails to discriminate appropriately (Weidemann & Kahana, 2016). In the present sample, participants generally displayed a high recognition ability, with a few participants fully avoiding specific mistakes in recognition judgements during some blocks. This makes the paradigm in the current concept likely to be suitable in an extension of the investigation. In fact, the ability to make meaningful comparisons in processing differences suggests that the paradigm has been established as effective in some key areas. Firstly, the length and employed stimuli of the experiment allows for the collection of meaningful data, which avoids being affected by either cognitive fatigue, by being too taxing; or ceiling effects, by being too undemanding. This strong ability to provide correct recognition judgements without reaching a ceiling effect in a younger sample is critical to increase the chance of avoiding cognitive fatigue in older age groups. Secondly, the amount of correct and incorrect recognition judgements allows for meaningful comparisons. Here, such a comparison suggests that stimuli is genuinely processed differently in cognition as RT differs between them. This latter point is especially important when making any assumptions based on other analyses from the collected data, as it suggests that the results likely reflect true differences in recognition due to applied manipulations. Consequently, the experiment has arguably been successful in recording responses, which have not been affected by other unforeseen factors.

4.2.5 The Effect of Temporal Manipulation Awareness. In this experiment, participants were made aware in advance that their memory was to be tested but were not made aware of the differing temporal encoding conditions. As such, differences in recognition between temporal conditions could be argued to be due to incidental effects of temporal structure during encoding on subsequent recognition memory. Considering that it is currently unknown whether explicit strategies employed by participants aware of the temporal manipulations could affect their performance, it is important to actively monitor this. For example, a participant who becomes consciously aware of the rhythmic presentation of timings in some blocks may attempt to actively use this information to somehow benefit their encoding of items. Although this comparison has, currently, been made by dividing an already small sample size further into groups of test aware and unaware participants, the analysis does suggest that test awareness of the differing temporal conditions does not affect recognition performance. Still, there is a trend with better performance overall in aware participants compared to unaware participants but, in a group of three aware participants, this could be reflecting a generally outstanding performance by one individual which might be due to other factors. Consequently, it is difficult to make further assumptions based on this data, but it remains an important area to monitor in an extension of this investigation, as younger age groups have previously been shown to be more capable of benefiting from explicit strategies than older age groups (Mather & Carstensen, 2005). That is, if young adults are more likely to become aware of temporal manipulations and use a particular strategy to boost their memory encoding, this may result in artificial differences between young and older adults. This should be closely monitored in future studies with the use of an awareness questionnaire such as that used in the current study.

4.3 Assessment of Current EEG Findings.

4.3.1 The Implications of Current FN400 Related Findings. Considering that the sample size in the present EEG investigation is even smaller than the one included for the behavioural analysis, it is important to keep a similar mindset in relation to these findings. Still, the current findings fully support the existing literature relating to the FN400 component. As with Jones and Ward (2019), the current study failed to find any differences during recognition due to temporal structure changes during encoding on the FN400 component. Jones and Ward's (2019) investigation relating to the FN400 appears to have been novel in its examination of the effect of temporal structure during encoding on the FN400 during recognition, and the current results provide support for their argument that it is unaffected by temporal manipulations. Furthermore, the more established claim that the FN400 displays an old/new effect (see Rugg & Curran, 2007, for a review) also seems to be supported in the current results. Considering that the current study was unable to complete its original intension, this replication of previous findings surrounding the FN400 component is promising, as it suggests that the design of the study is viable in this investigation surrounding recognition, if extended to its originally intended scope.

As previously mentioned, there has been some debate regarding whether the frontally distributed FN400 represents familiarity-based processes or whether it can be considered functionally identical to the N400; which is usually connected to semantic processing (Stróżak et al., 2016). Although contemporary research, such as Leynes et al. (2017) and Stróżak et al. (2016), suggest a more complicated relationship between these two components, the current research is unable to further directly inform this understanding of the relationship between FN400. Moreover, a recent study by Leynes and Mok (2020) suggest that neither explanation of the FN400 fully modulate its activity, as the context of the stimuli and one's expectancy of having to remember it, seems to affect its observed amplitudes. The current study is unable to shed further light on the underlying purpose of the neural processes of the frontal FN400 represent. However, it has, arguably, circumvented the possibility that old image sets simply are a collection of more memorable objects, while new images are more meaningless, as which image sets were considered old and new was alternated between participants.

