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The spacing effect:
Investigating the factors relating to and neural correlates of distributed practice

Thesis submitted to the Department of Psychology, Faculty of Science and Engineering, in fulfilment of the requirements for the degree of Doctor of Philosophy, National University of Ireland Maynooth.

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February 2022

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Acknowledgements

The last number of years have been an absolute privilege for which I am incredibly grateful. They say it takes a village to raise a child – I think it might be fair to say it takes a *city* to prepare a doctoral thesis.

First and foremost, I must extend the greatest thank you to my supervisor, Prof. Sean Commins. You have been an inspiration and it has been a pleasure and an honour to be under your tutelage for the last number of years. You have been so incredibly patient and kind, and you have shaped the person I am today. I could not imagine undertaking this journey with anyone else. Thank you, sincerely.

To Conor Thornberry, who has been the best friend. I feel lucky to have worked alongside you and to have learned from you over the last number of years. Without your guidance, this thesis would be significantly less substantial. Thank you, genuinely, for all of your support and help. Also to Keith O'Donnell & Sudha Raman, who have been so encouraging and who have bolstered me throughout this long and arduous process. Thank you.

To the various staff of the psychology department in Maynooth University, particularly Derek Walsh, Prof. Richard Roche, & Prof. Andrew Coogan, who gave advice regarding EEG equipment and questionnaires. To Caoilann Doyle, Ciara Molloy, Colin Burke, & Roy Fox, who taught me about Presentation software and multiple regression analyses. I am incredibly grateful.

To Kate Bartlett, Aoife O'Leary, Ciara McHugh, Kate McCreedy, Gordon Romley, Rosin Deery, Jill Jenkinson, Niall O'Tuathail, Meabh O'Shea, & Emer Lynham, who aided with various aspects of data collection. In particular, a sincere thank you to Calvin Ashe & Olivia Rowe. You were both a breath of fresh air in our lab, and more help than you will ever know.

To Rachel Hubble, who kept me sane and had to endure most of my negativity whenever something went wrong (which was frequently). I hope I can return the favour. Thank you also to Evelyn McHugh & Shannon Blaney. You are the best friends that anyone could ask for and I feel privileged to have you in my life.

To Brendan Doughty, who never once complained when I dictated the hours I could and couldn't work as I ploughed through this PhD. To all of my co-workers, who have been listening to me prattle on about spacing for years. In particular, thank you to Nathan Duff, Elaine Hubble, & Ryan McFadden, who were exceptionally supportive and helpful, always willing to lend a hand (or in this case, a brain) when I needed practice.

To my dad, who started this journey with me but, sadly, did not see it to completion. Wherever you are, whatever became of you, I hope you and mam would be proud.

To my extended family, who, despite questioning my sanity at times, were nonetheless very supportive of this endeavour.

Finally, to everyone who has contributed to this thesis in some way, particularly those who expressed an interest and participated in this research. You are the heart and soul of this work and it would not exist without you. Thank you.

Presentations arising from this thesis

Caffrey, M., & Commins, S., (2018). *The effects of distributed practice on short- and long-term memory in younger and older adults.* FENS Forum 2018.

Caffrey, M., & Commins, S., (2019). *The effects of distributed practice on short- and long-term memory in younger and older adults.* ENCODS Forum 2019.

Caffrey, M., & Commins, S., (2021). *An examination of the behavioural effects and neural correlates of distributed practice on short- and long-term memory.* Dublin Electrophysiology Research Clinic 2021.

Caffrey, M., & Commins, S., (2022). *The neural correlates of spacing.* FENS Forum 2022.

Abstract

The spacing effect (learning sessions which are distributed across time tend to generate superior learning compared to when sessions are massed) is a robust finding which has been replicated across many domains (Benjamin & Tullis, 2010). Despite the assertion that spacing should be considered an educational standard, extensive application is not a reality (Kim et al., 2019). This may be due to a lack of understanding combined with discrepancies between laboratory-based experiments and real-world applications. Some researchers maintain that spacing research is not ecologically valid nor generalisable to the more complex learning that occurs in real-world settings (Kapler et al., 2015). This research aims to contribute to current spacing literature by exploring a number of factors related to the spacing effect, such as interval, age, sleep, and medium of presentation. Furthermore, this thesis aims to address gaps in the literature by exploring the existence of a spacing effect when learning face-name associations, and by investigating the electrophysiological correlates of spacing through ERP analysis. Behavioural and electrophysiological measures were used to examine the spacing effect while learning face-name associations at recent and remote intervals (twenty-four hours, one week, and one month) in younger and older adults across different mediums of learning. Results suggest that spacing is beneficial when learning face-name associations, particularly at longer intervals of one month, and that older adults may also benefit from spacing at longer intervals, though to a lesser extent than younger adults. This effect is also evident in online learning, though to a lesser extent than in-person learning. Sleep quality does not affect objective measures of cognition, but does impact psychological measures and may contribute to our understanding of spacing. Furthermore, there is evidence of separate neural networks for spaced- versus massed-trained participants when retrieving correct face-name associations. These findings support a hybrid model of spacing, in particular one that encompasses theories of deficient processing and study-phase retrieval.

Chapter 1

General Introduction

Learning is crucial in everyday life, from studying for an exam to mastering a new set of skills at work. As a result, researchers tend to focus on the conditions of and events that occur during learning which may improve an individual's ability to remember (Gluckman et al., 2014). Memories form the basis of our unique identity, the enduring remnants of thoughts, emotions, and events that we experience daily. As evidenced by case studies such as Clive Wearing and patient HM, an inability to remember the experiences that we have can lead to a loss of sense of self, and a life somewhat devoid of meaning (Scoville & Milner, 1957; Wearing, 2005; Squire, 2009; Perez et al., 2021). The act of remembering is a complex process relevant to the most simple tasks. Every day, we as humans display a remarkable ability to remember, often without conscious effort. We remember how to drive our cars, we remember the route we take to work, we remember the names of our friends and co-workers. Sometimes, we remember seemingly insignificant details: The words to a song heard once on the radio, a few lines from a poem, what we were doing when news of 9/11 broke. Sometimes, we remember things that never happened: An exaggeration of a true experience, an email never actually sent, a memory based on suggestion. And sometimes, we forget. We forget the location of our phone, we forget to attend an important appointment, we forget the name of a famous actor. Most distressingly, we often forget information that we work particularly hard to retain.

1.1 Theories of Encoding

Encoding refers to the process by which experiences, thoughts, and feelings are converted into long-term memories (Ward, 2015). This is an active and constructive process; memories are not perfect portrayals of events, rather they are a combination of new sensory information and our existing knowledge and world views. As a result, successful encoding is often heavily dependent on existing knowledge. New information that has significant meaning, or which

aligns with our existing world views tends to make for stronger memories (Brown & Craik, 2000). Information is also easier to retain when it is organised in such a way that the relationships between stimuli are apparent (Mandler, 1967). Byrd (1986) observed that older and younger adults demonstrated an equal ability to remember textual information when organisational encoding was encouraged, while more recently McGatlin, et al. (2018) demonstrated that organising memories via event segmentation training improves memory in both young and older adults. Furthermore, a number of other factors have been identified that encourage stronger encoding, for example, novelty (Kishiyama et al., 2009), relevance (Gomarus et al., 2006; Meltzer, & Nielson, 2010; Wilhelm et al., 2011), emotion (Gagnepain et al., 2017; Tyng et al., 2017), and mnemonic devices (Bellezza & Reddy, 1978; Eisenman & Frenkel, 2021), among others. The way in which information is presented is also important. Individuals tend to use different mechanisms when encoding different types of information, such as verbal (Taconnat et al., 2020), visual (Hoffman & Senter, 1978), or a combination of the two, for example, when encoding face-name associations (Groninger & Guardado, 2012) – a theme of the current thesis.

1.1.1 Verbal encoding

There are numerous types of encoding that allow for successful retrieval and retention. Verbal encoding, that is, the interpretation and processing of words, is among the most commonly used consolidation techniques, and involves a number of specific factors. For example, Reichle et al. (2009) discuss the importance of attending to and processing one word at a time when reading to-be-learned material, as opposed to processing multiple words in tandem. Similarly, Taconnat et al. (2020) used eye-tracking data to demonstrate the advantages of adopting an organisational strategy when learning word sets. They found that participants

employed separate scanning techniques depending on connections between words in to-be-learned sets, and were significantly better at recalling word sets when an organisational encoding strategy was used. Other research has suggested that the physical appearance of to-be-learned words can affect how well those words may be encoded. For example, greater inter-letter spacing improves processing of words (Perea & Gomez, 2012a; Perea & Gomez, 2012b). Similarly, the amount of information to be retained can affect encoding ability. Pajkossy & Racsmany (2019) observed that participants were better able to learn word pairs when stimuli were presented in smaller blocks (for example, two at a time rather than eight at a time).