4.3.2 Discussion of Current LPC Related Findings. It is commonly reported that while both the FN400 and LPC effect both display an old/new effect in recognition paradigms, they are associated with differing neural processes and can be affected differentially by experimental manipulations (Curran, 2000; Danker et al., 2008; Smith, 1993). In relation to temporal manipulations, this was observed by Jones and Ward (2019) who found an old/new effect for both components but only found a difference due to temporal manipulations in the LPC. Specifically, they found an LPC old/new effect in the rhythmic temporal condition only, suggesting that the differences in temporal conditions affect the neural processes' ability to differentiate between old and new stimuli, which was further reflected in their behavioural results. Interestingly, the current results failed to fully reflect this effect in the LPC. Instead, it revealed a general effect of temporal structure but no difference between old and new items in this later component. Considering how well documented the LPC old/new effect is, it is difficult to fully maintain that its current absence is accurate, due to the present study's insufficient sample size. Still, Danker et al. (2008) maintain that while the FN400 is generally more associated with familiarity, the LPC has often been observed to accompany recollection, including source information and other specific details surrounding the encoding of the stimuli. Moreover, they argue that the FN400 appears to contribute more towards the recognition of stimuli, which can be easily verbally labelled compared to more meaningless stimuli. As such it is possible that the current paradigm elicited strong FN400 old/new effect leaving participants able to reliably differentiate old from new items based on familiarity processes, while simultaneously leaving participants with a decreased ability to produce specific recollection of old items. Both Jones and Ward (2019) and the current study has shown that the LPC is affected by temporal manipulations. Thus, it is possible that it is temporally affected, but participants were unable to produce specific recollection of old items in both current temporal conditions. This could further result in a lack of significant difference in recognition between rhythmic and arrhythmic temporal structures.

It is interesting to see that while participants are reliably able to differentiate old and new stimuli, an ability here likely represented by the FN400 old/new effect, the LPC old/new effect does not modulate this ability, as it does not significantly differ between old and new stimuli in any temporal condition. However, this does cement the notion that the recognition process represented by the LPC is affected by temporal structure as recognition differences due to temporally different encoding conditions are lacking while the LPC old/new effect is absent. Nevertheless, it remains unknown why participants were unable to produce significant recollection of old items. Still, two potential issues could have occurred. The first potential issue is that, even though image sets were alternated, images in the old and new image sets produced similar conceptual associations across both rhythmic and arrhythmic conditions (e.g., and old courgette and a new cucumber). Alternatively, as the images included in the study depicted familiar everyday objects, it could be that all images created a recollective association with the object. However, variations of this first issue are unlikely, as this would have to be a systemic issue across all blocks. In fact, considering that Jones and Ward (2019) found recognition and LPC old/new effect differences between temporal conditions and utilised stimuli similar to that used in the current study, it cannot be considered probable. The second, and more likely issue, is that the small sample size of the current study affected its ability to detect the difference. This, as previously stated, is supported by the trends in the data, which suggest that there is a difference in recognition and the LPC old/new effect, although with a lower positive amplitude for old than new images, between rhythmic and arrhythmic temporal conditions. Regardless, a future study employing the design of the current study and a larger sample size would be able to better settle this issue.

4.3.3 Current LFE Component Findings. The LFE component was primarily adopted to investigate processing differences between age groups. Contrary to the prediction surrounding the LPC and FN400 component, the LFE component was expected to increase in ERP amplitude as the difficulty of successful retrieval at recognition increased. Examples of this in aging can be found in Wolk et al. (2009) who investigated age differences in recognition and observed an attenuated FN400 and LPC, and an increased LFE in older age (mean age = 73.6) when compared to a young age group (mean age = 22.8). Again, due to the limited sample collected in the current study, age comparisons were not possible. However, some interesting observations can still be made to inform expectations in future studies based on the current results regarding the LFE component. As mentioned, the literature suggests that the LFE is involved in control-related processing functions (Allan et al., 2000; Curran et al., 2001; Donaldson & Rugg, 1999; Ranganath & Paller, 2000; E. L. Wilding & Rugg, 1997a, 1997b) and increased effort at retrieval or repeated retrieval attempts, when initial retrieval fails or is insufficient (Ally et al., 2008; Ally & Budson, 2007). In the current experiment it would, therefore, not be unreasonable to expect that the LFE should be more prominent in retrieval following the current arrhythmic compared to the rhythmic encoding condition. Yet, this was not found. Here, it is possible that the issues that caused the expected LPC old/new effect to be missing, further caused the LFE to be absent due to a similar difficulty of retrieval following both temporal encoding conditions. That is, the necessary post-retrieval effort was similar across conditions. However, the current comparisons have only been made using a young sample. In similarity with the current study, Wolk et al. (2009) also failed to find any significant LFE old/new effect in the younger age group. Indeed, they suggest that the LFE effect is reliably increased in older individuals with a further increase, if these individuals could be considered poor performers compared to their peers. As such, it is more likely that the young age group do not need post-retrieval processing to monitor retrieval success, and that such processing only increases in older age, as the two earlier neural processes decrease in potency. In addition, the current sample can be regarded as good performers with a generally high rate of correct discrimination between old and new objects. This, in addition to their young age, would render it unlikely that an LFE effect would be prevalent. Thus, despite lacking differences across manipulations, the current result is in accord with the existing literature. Nevertheless, an extension of the current study including an older age group and a larger sample size is necessary to produce more meaningful insights regarding the processing modulated by this ERP component.

4.2 Future predictions

Although the Covid-19 epidemic rendered it impossible to include an older adult group in the current experiment, some predictions on how results would manifest can be made based on the present observations and existing literature. It is apparent that cognitive attentional capacities are affected by aging. However, a range of factors seem to be relevant when examining these age-related changes. As an example, Roudaia and Faubert (2017) examined differences in visual attention due to age and found that participants across all age groups displayed similar capabilities in their ability to successfully direct their attention towards a single task or point. Conversely, they also found that such similarities disappeared when attention had to be divided across several tasks or points with older individuals displaying a detriment, compared to younger individuals, in relevant cognitive abilities when the attentional demands increase. Indeed, this notion is supported by Commodari and Guarnera (2008), who suggest that as task complexity increases, cognitive processing is slowed. This suggests that as attentional demand increases, performance differences increase between different age groups. The current paradigm cannot be considered especially demanding on attentional processes and is, therefore, unlikely to see the same age differences due to attentional capabilities between age groups as Roudaia and Faubert (2017). In fact, the current rhythmic temporal condition is likely to beneficially decrease attentional demands, thus, it can potentially capitalise on the similar attentional capabilities seen between age groups in single target attentional tasks. This could allow older individuals to experience a similar benefit to a rhythmic encoding structure as younger adults.

Although the inherent goal of the detection task during encoding remains the same across temporal conditions, it could be argued that the arrhythmic temporal encoding has an increased demand on attentional processes. Johndro et al. (2019) investigated the multi-sensory benefit of predictable temporal structures where auditory beats either appeared in or out of synchrony with visual stimuli. They found that temporal expectancy allowed participants to decrease the attentional load of the following memory task, further benefiting subsequent memory performance. To be specific, it remains unknown whether rhythmic structures provide a benefit to recognition or whether arrhythmic encoding is particularly detrimental to recognition, still, this distinction is less important in the current argument. The important distinction in this argument is that by increasing the temporal expectancy of stimuli onset during encoding, attentional demand is decreased. Given that a decrease in attentional capacity appears to occur following older age, it is likely that lowering the attentional demand in a task will result in improved recognition. As differing age groups show similar performance in non-demanding attentional tasks, as in Roudaia and Faubert (2017), it can therefore be considered plausible that an arrhythmic stimuli presentation is particularly detrimental to recognition in older age.

To further support the notion that older individuals are equally capable to perform recognition tasks following an encoding condition where temporal expectancy is high, the study by Droit-Volet et al. (2019) provides relevant observations. As previously mentioned, they found that older and younger individuals were equally capable of reacting to and assessing the length of intervals between targets if these were temporally predictable. Thus, it is unlikely that older individuals are hindered in their ability to temporally direct attention. Based on the reviewed literature, due to rhythmic encoding’s decreased demand on attentional processing and comparable performance between age groups in attentionally low-demanding tasks, they are simultaneously likely to display a similar benefit to a temporally predictive encoding as younger individuals. Consequently, any age discrepancy in recognition after a temporally predictive encoding is likely due to a general decrement in memory processing and not due to discrepancies in attentional ability.