Many learning strategies have been proposed to improve retention of verbal stimuli, including repetition, written summaries, and multiple study sessions (Dunlosky et al., 2013). Dunlosky et al. (2013) evaluated ten different learning techniques and concluded that repeated testing was particularly effective when compared to other strategies (Dunlosky & Rawson, 2013). Similarly, Roediger & Karpicke (2006a; 2006b) found that repeated testing of a to-be-memorised prose passage led to significantly better retention than repeated study and single test strategies. However, when it comes to learning novel or unfamiliar words, it seems that verbal encoding is enriched when implemented in conjunction with other strategies. Marecka et al. (2020) found that participants were better able to learn second language words when to-be-learned vocabulary was similar in structure and pronunciation to first language words, while Macedonia et al. (2019) suggested that second language learning was significantly improved when classic study methods (rereading and repeating words) were accompanied by visual images and visual actions. Similarly, individuals are more likely to struggle with learning names than most other verbal stimuli, due in part to a lack of meaning and low recurrence in comparison to other words (Swanson et al., 2021). In addition to repeated study and testing, names are better remembered when they are descriptive rather than

nondescriptive, rare rather than common, and when they are presented with images, such as an accompanying face (Fogler & James, 2007; James & Fogler, 2007; Swanson et al., 2021).

1.1.2 Visual encoding

Visual encoding is among the most robust ways to create long-lasting memories (Hoffman & Senter, 1978). Crovitz & Harvey (1979) demonstrated that imagery encoding allowed for better recognition than semantic encoding, while Haj et al. (2019) suggest that the inability of Alzheimer's patients to mentally relive past events contributes to over-generality, making it difficult to remember specifics. Similarly, Bainbridge et al. (2021) observed that aphantasic participants displayed a significantly poorer ability to recall objects compared to non-aphantasic participants, while Wammes et al. (2016) indicate that drawing as a mnemonic strategy improves memory when compared to written mnemonic strategies. Given that the association of mental images with to-be-encoded information encourages a connection with pre-existing knowledge and memories, it is not surprising that visual imagery encoding is so advantageous.

Furthermore, there is evidence to suggest that memories are consolidated and stored in different brain regions depending on a number of factors, such as type of stimuli and type of encoding (Wenk, 2017). For example, there is evidence of activation in the prefrontal cortex and left cerebellar hemisphere when encoding verbal information, and evidence of activation in the temporal lobes when encoding auditory information (Belin et al., 2000; Pleger & Timmann, 2018; Sandrini et al., 2019; Boenniger et al., 2021). It is likely that visual imagery encoding allows for additional activation that contributes to greater consolidation. Neuroimaging studies have demonstrated that many of the same cortical areas are used for both visual and mental imagery, such as the primary visual cortex in the occipital lobe (Kosslyn et al., 1993; Kosslyn & Ochsner, 1994; Pearson, 2019).

1.1.3 Encoding face-name associations

The ability to recall the names and faces of our friends, families, and colleagues may seem relatively straightforward, but successful retrieval requires a deeper level of encoding that comprises four elements (Groninger & Guardado, 2012). These include processing the face in context (facial features, particularly in relation to traits, and the context in which a face was encountered), drawing associations between the name and existing knowledge (for example, if that name is already familiar), connecting the face and the name, and processing of other contextual information that may later act as retrieval cues. These processes require a number of encoding strategies: One must be able to visually process the individual elements of a face, verbally process the name, draw semantic connections between the name and existing memories, and form an association between the face and the name, and between the face-name pair and the context in which learning occurs. Furthermore, a face-name association is more likely to be remembered if a given face or name is novel (for example, a name that has never been encountered before), familiar (a given face and/or name is similar to one already stored in long-term memory), or relevant (remembering the name of a new boss versus the name of a cashier at a shop) (Wells & Hryciw, 1984; Groninger, 2000; Bernstein et al., 2002; Groninger, 2006; Groninger & Guardado, 2012).

There is significant evidence to suggest that face-name associations are particularly well-remembered when encoding is deep, and involve development of a learning system whereby new information is successfully processed and cultivated (Bernstein et al., 2002). For example, Manasse et al., (2005) demonstrated that survivors of traumatic brain injury were better able to recall real face-name associations following implementation of a training programme, which included viewing photographs of to-be-remembered face-name associations, making a statement about a given photograph in an attempt to draw participant's attention to particular features of the face, and having participants repeat the associated name.

Similarly, Neuschatz et al. (2005) found that implementing a schedule of expanding rehearsal (increasing gaps between repetitions of stimuli) was particularly beneficial when learning face-name associations, and allowed for better results than visual and verbal cues, which in turn were preferable to no strategy. Other research shows that face-name associations are better remembered when faces display social signals (Tsukiura & Cabeza, 2008). For example, happy, smiling faces tend to be more easily identifiable compared to neutral, angry, or frightened faces (Leppanen & Hietanen, 2004; Shimamura et al., 2006). More recent literature has demonstrated that individuals are more likely to remember face-name associations when the age and gender of a to-be-remembered face matches their own, and when mental imagery mnemonics (for example, using techniques such as "Sally with the smile, Emma with the eyebrows" to better remember associations) and spaced training schedules (longer lags between study sessions) are implemented (Herlitz & Loven, 2013; Bredart, 2019; Strickland-Hughes et al., 2020).

In fact, spaced training schedules are considered to be an optimal encoding strategy by many researchers when attempting to improve retention of face-name associations (Landauer & Bjork, 1978; Neuschatz et al., 2005; Rand-Giovannetti et al., 2006; Bredart, 2019). Neuschatz et al. (2005) demonstrated that implementation of spaced training schedules led to better results on a face-name pairs task compared to visual or verbal prompts, while Carpenter & DeLosh (2005) found that spaced-trained participants significantly outperformed other groups when recalling face-name associations. Although other mnemonic and cuing strategies are beneficial to face-name retrieval, they are often not ecologically valid (Bredart, 2019). For example, it is unlikely in a real-world context that an individual will have the time or wherewithal to indulge in elaborate encoding strategies that involve the use of imagination, nor are they likely to be prompted with bonus visual or verbal cues. Distributed practice, in

contrast, is somewhat more efficient, and can be applied both within laboratory and real-world settings (Helder & Shaughnessy, 2008; Bredart, 2019).

1.2 The spacing effect

Perhaps the most prominent finding in the area of memory is that of the effect of timing on long-term memory consolidation, in particular the spacing effect (Kang, 2016). Spacing refers to multiple study sessions that occur across time and is thought to be distinctly advantageous when compared to other types of learning, for example, massed learning or "cramming" (learning that is condensed into one short timeframe) (Benjamin & Tullis, 2010). The effects of spacing have been observed for many years, dating back to Ebbinghaus' forgetting curve (Ebbinghaus, [1885] 1964). The spacing effect has shown some of the most robust findings across many domains, such as vocabulary learning, mathematics, medical training, and improving motor skills, among others (Bahrick et al., 1993; Shea et al., 2000; Pavlik Jr & Anderson, 2005; Spruit et al., 2015; Spruit et al., 2017; Sahu, 2018; Barzagar et al., 2019). However, despite many researchers calling for the spacing effect to be considered an educational standard, extensive application is not a reality (Dempster, 1988; Murphy & Pavlik Jr, 2018; Walsh et al., 2018; Kim et al., 2019).

The spacing effect refers to the fact that practice which is distributed across time has reliably demonstrated favourable outcomes when compared to massed learning, or practice that is crammed together with no delay between repetitions of material (Murphy & Pavlik Jr, 2018). For example, Barzagar et al. (2017) noted significant improvement in the mathematical performance of seventh graders following utilisation of a spaced training schedule, while Koval (2019) found that adult native English speakers were better able to remember Finnish words following distributed practice. Although this effect has been replicated across many

domains, there is some doubt regarding the application and generalisability of these results (Anderson & Schunn, 2000; Walsh et al., 2018). Dempster (1988) observed that this may be due, in part, to a lack of understanding of the spacing effect (that is, why spacing is so advantageous), as well as discrepancies between material studied in the laboratory versus in a classroom setting (there is a big difference between simple vocabulary and mathematics tasks used in laboratories versus the complex learning that may occur in a classroom) (Dempster, 1986). More recently, Rohrer & Pashler (2010) and Kapler et al. (2015) maintain that simple, laboratory-based tasks which require only retrieval of information are not representative of the more complex cognitive abilities required in an educational or other real-world setting.

However, research shows that spacing can and does occur even when utilising higher-level skills. For example, Helsdingen et al. (2011) demonstrated that participants were better able to learn a complex judgement task following implementation of spaced schedules, while Price Kerfoot (2009) found that online distributed practice significantly improved the test scores of urology students, an effect that was still evident two years later. Similarly, Zulkiply et al. (2012) demonstrated improvements in inductive learning following distributed practice. These results are also transferable to more real-world, ecologically valid tasks, such as the Face-Name Pairs Task (Carpenter and DeLosh, 2005). Findings seem to be dependent on other factors however, such as material to be learned and attention. Murphy & Pavlik Jr (2018) found no difference in inductive learning when utilising massed versus spaced training schedules, and Wiseheart et al. (2017) found no evidence of spacing when learning a seventeen-note piano sequence and song phrases. Though robust and relatively generalisable, spacing is not always guaranteed to be advantageous. In light of this, researchers have sought to comprehend the theories behind and underlying mechanisms of spacing in order to better understand the conditions in which it might be used optimally. Currently, there is no one hypothesis underlying the spacing effect, however there are three prominent theories which

attempt to explain the advantage of distributed practice (Delaney et al., 2010). These are encoding variability theory, study phase retrieval theory, and deficient processing theory (Benjamin & Tullis, 2010).

1.2.1 Encoding variability theory

Encoding variability theory suggests that an increase in time between study sessions allows for greater variability in encoding. This can refer to a number of factors, such as encoding strategy (for example, processing of information may differ on subsequent study sessions either by conscious choice, or due to individuals feeling less familiar with to-be-learned material in comparison to those who complete consecutive study sessions in one sitting), context (greater lags between study sessions allow for more contextual representations which may be associated with to-be-learned material, thus making it easier to recall), and the possibility of each study session leaving a distinct and individual memory trace (Bray et al., 1976; Glenberg, 1979; Benjamin & Tullis, 2010). Encoding variability theory has a basis in stimulus sampling theory, which suggests that contextual cues (including, but not limited to, other available visual and auditory stimuli, the setting in which encoding takes place, and the emotional state of an individual) are encoded alongside a to-be-learned item, and as a result, individuals often form associations between to-be-learned items and these other contextual cues (Estes, 1955a; Estes, 1955b). The contextual elements of any given setting are likely to change over time, therefore spacing study sessions with significant lags between each one allows for differences in the contextual cues available at each session. This in turn allows for the possibility of greater retrieval options, thus increasing the likelihood of successful retrieval (Maddox, 2016).

More recent research has sought to expand upon this theory following a number of studies that failed to provide supporting evidence for encoding variability (Bird et al., 1978; Dempster, 1987; Leicht & Overton, 1987). The current consensus is that rather than allowing for a number of independent memory traces, encoding variability actually requires some consistency across study sessions while still allowing for variation in other contextual cues. This allows for the creation of a number of memory traces which are dependent on at least one consistent element (for example, the semantic meaning of a to-be-learned item), but may be enriched or expanded upon by association with other contextual elements which vary between presentations (Benjamin & Tullis, 2010; Maddox, 2016). Furthermore, the success of encoding variability is highly dependent on a number of variables. Zawadzka et al. (2021) found that encoding variability can improve memory, but only under very specific conditions, including sufficient study sessions, and particular cued-recall tests. Similarly, Maddox (2016) provides examples of instances where encoding variability may or may not be beneficial, depending on variables such as stimulus, stimulus presentation, and amount of time between study sessions. For example, if too much time elapses between study sessions, forgetting of the first stimulus presentation may occur, which defeats the purpose. Moreover, if extended lags are coupled with lack of consistency (such as, if a to-be-learned word has more than one semantic meaning and these differing definitions are used interchangeably across study sessions), it is likely that the original memory trace will not be enhanced by subsequent sessions, rather new, distinct memory traces will be created which are not associated with the original memory trace (Maddox, 2016).

One must also consider the encoding specificity principle, which implies that individuals remember better when the contextual cues available at recall match those available during study sessions (Tulving & Thompson, 1973). This principle may explain variation in encoding variability outcomes to some extent. When a spaced training schedule is utilised, it

is expected that individuals will be privy to a greater array of contextual cues. However, these may be rather weakly associated with the to-be-learned stimuli. In contrast, when a massed training schedule is utilised, it is expected that individuals will be exposed to less contextual cues. However, the environmental stimuli that are encoded will be more strongly associated with to-be-learned stimuli due to study sessions being crammed together. As a result, when material is tested at shorter intervals, massed-trained participants may perform better due to a stronger association with contextual cues, particularly if the test environment is similar to the study environment. At longer intervals, however, it is expected that spaced-trained participants may perform better due to ability to access a greater number of retrieval routes, given that the test environment is increasingly less likely to be similar to the study environment following a longer time interval (Tulving & Thompson, 1973; Maddox, 2016). This suggests that while encoding variability theory provides a reasonable explanation for the advantages of distributed practice under certain circumstances, it cannot, by itself, explain the prominence of the spacing effect.

1.2.2 Study-phase retrieval theory

Study-phase retrieval refers to the likelihood of subsequent study sessions separated by time prompting the retrieval of initial study sessions, thus strengthening a memory through constant retrieval that is not present in massed training schedules (Thios & D'Agostino, 1976; Benjamin & Tullis, 2010; Maddox, 2016). This is due to the lack of time between massed trials, which means that there is no need for processes such as retrieval or reactivation; in other words, little effort is required to keep a memory trace active across consecutive trials. However, due to the lag involved with spaced training schedules, individuals are encouraged to reactivate and reinforce memory traces created in previous study sessions, therefore

retention is superior (Delaney et al., 2010). This effect has been observed across a number of domains, including learning lists of words, faces, and face-name pair associations (Tzeng & Cotton, 1980; Taylor, 2018; Feng et al., 2019). There is also evidence to suggest that this effect occurs spontaneously, even when participants are not directly instructed to access previous memory traces (Sahakyan & Goodmon, 2007).

Study-phase retrieval is, however, somewhat problematic. Given that retrieval is more likely to occur following short intervals, one might assume that study-phase retrieval is more likely to occur during utilisation of massed rather than spaced training schedules (Benjamin & Tullis, 2010; Maddox, 2016). However, this is not the case. There are a few suggestions posited to explain this phenomenon. Delaney et al. (2010) suggest that the efficiency of study-phase retrieval as an encoding mechanism underlying the spacing effect is heavily dependent on the difficulty of a to-be-learned stimulus. For example, as demonstrated by Paivio (1974), a significant spacing effect will only be produced following shorter lags when stimuli are more difficult to retrieve on subsequent study sessions. However, if the to-be-learned stimulus is easier to recall (such as a picture rather than a word), a significant spacing effect may also be observed at longer lags. Furthermore, a significant spacing effect following longer gaps between study sessions is more likely to occur when learning is intentional rather than incidental (Paivio, 1974). Meanwhile, there is evidence in the literature to suggest that a given memory is particularly enhanced by successful retrieval under difficult circumstances (Bjork, 1994; Roediger & Karpicke, 2006). Longer lags between study sessions makes retrieval more difficult, therefore it is possible that when retrieval does occur following longer time intervals, memory of a given stimulus is strengthened. In contrast, massed-trained individuals may also experience study-phase retrieval, but to a lesser extent as shorter lags between study phases makes retrieval easier (Jacoby, 1978; Maddox, 2016). This suggestion, however, is dependent upon successful retrieval at longer time intervals, which is not guaranteed.

As with encoding variability theory, study-phase retrieval can explain the benefits of spacing to a point, but falls short in other regards. Greene (1989) proposed a combination of the two theories which allows for a more all-encompassing explanation of the spacing effect. Under this *dual-approach*, study-phase retrieval allows for recognition and encoding of contextual cues that have changed between study sessions. A greater array of contextual elements are stored at longer intervals, and therefore ongoing study-phase retrieval is made more likely at longer intervals due to greater contextual associations (Benjamin & Tullis, 2010). This dual approach seems to fit with much of the existing literature. Raaijmakers (2003) proposed a similar, combination approach to spacing based on the Search of Associative Memory theory. In order to explain the spacing effect, Raaijmakers (2003) proposes three potential scenarios when to-be-learned stimuli are presented for a second time, depending on lag between subsequent presentations: The stimulus may still be present in the short-term store and, therefore, is remembered correctly, but without the added benefit of encoding new contextual cues as no long-term memory trace based on previous presentations is activated; the stimulus is no longer present in the short-term store, but a long-term memory trace based on previous presentations is reactivated and therefore, the stimulus is remembered correctly; the stimulus is no longer present in the short-term store, and is not remembered correctly, therefore creating a new long-term memory trace independent of the previous presentations. This model provides a reasonable explanation of spacing, while accounting for and correcting many of the failures in theories such as encoding variability and study-phase retrieval when considered separately (Maddox, 2016).

However, there are some criticisms of a dual-approach model that includes encoding variability theory. Benjamin & Tullis (2010) agree that a combination of encoding variability theory and study-phase retrieval could conceivably explain spacing, however, they propose a theory of reminding which they claim is both simpler and less problematic than encoding

variability theory. Reminding is based on, and works in tandem with, study-phase retrieval, and proposes that subsequent presentations of to-be-learned stimuli may allow for spontaneous cue retrieval. In other words, subsequent presentations may "remind" individuals of previously presented stimuli (Benjamin & Tullis, 2010). The extent to which this "reminding" occurs can enhance retention, and, as with study-phase retrieval, the difficulty one experiences with retrieval corresponds directly to memory strength. Although reminding provides a simpler account of spacing, the dual encoding variability and study-phase retrieval approach accounts for more findings in the literature (Maddox, 2016).

1.2.3 Deficient processing

A third theory proposed to explain the spacing effect is that of deficient processing. Deficient processing assumes that information is processed and encoded differently under spaced versus massed schedules of learning. Because massed study sessions occur in quick succession, this encourages a sense of familiarity with to-be-learned material; this familiarity is often grossly exaggerated. In contrast, due to the lag between spaced study sessions, individuals experience a reduced sense of familiarity with to-be-learned material. As a result, spaced-trained individuals are more likely to engage in deeper processing and encoding than massed-trained individuals, which in turn allows for a stronger long-term memory trace (Hintzman, 1974; Limons & Shea, 1988; Benjamin & Tullis, 2010; Delaney et al., 2010; Maddox, 2016).