This literature suggest that older individuals retain the ability to take advantage of temporal expectancy, suggesting that an extension of the current experiment will result in similar benefit to recognition memory in older and younger age groups. However, based on this literature, it remains unclear how such performances will compare to arrhythmic encoding conditions in differing age groups. However, Johari et al. (2018) offer insights that are useful when making predictions on age related differences in recognition performance, following arrhythmic encoding conditions. They investigated age differences in speech and motor RT to target onset following predictable and unpredictable cuing paradigms. Although these tasks differ from recognition memory, it can arguably help to inform a more general effect of differing temporal environments on processing in aging. In support of the previously discussed similarities between age groups in benefit due to predictive temporal structure, Johari et al. (2018) argue that older and younger individuals are equally able to beneficially utilise predictive temporal cues. However, they continue to argue that temporally unpredictable environments appear to cause a higher detriment to performance in older adults. If this effect is extended to recognition memory, it can be expected that arrhythmic encoding of stimuli will result in an increased age-related discrepancy in behavioural recognition results, with older adults performing worse. Indeed, although the data necessary to make a strong claim on the matter is lacking, it appears that the literature decisively suggests that older adults will experience memory benefits from increased temporal expectancy, while simultaneously experiencing a detriment to memory when such expectancy is decreased.

4.3 Conclusion

As a concept to be extended to include an investigation of differences in recognition memory between young and older adults, the paradigm and initial analysis appears promising. It illustrates that participants are able to make recognition judgements with a generally high level of accuracy, with a clear trend to support the predicted greater recognition following rhythmic than arrhythmic encoding. The paradigm also demonstrates a benefit to processing speed when correct recognition judgements are made, suggesting that the paradigm is successful in making a meaningful impact on processing even when a high degree of correct recognition judgements is made. In addition, although based on a very limited sample, it is encouraging that awareness of the temporal manipulation does not appear to impact recognition, such that any benefit of temporal structure largely occurs outside of awareness. If awareness of the temporal manipulation had resulted in reliably higher recognition scores, this may provide a test advantage to younger individuals, who have previously been shown to display a better ability to employ explicit strategies to improve memory performance. The lack of a significant difference in recognition between the temporal conditions, both in the behavioural and EEG results, is not as expected, however, there are some noteworthy factors that could attribute similarly lacking differences in other studies to important differences in methodology. In addition, most other studies that have methodology that more closely resemble that of the current study appear to reliably uncover a difference in recognition between predictable and unpredictable temporal encoding structures. Considering that the current study was only able to recruit an unusually small sample prior to government enforced Covid-19 restrictions, the lack of significant difference is likely due to insufficient power. Indeed, this is supported by a trend in the data in the expected direction with greater recognition in the rhythmic than the arrhythmic temporal condition. As such, the current paradigm has, to a reasonable degree, proven effective in investigating changes in memory as a function of temporal structure manipulations during encoding.

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Appendix A

WTAR Premorbid Intelligence Test

WTAR task of words to read out loud, used to assess participants' premorbid intelligence.

Removed due to copyright.

Appendix B

WAIS-IV Processing Speed Task

WAIS-IV is a 2-minute processing speed task used to assess participants' cognitive processing speed.

Removed due to copyright.

Appendix C

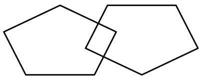
Mini Mental State Examination

MMSE used to screen for and assess abnormal cognitive development in older adulthood.

Mini-Mental State Examination (MMSE)

Patient's Name: ____ Date: _____________

***Instructions:* Ask the questions in the order listed. Score one point for each correct response within each question or activity.**

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials: ___________
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, …) Stop after five answers. Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		TOTAL

(Adapted from Rovner & Folstein, 1987)

Source: www.medicine.uiowa.edu/igec/tools/cognitive/MMSE.pdf

Provided by NHCQF, 0106-410

Appendix D

Participant Information Sheet

Participant information sheet given to participants prior to participation.

Psychology Department
Middlesex University
Town Hall, The Burroughs, Hendon,
London NW4 4BT

EEG and Recognition Memory (2019)

Participant Information Sheet

Dear Participant,

You are being invited to take part in a research study. It is important that you understand what participation involves and why the current study is being done before you decide whether to take part. Please take the time to read the following information thoroughly and ask questions at any point if you feel that anything is unclear, before you make a decision on whether you want to participate.

All proposals for research using human participants are reviewed by an Ethics Committee before they can proceed. The Middlesex Psychology Research Ethics Committee has reviewed and approved this proposal (ID number 8615).

What is the purpose of the study?

The current study aims to investigate recognition memory performance for visually presented objects and the associated brain activity in different age groups. EEG (scalp surface electrical activity) will also be recorded as part of this study, to examine the neural mechanisms of memory and potential age differences.

What will happen if I take part in this EEG study?

If you decide to partake in this study, you will be asked to attend one session in a psychology laboratory at Middlesex University in Hendon NW4 4BT.

During this session you will complete a straightforward task on the computer. In this task you will be shown images of everyday objects and will be asked to make a keypress when you spot specific targets. You will also be asked to try to solve some simple mathematical equations and complete some memory tests. To ensure that the results are not affected by other variables you will also be asked to complete a number of simple screening tests, including a vision test, a brief English reading test, and other brief tests to assess your general cognitive function.

While you will complete the computer tasks, we will record electroencephalography (EEG). This is recorded from the scalp of your head, this is done through an EEG cap that you wear on your head, which is further attached to electrodes. EEG records the small electrical activity your own brain produces using electrodes. To ensure that eye movements and blinks does not affect these readings, electrodes will also be placed near your eyes.

In order for the electrodes to be able to read electrical activity, a gel, specifically manufactured for use with EEG, must be applied into the cap where we attach each individual electrode. This gel is very unlikely to cause any irritation. However, it should not be used on damaged skin or if you have a history of skin allergies. If you are unsure about the use of this gel, we are happy to provide specific details of the content of the gel, and you are welcome to apply a small amount of gel on your arm first if you wish to test what it feels like. This gel easily washes out with warm water. After testing is finished you will be provided with access to shower facilities, shampoo, a towel to dry your hair and a hairdryer, should you wish to wash your hair. From start to finish the testing will take about 2-2.5 hours. This includes setting everything up and putting the electrodes on your head, and you washing your hair after.

Should you like to know more about EEG and this study, please do not hesitate to contact one of the researchers named below.

<u>What will happen to the study results?</u>

When data collection is completed, the responses will be used to further the understanding of how cognitive brain functions involved in memory encoding and retrieval manifest in different age groups. This will be done through presenting the results at conferences and publish them in appropriate outlets (e.g., academic journals). The data presented as a result of this study will only display the average results of each group and your individual data will therefore remain anonymous. As a result of this, you are not identifiable following the conclusion of this study. Any data you contribute cannot be associated with your name following the final analysis and will be stored on a password locked computer in a secure office at Middlesex University. Your data will only be accessed by authorised members of the research team. Our procedures adhere to the General Data Protection Regulation. If you would like to receive a copy of any papers that are published as a result of this study, please let the experimenter know.

<u>Do I have to take part?</u>

Your participation is completely voluntary, and you can withdraw from the study at any time without giving a reason. If you decide to take part, you will be asked to sign a consent form. It is important that you are aware that there is no penalty if you decide that you do not wish to take part. This includes withdrawing your participation at any point during the experiment. Should you decide that, for any reason, you would like to withdraw your data following completion of your participation, then you may do so up until the point at which data analysis begins (01.05.2020). After this point, researchers will be unable to identify your data. It is important that you are aware that you do not need to state a reason should you at any point wish to withdraw your data or participation. Please contact the principle investigator to make this request, quoting your unique participation code (can be found on the debrief form).

<u>Who has reviewed the study and who will collect the data?</u>

All proposals for research using human participants are reviewed by an Ethics Committee before they can proceed. The Middlesex Psychology Department’s Research Ethics Committee have approved this proposal.

Your information will be collected by Petter Lindseth Møller led by Principle Investigators Dr Emma Ward, Dr Alexander Jones, and Dr Jon Silas. The data is kept confidential and shall be stored anonymously in a password locked computer. Your identity will be kept confidential irrespective of whether the study is published.

<u>Are there any other requirements?</u>

This study contains flashing images, as a consequence, participants with photosensitive epilepsy should not take part in this study. As additional requirements, participants should be aged between 18-30 years or be above 65 years of age, have normal or corrected vision, and be fluent in the English language. Additionally, it is a requirement in this study that all older adults are free of cognitive impairment and dementia.