Deficient processing may be either controlled or automatic. Controlled deficient processing assumes that massed-trained individuals intentionally study less effectively than spaced-trained individuals due to a sense of familiarity (earned or not) with to-be-learned material. For example, Delaney & Verkoeijen (2009) found that massed-trained participants devoted significantly less time to rehearsal than spaced-trained participants, while Koval

(2019) observed that subsequent study sessions in the massed condition received less attentional processing than subsequent study sessions in the spaced condition. Automatic deficient processing refers to an unintentional reduction of both quantity and quality of processing. For example, during massed training, a to-be-learned stimulus may still be present in the short-term store on subsequent presentations, and therefore receives less processing as there is no need for retrieval or activation of an existing long-term memory trace (Greeno, 1967). Meanwhile, with increasing lags between study sessions, increasing effort is required on the part of spaced-trained individuals to retrieve stimuli presented earlier. As previously discussed, the more difficult it is to retrieve a memory, the stronger that memory is likely to be on successful retrieval. Massed training requires less effortful retrieval and therefore, massed-trained individuals do not engage in the same level of processing as spaced-trained individuals (Jacoby, 1978). This theory is supported by various neurological studies. For example, Callan & Schweighofer (2010) found activation in the left frontal operculum of spaced-trained participants that was not present in massed-trained participants, consistent with automatic deficient processing. Similarly, Zhao et al. (2015) demonstrated that neural activity is strengthened with increasing lags between study sessions.

As with encoding variability and study-phase retrieval, deficient processing can explain elements of spacing satisfactorily, but cannot account for all findings reported throughout the literature. One such criticism is that deficient processing suggests that with an increase in time between study sessions, retrieval difficulty should also increase, therefore leading to stronger memories upon successful retrieval. The problem is that with an increase in lag, so too is there an increase in likelihood of forgetting. Deficient processing does not adequately address this (Benjamin & Tullis, 2010; Maddox, 2016). Again, a number of dual-processing approaches which apply deficient processing in tandem with other theories have been proposed. Greene's (1989) original dual-approach also refers to deficient processing as

a way of explaining the inferior performance of massed-trained individuals. Similarly, Bjork & Bjork (2006) proposed a new theory of disuse which seeks to combine deficient processing and study-phase retrieval. According to Bjork & Bjork (2006), enhancements in learning and memory are dependent on storage strength (our ability to remember information long term) and retrieval strength (our ability to access information). Retrieval strength decreases over time, while storage strength increases monotonically, however both may be enhanced by subsequent presentations of material which encourage retrieval and consolidation. The timing between these subsequent presentations, however, is very important. If study sessions are massed together, retrieval will require little effort encouraging only a weak memory trace, and deficient processing, either controlled or automatic, will occur. As more time elapses between subsequent study sessions, however, previously discussed elements of study-phase retrieval kick in, allowing for the spacing effect. Furthermore, if too much time passes between subsequent study sessions, retrieval is too difficult and spacing does not occur. In other words, massed training allows for strong retrieval, but weak storage as a result of deficient processing. This can be overcome by spacing, but only if the lag between study sessions is not too long so as to encourage forgetting (Bjork & Bjork, 2006; Zhao et al., 2015).

As with many psychological phenomena, the answer appears to lie in combining individual theories proposed to explain spacing. In summary, combining the aforementioned theories suggests that massed learning is inferior due to deficient processing. This may be intentional on the part of an individual, or occur automatically. In addition, massed study sessions allow for easy retrieval, which in turn encourages only a weak long-term memory trace. This may be overcome by spacing study sessions so that individuals feel less familiar with material and engage in deeper processing. Moreover, when study sessions are spaced apart, retrieval becomes more difficult, and thus successful retrieval encourages strong memory traces. Additionally, spaced study sessions allow for the encoding of greater

contextual cues. This may be a disadvantage in the short term, due to the encoding specificity principle, however, encoding variability allows for a stronger overall memory trace, particularly at longer intervals. If, however, the lag between study sessions is too long, forgetting may occur. This could result in subsequent presentations being encoded individually, which eliminates the spacing effect. Although it is likely that a combination of these theories explain spacing, there is still some question as to how much influence each theory has, and under what conditions?

1.3 Theories of Consolidation

Consolidation refers to the process by which recently encoded material is transformed into long-term memories (Wenk, 2017). Consolidation is dependent on a number of factors, including influence of prior knowledge, strength of encoding, available memory traces, and regular retrieval, among others (Squire et al., 2015). Though many areas are known to be involved in memory consolidation, depending on type of information to be learned, the hippocampus is acknowledged as being particularly important (McClelland & Goddard, 1996; Dudai & Morris, 2013; Squire et al, 2015). Scoville & Milner (1957) found that patient HM could not create new declarative memories following bilateral hippocampal lesions. Furthermore, HM experienced retrograde amnesia to an extent; though he could recall childhood memories, events that occurred in the years immediately preceding his surgery alluded him. Similarly, Manns et al. (2003) found that patients with bilateral hippocampal damage demonstrated temporally graded memory loss whereby they could not remember noteworthy news events that occurred after, or indeed a couple of years prior to, the infliction of hippocampal damage. This research has resulted in the view that the hippocampus is crucial to the successful consolidation of new declarative memories, backed by extensive patient

studies and the fact that the hippocampus is not fully formed at birth, which may explain why infants do not remember distinct events until later in development (Liston & Kagan, 2002; Squire et al., 2015). As a result, standard consolidation theory assumes that memories which are encoded by the hippocampus become memory traces, successful activation of which remains dependent on the hippocampus (Sekeres et al., 2018).

Systems consolidation refers to the fact that over time, with subsequent retrieval, memories are reorganised. That is, rather than a memory being solely dependent on the hippocampus, regular retrieval may allow for changes in other cortical regions. This in turn allows for a stronger memory trace, supported by distribution throughout a number of cortical regions. Furthermore, memories are more easily retrieved due to the existence of a number of different retrieval routes now that the memory trace is not solely dependent on the hippocampus (Tse et al., 2007; Squire et al., 2015). This theory implies that successful long-term consolidation is heavily dependent on consistent retrieval, which aligns nicely with the spacing effect. In particular, study-phase retrieval may account for successful long-term consolidation, given that the lag between distributed study blocks requires successful retrieval during subsequent learning sessions (Benjamin & Tullis, 2010; Maddox, 2016). In contrast, massed-trained individuals often do not need to retrieve material, as the shorter lag between study sessions means that to-be-learned information is kept active in working memory throughout the duration of learning. Of course, increased retrieval also leads to an increased chance of memories being re-encoded incorrectly (Schacter & Dodson, 2001).

Multiple trace theory was proposed to account for some of the failings of standard consolidation theory. According to multiple trace theory, memories are consolidated differently depending on whether they are episodic or semantic, with episodic memories being hippocampus dependent and semantic memories relying on the neocortex instead (Nadel & Moscovitch, 1997; Sekeres et al., 2018). Nadel & Moscovitch (1997) suggest that upon

successful reactivation of a given memory trace, a new memory trace is formed and consolidated, thus creating multiple traces for the same memory. Over time, with subsequent reactivations and the development of further memory traces, a memory becomes more robust (Sekeres, 2018). This idea of consolidation aligns nicely with theories of encoding variability. Encoding variability suggests that variation across learning trials allows for a stronger memory due to a greater number of associations between the memory and the context in which that memory is encoded. Furthermore, encoding specificity states that individuals should experience greater recall when remembering occurs in a similar context to learning. Multiple trace theory would imply that greater variation in encoding could allow for the development of further memory traces, which are more likely to be successfully reactivated when prompted by contextual cues. More recently, however, multiple trace theory has been found to be somewhat lacking and newer theories of consolidation have been posed to rectify its shortcomings (Sekeres, 2018).

1.3.1 Reconsolidation

Reconsolidation refers to the fact that upon retrieval, memories become temporary and unstable once more, and must be restabilised in order to endure long-term (Nader & Einarsson, 2010). In other words, rather than retrieved memories perfectly encapsulating the original memory trace and returning to storage unchanged, retrieved memories are susceptible to alterations. This altered memory may then itself be retrieved at a later time. Moreover, this theory implies that even consolidated memories are not “stable”, in that anytime they are activated or retrieved, they are susceptible to change via reconsolidation (Alberini & LeDoux, 2013). Reconsolidation has a number of implications for optimising encoding and retrieval strategies, implying that retrieval could actually weaken a previously correct memory trace,

that incorrectly encoded memories could be positively changed and enhanced by subsequent retrieval, and that "stabilised" memories can be further improved by association with other memory traces.

Reconsolidation implies that optimising encoding and retrieval strategies for associative memory could be potentially problematic. Subsequent presentations that prompt retrieval but do not include both associative stimuli (for example, presenting a face without a name, or a name without a face) could encourage reconsolidation of a new, incorrect association, if retrieval is incorrect (Merlo et al., 2015). Finn & Roediger (2013) observed that participants who restudied face-name associations were better able to incorporate new information (in this case, profession) into the existing associative memory than participants who were tested (that is, presented with the face and asked to retrieve the associated name). Davis & Chan (2015) suggested that new learning is impaired when retrieval is mixed with new stimuli. In other words, if new learning occurs immediately following a test prompting retrieval of previously learned stimuli, individuals tend to reconsolidate the test information at the expense of new material. Conversely, retrieval enhanced learning of new material when testing and learning occurred separately. This suggests that when learning associative information, such as face-name pairs, retrieval can be useful, but only when conducted in such a way as to minimise reconsolidation of incorrect information. Fernandez et al. (2021) found that younger participants, older participants, and amnestic patients all performed better on the Face-Name Pairs task following utilisation of a reactivation-based intervention, which involved a prompted test, including presentation of the face and the first syllable of the associated name.

Reconsolidation aligns nicely with theories of spacing, particularly encoding variability and study-phase retrieval. For example, it is possible that on subsequent presentations, spaced-trained participants may be subject to a number of additional contextual

cues. These cues may include minor contextual changes where the study environment remains constant, major contextual changes where the study environment differs across sessions, and other, less overt contextual differences, such as time of day or mood of participant on subsequent study sessions. These additional cues may be associated with an existing, retrieved memory trace, and may be reconsolidated as part of a new memory, thus creating a greater number of memory traces and making subsequent retrieval easier (Smith & Scarf, 2017). This account could be potentially problematic, however, given the findings of Davis & Chan (2015), which suggest that learning of new associations is impaired when new associative stimuli are presented alongside retrieval cues. Reconsolidation occurring in the context of study-phase retrieval is, perhaps, more reasonable. Study-phase retrieval implies that a greater lag between study sessions makes a memory trace more difficult to retrieve, however when retrieval is successful, the memory becomes stronger as a result. Similarly, longer lags between study sessions allow for greater consolidation which in turn enhances reconsolidation when retrieval is successful (Smith & Scarf, 2017). This should also allow for enhanced systems consolidation, that is, greater generalisation of memories throughout the cortex, providing a greater array of memory traces (Lehmann et al., 2009). Spacing of study sessions may also introduce other factors that impact encoding and consolidation, namely sleep. If subsequent study sessions occur over a number of days, chances are that sleep in some capacity will occur between sessions. Furthermore, spacing of study sessions may have implications for the impact of age on memory. Is spacing an optimal encoding strategy regardless of age? It is these two factors that we will turn to next.

1.4 Factors that impact the encoding and retrieval process: Age & sleep.

*1.4.1. The effect of **age** on memory and the role of the spacing effect.*

It is known that learning and memory decline naturally with age, and that this decline can have a very serious impact in the form of diseases like dementia and Alzheimer's. As society ages, research seeks to improve cognitive health in older adults in an attempt to stave off or possibly prevent neurodegenerative diseases. There is evidence to suggest that factors such as diet, physical exercise, and keeping the mind active may lend themselves to preventing dementia and mild cognitive impairment (Marcer & Hopkins, 1977; Luszcz & Bryan, 1999; Snowden, 2003; Bowes et al., 2011; Xu et al., 2020). Furthermore, these factors have been shown to aid the preservation of memory into old age (Snowden, 2003; Swindell, 2011; Lin et al., 2015). Given that memory is known to decline naturally as we age, older adults are increasingly motivated to seek out successful preservation methods. This begs the question of whether, in addition to the aforementioned factors, implementing an optimal encoding strategy, such as spacing, could be beneficial to older adults.

There is significant research to suggest that older adults also benefit from spacing (Benjamin & Craik, 2001; Hawley et al., 2008; Logan & Balota, 2008; Kornell et al., 2010; Maddox et al., 2011; Wahlheim et al., 2011; Jackson et al., 2012; Simone et al., 2013; Bercovitz et al., 2017). For example, Simone et al. (2013) found that spaced-trained older adults outperformed their massed-trained peers, however this spacing effect was significantly diminished compared to younger adults. Similarly, Kornell et al. (2010) found that spacing benefited older adults in both repetition and inductive learning, while Logan & Balota (2008) observed that older adults benefited from the inclusion of any spaced lag between study sessions. However, although older adults benefit from spacing, the effect appears to be greatly diminished compared to younger adults, who tend to remember more overall (Simone et al., 2013; Bercovitz et al., 2017). According to Benjamin & Craik (2001), spacing benefits older adults to an extent, but can also be a hindrance depending on context. Participants were asked to learn two separate lists of words, and subsequently instructed to either accept or reject

certain words depending on which list they came from. Spaced-trained older adults were significantly better at correctly accepting words compared to massed-trained participants, however, spaced training led to older adults incorrectly accepting to-be-rejected words. As a result, massed-trained participants performed better on this element of the test. In contrast, spaced-trained younger adults performed better on both elements of the test (Benjamin & Craik, 2001).

A number of theories have been proposed to explain the differences in performance between older and younger adults on different types of memory tests, most of which concern the neural activity underpinning the processes involved in each task. Specifically, there is evidence to suggest that, in order to compensate for brain regions that have been disrupted or adversely effected by ageing, older adults are able to engage a wider span of brain regions than younger adults during cognition (Grady, 2012). Such theories may help to explain why spacing is diminished in older adults. For example, the compensation-related utilisation of neural circuits hypothesis (CRUNCH) suggests that older adults may engage additional brain regions compared to younger adults when performing cognitive tasks (Reuter-Lorenz & Cappell, 2008). This theory implies that older adults should perform just as well, if not better than younger adults, however compensation related activity may result in the under-utilisation of certain brain regions thus leading to greater errors (Nashiro et al., 2018). Furthermore, there is no guarantee that compensation will be successful, particularly depending on difficulty of task (Zarahn et al., 2007; Jamadar, 2020). Reuter-Lorenz & Cappell (2008) propose that as a task increases in difficulty, a greater number of cortical regions are engaged. Older adults begin to struggle before younger adults, resulting in differences in compensatory activity. This compensatory activity may be useful to a point (accounting for older adults occasionally performing as well as younger adults), but when a task becomes too difficult, the compensatory activity becomes redundant (resulting in poorer performance on the part of older

adults despite the utilisation of more cortical regions) (Jamadar, 2020). There is significant evidence in the literature to back up this theory, with numerous neuroimaging studies finding significantly more activity in older versus younger adults (Davis et al., 2007; Zarahn et al., 2007; Spreng et al., 2010).

CRUNCH implies that compensation activity is directly dependent on task difficulty, however it would seem that there is more to the story. Davis et al. (2007) observed a phenomenon dubbed PASA: A posterior-anterior shift in ageing. In other words, as individuals age, they tend to experience a significant reduction in occipital activity, but a subsequent increase in frontal activity. Originally, PASA was thought to be a symptom of CRUNCH, however, Davis et al. (2007) demonstrated that this posterior-anterior shift occurs even when task difficulty is controlled for, suggesting that this activity (or lack thereof) is a direct result of ageing rather than any other factors. Furthermore, Davis et al. (2007) found that increased activity in the pre-frontal cortex was positively correlated with task performance, but negatively correlated with occipital activity, suggesting that activity observed as a result of PASA is indeed compensatory. Related to PASA is the HAROLD model proposed by Cabeza (2002). This model suggests that as we age, differences in hemisphere are reduced, and in particular, prefrontal activity becomes less lateralised in older adults (Cabeza, 2001; Cabeza, 2002; Dolcos et al., 2002; Dennis & Cabeza, 2008; Hatta et al., 2015). Taken together, we can deduce from models such as CRUNCH, PASA, and HAROLD that compensatory brain activity does occur in older adults. Much of this activity is due to ageing, but it may be influenced by other factors such as task difficulty too. This compensatory activity can be both help and hindrance, depending on type and difficulty of task, among other variables (Cabeza, 2002; Davis et al., 2007; Reuter-Lorenz & Cappell, 2008).

These models may further combine with the aforementioned theories posed to explain the spacing effect, accounting for why spacing is advantageous, but only to a point. For

example, there is evidence to suggest that older adults are unable to apply context-specific cues in the way that younger adults can, implying that while encoding variability may be beneficial to an extent, older adults cannot make full use of encoded contextual elements (Smith et al., 1998). Further to this, more recent evidence suggests that older adults are more susceptible to hyper-binding, an effect where associations are formed between target information and distractors, which younger adults would be more likely to successfully reject (Powell et al., 2018). In this scenario, encoding variability could work against older adults, allowing for too much association and thus making it difficult to recall the target stimulus. Moreover, disruption in certain brain regions caused by ageing may result in retrieval difficulty and deficient processing (Cabeza, 2002). That is not to suggest that these mechanisms are completely unhelpful; rather, they are beneficial in so far as demonstrating a significant spacing effect, however, due to a natural decline in neural processing with age, this effect will most likely be minimal compared to younger adults. These implications are promising in terms of improving memory with age. Spacing could potentially serve as a useful, and perhaps even optimal, learning technique for older adults.