Researcher

Petter Lindseth Møller (pm929@live.mdx.ac.uk)

Principal Investigators:

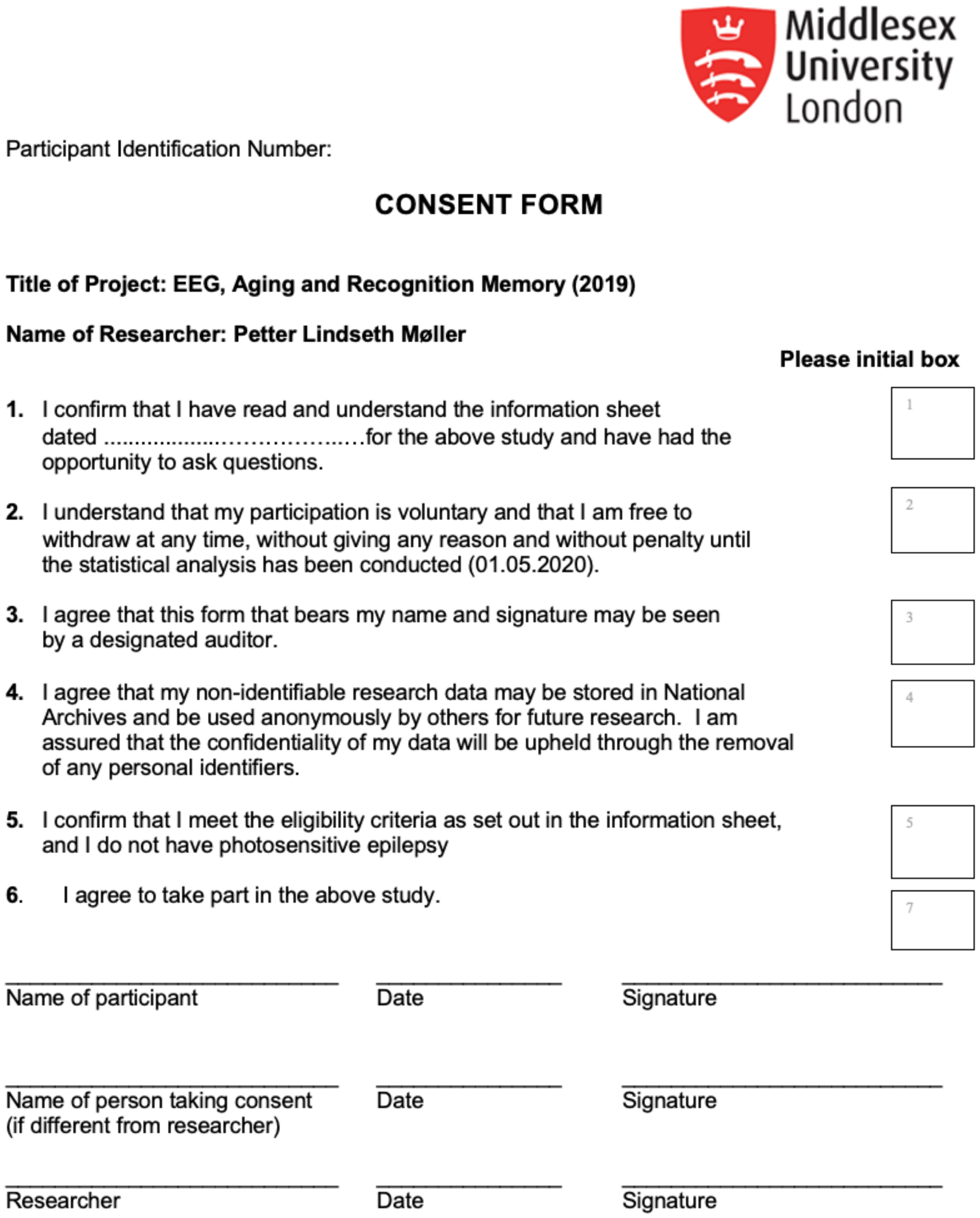
Dr A.Jones (A.J.Jones@mdx.ac.uk)
Dr E. Ward (E.Ward@mdx.ac.uk)

If you have any complaints about this research please contact the Chairs of the Psychology Ethics Committee Dr N. Brunswick, n.brunswick@mdx.ac.uk and Dr L. Marzano, l.marzano@mdx.ac.uk

Appendix E

Participant Consent Form

Consent form given to participants to collect written consent of participation prior to participation.