*1.4.2 The effect of **sleep** on memory consolidation*

Sleep is acknowledged as being vitally important with regard to memory consolidation, and there are many studies to suggest that quality and duration of sleep may correlate directly with memory strength and overall cognitive ability (Ellenbogen et al., 2007; Gillen-O'Neel et al., 2013; Rieth et al., 2010; Maurer et al., 2015; Huang et al., 2016; Chambers, 2017; Wilckens et al., 2018; Kapsi et al., 2020). For example, Wilhelm et al. (2012) observed that sleep improves the encoding of motor skills in children and adults, while Durrant et al. (2011) demonstrated that statistical learning benefits from sleep. Similarly, Hu et al. (2006) found that emotional declarative memory is improved by sleep.

There are some studies to suggest that sleep is particularly beneficial when encoding associative stimuli, such as face-name pairs. Maurer et al. (2015) found that participants were more likely to correctly identify face-name pairs, and more likely to be confident doing so, following the opportunity to sleep between encoding and recall. Similarly, Whitmore, Bassard, & Paller (2022) observed improvements in recall of face-name associations following the reactivation of names during a nap, while Yuan et al. (2020) found that participant's ability to recall face-name associations deteriorated significantly over the course of the day, suggesting that associative memory may be effected by time awake. Furthermore, face-name retrieval was also effected by circadian phase. However, there is research to suggest that, while sleep can be beneficial in the learning of face-name associations, it may also encourage consolidation of false memories (Day & Fenn, 2020). According to Day & Fenn (2020), sleep can both encourage and defend against memory consolidation of false memories, depending on when misinformation is presented. Similarly, Calvillo et al. (2016) found that the misinformation effect was largest in participants who slept between witnessing an event and taking a recognition test. Studies such as these imply that while sleep may be beneficial to an extent, it could also hinder correct recall by encouraging the consolidation of inaccurate information. Both the advantages and disadvantages of sleep to consolidation may depend on type of sleep.

Although there is a demonstrable effect of sleep on cognition that has been replicated across a number of domains, there are some discrepancies in the literature (Wood et al., 1992). For example, Mednick et al. (2009) observed equal improvements in a visual search task across participants who had the opportunity to sleep and participants who merely rested, suggesting that while sleep does improve memory, it is no more effective than simply resting. Similarly, Casey et al. (2016) observed no effects of sleep deprivation on implicit verbal memory, however explicit verbal memory was significantly adversely effected by sleep

deprivation. Rieth et al. (2010) eliminated sleep-attributed improvements in implicit and explicit motor learning by controlling for non-sleep factors. In contrast, Geyer et al. (2013) did find improvements in implicit visual search tasks which were directly correlated with sleep, suggesting that type of learning and stimulus might have an important role to play. Interestingly, Andrillon & Kouider (2016) found that participants were unable to recall implicitly learned words that had been processed during sleep, however, behavioural and EEG data indicated the existence of an implicit memory trace for those words, suggesting that sleep does play a role, though perhaps not as distinctly as current research claims. In fact, Mednick et al. (2009) and Rieth et al. (2010) suggest that many observed sleep effects throughout the literature might potentially be eliminated by controlling for severe fatigue. In other words, though sleep is beneficial, similar effects may be achieved by resting, or creating a spaced lag between study sessions so that participants do not become tired.

A deeper analysis of sleep reveals that different types of memory may be effected by different types of sleep. For example, Stickgold (2005) noted that enhancements on a visual texture discrimination task following sleep tended to be dependent on levels of Rapid Eye Movement (REM) and slow wave sleep, while enhancements on motor sequence and motor adaptation tasks following sleep were dependent on stage 2 Non Rapid Eye Movement (NREM) and slow wave sleep respectively. A number of other studies support the notion that different stages of sleep affect different types of memory (Fowler et al., 1973; Smith, 1996; Dikelmann et al., 2009; Dikelmann & Born, 2010; Boyce et al., 2017; Manoach & Stickgold, 2019). Although some confusion remains as to the exact role of various sleep stages in consolidating different types of memory (Cordi & Rasch, 2021), a clear pattern emerges whereby significant and repeated sleep disruption and deprivation tends to negatively impact memory consolidation. These impacts may be more or less pronounced depending on type of task and the stage at which sleep was interrupted.

Overall, these findings imply that sleep is beneficial to, and perhaps even necessary for memory consolidation, however these advantages are dependent on a number of factors. REM and different stages of slow wave sleep appear to be responsible for the processing of different types of information (Stickgold, 2005; Dikelmann et al., 2009; Dikelmann & Born, 2010; Boyce et al., 2017; Manoach & Stickgold, 2019). As a result, sleep disruption or deprivation may or may not affect consolidation, depending specifically on type of information to be processed (such as verbal, visual, spatial, et cetera.) and the way in which sleep is disrupted. For example, one to two hours of slow wave sleep appear to be enough to benefit consolidation of declarative memories, whereas longer sleep intervals that include both REM and slow wave sleep are required for consolidation of non-declarative memories (Dikelmann et al., 2009). Furthermore, the effects observed following a good night's sleep, though advantageous, may often be observed following a rest period, or by controlling for factors that encourage fatigue, such as massed learning (Mednick et al., 2009; Rieth et al., 2010). Taking both of these points into account suggests that sleep deprivation and fatigue are most influential with regard to effects on memory and cognition. It is possible that improvements in consolidation and other cognitive functions may be encouraged by reducing or eliminating variables that contribute to tiredness, rather than engaging in cumbersome and time-consuming sleep interventions.

1.5 The neural correlates of encoding and consolidation

When seeking to enhance memory, it is important to explore the neural underpinnings of memory processes. Such explorations allow for a better understanding of precisely how memory works and the kinds of processes and factors that may be advantageous to encoding (Schacter et al., 2012). To date, a number of functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), and electroencephalography (EEG) studies have been conducted in an attempt to pinpoint the brain activity underlying cognition. Perhaps the most

prominent finding is the importance of the hippocampus when consolidating declarative, long-term memories (Tompary & Davachi, 2017; Sawangjit et al., 2018; Schapiro et al., 2019). The influence of the hippocampus to general consolidation is particularly broad, given that it is involved in the processing and consolidation of non-hippocampal dependent information too (Sawangjit et al., 2018; Schapiro et al., 2019). Various other regions of the medial temporal cortex have been linked with associative and emotional encoding (Mayes & Montaldi, 1999; Dolcos & Denkova, 2008; Dahlgren et al., 2020). Also significant is the pre-frontal cortex, which is activated during episodic, verbal, and emotional encoding and retrieval, working memory, and explicit retrieval (Buckner & Koustal, 1998; Lee et al., 2000; Rugg et al., 2002; Blumenfeld & Ranganath, 2007; Dolcos & Denkova, 2008). In fact, neural activation appears to be dependent on type of information to be processed, with multiple cortical sites involved (Rugg et al., 2002). Furthermore, retrieval appears to engage much of the same regions as initial encoding, but with additional activity (Buckner & Koustaal, 1998; Dahlgren et al., 2020). Similarly, explicit and implicit encoding cause activation in similar regions, however, retrieval patterns are noticeably different (Kim, 2019). In other words, neural activation is heavily dependent on a given stimulus.

1.5.1 The neural correlates of face-name associations

Successful retrieval of face-name associations is also dependent on the hippocampus (Tsukiura & Cabeza, 2008; Tsukiura et al., 2011). Tsukiura & Cabeza (2008) found significant activation in both the hippocampus and the orbitofrontal cortex during encoding and retrieval of face-name associations. This activation was heightened when faces were smiling. Similarly, Tsukiura et al. (2011) found significant activation in hippocampal regions when encoding both face-name and face-job associations, however the left anterior temporal lobe was also involved in face-name retrieval, but not face-job retrieval. There is evidence to

suggest that representations of face-name associations cause unique activation patterns and event-related potentials (ERPs) compared to representations of faces and names individually and compared to other associative stimuli (Campanella et al., 2001; Joassin et al., 2004; Guo et al., 2005; Tsukiura et al., 2011).

Campanella et al. (2001) propose a network of three left hemispheric regions in which face-name associations are represented, including the inferior and medial frontal gyri, and the supramarginal gyrus of the inferior parietal lobe. This was supported by further investigations using EEG (Joassin et al., 2004). Guo et al. (2005) found significantly different ERPs depending on whether participants learned names alone compared to faces alone or face-name associations. Correct retrieval of auditorily encoded names was associated with a negative ERP, while forgotten names elicited a more positive ERP. Conversely, correct retrieval of visually encoded faces was associated with a positive ERP, whereas forgotten faces elicited a more negative ERP. Similarly, correct retrieval of face-name associations was correlated with a prolonged positive ERP, while forgotten associations elicited a more negative ERP. This similarity could be attributed to similar encoding processes, however, topographic divergence implies that different encoding systems may have been used (Guo et al., 2005).

1.5.2 The neural basis of the spacing effect

Given that distributed practice has been suggested as an optimal and efficient way of enhancing our ability to remember face-name associations, it is also worth examining the neural correlates of the spacing effect (Bredart, 2019). As mentioned above, the hippocampus is crucial when consolidating new memories, regardless of task. Studies using fMRI have demonstrated that in the initial stages of spacing, the hippocampus is fully engaged during retrieval. However, with subsequent study sessions, hippocampal activity is reduced during retrieval; instead, various other regions in the cerebral cortex are activated. This demonstrates

a shift as the to-be-learned stimulus is incorporated into a more all-encompassing neural network. In other words, the memory trace is no longer reliant on one, single system (the hippocampus), but can be accessed via a number of different neural routes (Gerbier & Toppino, 2015; Van Hoof, Sumeracki, & Madan, 2021).

EEG studies demonstrate distinct ERPs for spaced- and massed-trained individuals during encoding. Weston (2018) found that the mean amplitude of the late positive component was reduced in spaced-trained participants compared to massed-trained participants. Furthermore, the late positive component of spaced-trained participants peaked significantly after that of massed-trained participants, in line with study-phase retrieval. Similarly, Mollison & Curran (2015) found that spaced-trained participants exhibited similar electrophysiological activity across subsequent study sessions, while massed-trained participants did not. This supports both study-phase retrieval and deficient processing, implying that spaced participants actively recalled the first study session during subsequent presentations, and massed participants did not engage in the same levels of encoding, particularly on subsequent sessions.

Combined, these findings suggest that a closer examination of the neural underpinnings of distributed practice could enlighten us as to why spacing is so advantageous compared to massed learning. Functional neuroimaging and electrophysiological research to date particularly supports study-phase retrieval and deficient-processing (Mollison & Curran, 2015; Weston, 2018; Van Hoof et al., 2021). Electrophysiological analyses indicate greater similarities between activity on subsequent presentations when there is a significant lag between study sessions and delayed activity compared to massed-trained participants, suggesting that spaced-trained individuals are actively retrieving information from initial presentations, but struggling to do so, while massed-trained individuals do not engage in the same level of processing (Mollison & Curran, 2015; Weston, 2018). Studies involving fMRI

demonstrate greater activation over time in spaced-trained individuals, suggesting a more robust memory trace and the utilisation of more cortical regions during processing (Callan & Schweighofer, 2010; Van Hoof et al., 2021). A greater emphasis on the neural correlates of spacing could help to further explain and hone the effect, thus optimising it for real-world use.

1.6 Knowledge gap and implications

Despite extensive research highlighting the importance and effectiveness of spacing (Benjamin & Tullis, 2010; Maddox, 2016), much remains unclear. Though spacing has been recommended as an educational standard, it is not widely utilised in everyday settings (Dempster, 1988; Murphy & Pavlik Jr, 2018; Walsh et al., 2018; Kim et al., 2019). Of course, given the time required, spacing is not, by definition, as desirable as massed learning. Furthermore, research into the effects of spacing tends to focus on simple tasks, which may not be indicative of higher cognitive processes required in everyday life. In other words, much of the current spacing research is not necessarily ecologically valid (Rohrer & Pashler, 2010; Kapler et al., 2015). As such, it seems unlikely that spacing will ever become widely accepted without further clarification, research, and dissemination. Currently, there is disagreement among researchers as to the main theory underlying the spacing effect, which may contribute to the indifference of the general public. Three key theories have been outlined, but there is still disagreement as to the extent that each theory is involved in explaining the benefits of distributed practice. Additionally, there is little research exploring the electrophysiological correlates of the spacing effect. Such temporal techniques may provide evidence in support of or contrast to theories such as study-phase retrieval, as well as complementing or contradicting existing fMRI and PET studies. When there is no clear explanation as to why

spacing is advantageous in addition to the extra effort it requires, it is not surprising that people are reluctant to engage in distributed practice.

Furthermore, given the current replication crisis, it is important that even the most well-established theories and effects are held under scrutiny. Given the ever-changing environment in which experiments are conducted, particularly in light of the recent COVID-19 pandemic, it is imperative that researchers continue to investigate the various factors that may impact a given effect. In particular, further research is needed to investigate the effect of age on spacing, and the role of sleep. Though literature suggests that spacing is beneficial for older adults (Benjamin & Craik, 2001; Hawley et al., 2008; Logan & Balota, 2008; Kornell et al., 2010; Maddox et al., 2011; Wahlheim et al., 2011; Jackson et al., 2012; Simone et al., 2013; Bercovitz et al., 2017), the effect is diminished compared to younger adults. It remains unclear whether this reduced effect is fixed, or could be improved by manipulating other variables associated with spacing.

Additionally, though it is clear that sleep can affect memory and cognition, researchers continue to debate the extent to which sleep may be involved (Ellenbogen et al., 2007; Gillen-O'Neel et al., 2013; Rieth et al., 2010; Maurer et al., 2015; Huang et al., 2016; Chambers, 2017; Wilckens et al., 2018; Kapsi et al., 2020). There is suggestion that the effects of sleep are greatly exaggerated in the literature (Mednick et al., 2009; Rieth et al., 2010). Some researchers posit that any effects attributed to sleep may also be observed following a short nap, or even just a break from study. Moreover, it is possible that controlling for severe fatigue eliminates sleep effects, suggesting that though sleep has a role to play, it is not as important as might previously have been believed.

In sum, the exact mechanisms underlying spacing remain unclear. Though many studies have sought to investigate the neural correlates of the spacing effect, there is little in the way of EEG research. Given the superior temporal information supplied by electrophysiological research, it is likely that such experiments could provide significant evidence for theories of study-phase retrieval. Furthermore, it is unclear to what extent spacing is affected by age and sleep. Though spacing appears to be beneficial to older adults, it is uncertain whether the decline in this effect when compared to younger adults can be overcome. Additionally, it is unclear whether sleep may be responsible for the benefits observed when spaced learning occurs. A better understanding of the variables that impact encoding and consolidation, as well as strategies that optimise the memory process, is vital to improve general learning and retention.

1.7 Thesis aims and overview

Overall, this thesis aims to contribute to existing literature regarding distributed practice and advance knowledge of the spacing effect. The spacing effect is arguably among the most robust findings in the area of memory, however, uncertainty surrounding the underlying mechanisms of spacing and the circumstances under which it is most robust mean that it is underutilised as an optimal encoding strategy, with individuals tending to choose easier but inadequate learning techniques instead, such as cramming (Dempster, 1988; Murphy & Pavlik Jr, 2018; Walsh et al., 2018; Kim et al., 2019). We hope that a better understanding of the spacing effect as a whole will bring more awareness and recognition to the phenomenon. Furthermore, we hope to establish the existence of the spacing effect when learning more abstract but ecologically valid concepts, such as face-name pair associations.

The specific thesis aims are:

- To establish the existence of the spacing effect when learning face-name associations, and to investigate the effects of spacing on consolidation at recent and remote time intervals (twenty-four hours, one week, and one month);
- To establish the existence of the spacing effect in a cognitively healthy older population when learning face-name associations at recent and remote time intervals (twenty-four hours and one month);
- To investigate the effect of sleep quality on spacing when learning face-name associations;
- To investigate the underlying neural networks associated with recall of spaced-trained and massed-trained face-name associations using electrophysiological event-related potential (ERP) analysis.

1.7.1 Thesis overview

Chapter 2 provides a broad overview of the general methodologies employed throughout this thesis, including an outline of the various control tasks and surveys used, a discussion of the different versions of the Face-Name Pairs task, and details of electrophysiological analysis. Chapter 3 sought to establish the existence of the spacing effect in younger adults when learning face-name associations at twenty-four hours, one week, and one month. Chapter 4 examined the existence of the spacing effect in cognitively healthy older adults when learning face-name associations at twenty-four hours and one month, and compares the performance of older adults to younger adults. With the disruption of lab-based experimentation due to COVID-19, we were afforded an opportunity to explore spaced-learning in an online context.

In Chapter 5 we specifically examined whether a spacing effect is still visible in younger adults when the Face-Name Pairs task is adapted for online administration. The following experiment in Chapter 6 examined the effect of sleep quality on a number of cognitive factors, including memory and planning tasks and psychological measures. Chapter 7 compared the ERPs of spaced- and massed-trained younger adults while performing the retest of the Face-Name Pairs task. Finally, Chapter 8 provides a general discussion of the results and findings presented within this thesis, offering consideration of general limitations and future implications of the work presented herein.

Chapter 2

General methods

Overview

Many of the methodologies discussed throughout this thesis are used repeatedly over the course of the five experiments. These methodologies can be generally broken down into control measures, cognitive tasks, questionnaires, and electrophysiological measures of brain activity. This chapter aims to outline these procedures in detail and to justify why these particular measures were chosen. This chapter begins by discussing various control measures used for each of the experiments included in this thesis, with details of materials needed and scoring for each (see section 2.1). Subsequently, the cognitive tasks used throughout the thesis are discussed, including administration and scoring (see section 2.2). Section 2.2 also details the software needed for each task, as well as giving details regarding different versions of the face-name pairs task and describing the different learning conditions (spaced versus massed) that participants were divided into. Section 2.3 discusses the questionnaires used throughout the thesis, including sleep-based questionnaires, mental health-based questionnaires, and the Alcohol Use Disorders Identification Test (AUDIT). Section 2.4 explains electrophysiological measures of neural activity, including details of electroencephalogram (EEG) signal recording, equipment used, and event-related potential (ERP) data processing. Section 2.5 briefly outlines the statistical analyses used for each experiment. This chapter concludes with a short description of ethical approval codes and participant recruitment measures (see section 2.6).