Middlesex University London

Participant Identification Number:

CONSENT FORM

Title of Project: EEG, Aging and Recognition Memory (2019)

Name of Researcher: Petter Lindseth Møller

Please initial box

1. I confirm that I have read and understand the information sheet dated ....……………..….for the above study and have had the opportunity to ask questions. ☐ 1

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without penalty until the statistical analysis has been conducted (01.05.2020). ☐ 2

3. I agree that this form that bears my name and signature may be seen by a designated auditor. ☐ 3

4. I agree that my non-identifiable research data may be stored in National Archives and be used anonymously by others for future research. I am assured that the confidentiality of my data will be upheld through the removal of any personal identifiers. ☐ 4

5. I confirm that I meet the eligibility criteria as set out in the information sheet, and I do not have photosensitive epilepsy ☐ 5

6. I agree to take part in the above study. ☐ 7

Name of participant	Date	Signature
Name of person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature

Appendix F

Awareness Questionnaire

Awareness questionnaire given to participants to assess each participant's level of awareness regarding temporal manipulations:

Participant Number:

1. Did you notice any differences between blocks in the computer task? If so, please explain here:

2. Each block consisted of a Detection Task and a Memory Task. In the Detection Task, you pressed the Space bar whenever you saw an animal. Did you notice any differences in the Detection Task between blocks?

If you answered 'No' to Q2 above, then you do not need to complete the rest of the form.
If you answered 'Yes' to Q2 above, please continue:

3. If you think that there was a difference in the Detection Task between blocks, what do you think this was?

4. If you think that there was a difference in the Detection Task between blocks, did you notice this during the task, or did you become aware of this afterwards/in hindsight?

Appendix G

Participant Debrief Sheet

Debrief sheet given to participants following the completion of participation.

Psychology Department
Middlesex University
Town Hall, The Burroughs, Hendon,
London NW4 4BT

Participant Code ________________

EEG and Recognition Memory (2019)

Participant Debriefing Sheet

Study title: The effect of aging and temporal structure on recognition memory.

Thank you for taking part in my study.

The aim of the current study was to investigate whether the memory of older individuals is affected differently by presenting information rhythmically as opposed to arrhythmically when compared to younger individuals. Previous research suggests that memory capacity declines as we get older, however, presenting information in rhythm is found to be beneficial for memory. In addition, research suggests that age is irrelevant to our capacity to entrain to such rhythmic presentation of information. The current study therefore hypothesised that by presenting information rhythmically, it is possible to help alleviate the memory decline seen in aging.

The current study investigates this by asking individuals either between 18 and 30 or above 65 years of age to participate in the experiment you just took part in. The experiment contained 8 blocks of images. Each block exposed you to a set of images and later asked you to differentiate these same images from an equal number of new images. Half of the blocks presented images in the first phase rhythmically while the remaining half of the blocks presented the first phase arrhythmically. These two conditions were used so that we can analyse whether there is a difference in how many images people are able to recognize depending on whether the images were presented rhythmically or arrhythmically. Furthermore, the result of each age group will be compared to see if there is a difference in how much people of different ages can recognise and whether presenting information rhythmically can benefit the memory decline seen in aging.

Your EEG was recorded to further investigate the underlying neural processes that facilitate memory and how these interact with rhythm. Specifically, we expect to find similarities between how neural processes operate in different age groups during rhythmic learning and differences in these same neural processes when information is presented arrhythmically. Indeed, this can potentially explain why arrhythmic presentation is particularly detrimental to memory in older age.

The analysis will only use the average results of each age group and your anonymity will be maintained and respected. The personal information you have provided will be kept secure and will only be accessible by authorized researchers. Should you wish to do so, you have the right to withdraw without giving any reason. It is also important that you are aware that withdrawing your data from the study does not include any penalty.

Should you wish to withdraw your data, this can be done until the data has been completely anonymised which occurs directly prior to analysis (01.05.2020). After this point, we will not be able to identify you and therefore will be unable to withdraw your individual data. If you would like to withdraw your data, then this can be arranged by contacting Dr Emma Ward using the details given below.

Principal investigator:

Dr Emma Ward
Email: E.Ward@mdx.ac.uk
Telephone: +44 (0)20 8411 6329

Kind regards,

Petter Lindseth Møller
Email: pm929@live.mdx.ac.uk