2.1 Control measures

2.1.1 National Adult Reading Test (NART)

The National Adult Reading Test (NART) was developed to allow an estimation of premorbid intelligence in adults who are potentially experiencing cognitive and intellectual decline (Nelson & Willison, 1991). The NART (see Appendix A) consists of a list of fifty words common to the English language, with each word increasing in phonological difficulty as the list goes on. The words do not follow the common rules of pronunciation. Participants are asked to read the list aloud, while any errors in pronunciation are recorded (Nelson, 1982). The number of errors recorded for each participant gives an estimation of verbal IQ, performance IQ, and full scale IQ. It is argued that, because the words listed in the NART do not follow the common rules of pronunciation, they can only be read correctly if a participant has prior knowledge of the words. As a result, NART scores give a good estimation of premorbid IQ, which can then be compared to actual IQ scores, thus allowing for an indication of intellectual deterioration (Nelson & Willison, 1991).

In the context of this thesis, the NART allows for a good estimation of general intelligence. As indicated in the literature, reading ability is highly correlated with general IQ (Birch & Belmont, 1965; Nelson & McKenna, 1975; Crawford et al., 1988; Carver, 1990; Crawford et al., 1992). Research also indicates that performance on the NART is correlated with WAIS IQ score, suggesting that in a neurotypical population, the NART can be used as a relatively simple method of inferring participant's general intelligence (Crawford et al., 1989; Willshire et al., 1991). A number of papers have demonstrated t0he validity of the NART, further supporting its use (Crawford et al., 1988; Blair & Spreen, 1989; Bright et al., 2002).

2.1.2 Trail Making Tests (TMTs)

The Trail Making Tests (TMTs) were initially developed as part of the Army Individual Test Battery (1944) and retained appreciation due to their ability to measure elements of executive functioning, including processing speed and mental flexibility (Tombaugh, 2003; Wagner et al., 2011). The TMTs (see Appendices B & C) consist of two separate tests: The TMT-A comprises a page of twenty-five encircled numbers which participants must connect in ascending order via drawn lines. The TMT-B comprises a page of twenty-four encircled numbers and letters which participants must also connect in ascending order via drawn lines. On the TMT-B, participants must alternate between number and letter with each subsequent line drawn. Participants are timed on both tasks; faster times tend to indicate better executive functioning (Tombaugh, 2003; Bowie & Harvey, 2006). The TMT-A measures visual processing and motor speed skills while the TMT-B measures higher-level cognitive processes, including working memory and task-switching ability (Bowie & Harvey, 2006; Sanchez-Cubillo et al., 2009).

The TMTs provide a comprehensive account of cognitive performance, and thus act as excellent tools when ensuring that neurotypical participants are cognitively matched (Bowie & Harvey, 2006; Salthouse, 2011). Research indicates that the TMTs are particularly useful in indicating neuropsychological impairment and brain damage (Reitan, 1958; Reitan, 1971; Reitan & Wolfson, 2004). The TMT scoring system also controls for age and education (Boll & Reitan, 1973; Tombaugh, 2003), and has proven to be reliable and valid over a number of decades (Gaudino et al., 1995; Atkinson & Ryan, 2008; Sanchez-Cubillo et al., 2009). As such, we decided to use it as a simple and easy-to-administer control for general cognitive functioning, which taps into more than IQ. Criticisms of the TMTs include the potential for participants to become overly-familiar with the task if they have encountered it before, and the potential for dyslexic participants to struggle not because of failures in executive function but because of slower letter processing (Atkinson & Ryan, 2008; Avila et al., 2019). However

these criticisms may be overcome; a number of alternative tests have been proposed in cases where participants have taken the TMTs before, and writing the alphabet on top of the TMT-B in cases where participants are dyslexic, or are used to a different alphabet, has been shown to aid performance without contaminating the test (Atkinson & Ryan, 2008; Egeland & Folleso, 2020).

2.1.3 Rey Auditory-Verbal Learning Test (RAVLT)

The Rey Auditory Verbal Learning Test (RAVLT) was developed to give an indication of a person's ability to encode, store, and retrieve verbal stimuli (Schoenberg et al., 2006). It acts as a particularly useful measure of different components of verbal learning and memory, and has been used extensively with both healthy and memory impaired populations (Rosenberg et al., 1984; McMinn et al., 1988; Vakil & Blachstein, 1993). The RAVLT (see Appendix D) comprises a list of fifteen nouns read aloud by the researcher. The participant must then attempt to recall as many of the fifteen words as possible, while the researcher takes note of correct recollections. This process is repeated five times, following the same format on subsequent trials. After the fifth presentation, a second list of fifteen nouns – a distraction list - is read aloud by the researcher, and again, the participant must attempt to recall as many of the fifteen words as they can. Following the distraction list, participants are asked to recall as many words as possible from the original list without further cues or prompting (Rosenberg et al., 1984; McMinn et al., 1988).

The RAVLT is a particularly apt control task for the current thesis due to its subject matter. The focus of the current thesis is on learning and memory; particularly, enhancing memory in cognitively healthy populations. Research shows that the RAVLT is a valid, reliable, and easily administered task which can aid in the identification of memory impairment (McMinn et al., 1988; de Souza Magalhaes et al., 2012; Aschendorf, 2019; Jagtap

et al., 2021). Although variables such as age, education, and gender have been demonstrated to have an effect on RAVLT score, a number of studies have presented normative data for both cognitively healthy and clinical populations (Bolla-Wilson & Bleecker, 1986; McMinn et al., 1988; Schmidt, 1996; Schoenberg et al., 2006; Paula et al., 2012).

2.1.4 Montreal Cognitive Assessment (MoCA)

The Montreal Cognitive Assessment (MoCA) was developed for use in tandem with or, in some instances, as an alternative to the Mini-Mental State Exam (MMSE) (Nasreddine et al., 2005). The MMSE tests cognitive function in the elderly and is commonly used to screen for dementia. However, the MMSE is not particularly sensitive to Mild Cognitive Impairment (MCI), and as a result, individuals with MCI are often overlooked due to scoring above the diagnostic threshold recommended for the MMSE (Smith et al., 2007). Researchers sought to develop an easy-to-administer task that could aid diagnosis of MCI in individuals who score just above the diagnostic threshold of the MMSE, thus eliminating some of the limitations associated with the MMSE. As a standalone test, the MoCA (see Appendix E) can act as an indicator of cognitive impairment in elderly participants (Wong et al., 2015). The MoCA comprises a single-page test of approximately thirty items that can be administered in ten minutes. Cognitive impairments are detected via a cut-off score of twenty-six. Among the thirty items included within the MoCA are tests of executive functioning, memory, and attention (Smith et al., 2007).

Research suggests that the MoCA is a valid and reliable tool for identifying cognitive impairment, with some suggesting that it is preferable to the MMSE (Smith et al., 2007; Gill et al., 2008; Freitas et al., 2013). Furthermore, the MoCA may aid in the detection and diagnosis of non-AD dementia, due to the inclusion of more frontal tasks when compared to the MMSE (Smith et al., 2007). Criticisms of the MoCA suggest that the cut-off score of

twenty-six is not adequate, and can lead to false positives and misclassification (Wong et al., 2015; Carson et al., 2017). Wong et al. (2015) advise that researchers may want to use different cut-off scores depending on the clinical population being tested, while Carson et al. (2017) suggest that a cut-off score of twenty-three is preferable in terms of diagnostic accuracy. With regard to this thesis, the MoCA is utilised in Chapter 4 to test cognitive function in older adults for exclusion purposes. Given that the aim is to distinguish cognitively healthy older adults, the MoCA is a suitable choice of test, without concern for the limitations associated with clinical populations.

2.2 Cognitive tasks

2.2.1 The Face-Name Pairs Task (FNPT)

The Face-Name Pairs Task (FNPT) is a well-known associative learning test that gives an indication of a person's ability to successfully learn unfamiliar face-name pairs (Zeineh et al., 2003; Smith et al., 2014). Given that face-name associative learning is relevant to daily life, the FNPT has been confirmed to be ecologically valid, making it superior to many other associative memory tasks (Zeineh et al., 2003; Hampstead et al., 2008; Irish et al., 2011). Furthermore, the FNPT can be used with both cognitively healthy and clinical populations, having demonstrated sensitivity to people with dementia, MCI, depression, and bipolar disorder, among others (Hampstead et al., 2008; Glahn et al., 2010; Irish et al., 2011; Smith et al., 2014).

Our ability to remember face-name associations is essential to many aspects of our daily lives. Moreover, the ability to recall familiar faces and names is among the first aspects of memory to be affected by natural decline as a result of ageing (D'Argembeau & Van der Linden, 2010; Martschuk & Sporer, 2018). Additionally, the FNPT is known to be a hippocampal-based task; participants undertaking the FNPT have demonstrated specific activation in various hippocampal regions (Zeineh et al., 2003; Dickerson & Sperling, 2008; Nestor et al., 2008; Smith et al., 2014). As a result, the FNPT is a strong choice of cognitive test when investigating learning and memory; it is an applicable, explicit task which engages the hippocampus, an area known to be heavily involved in the consolidation of new memories and connecting previously unrelated information (Sperling et al., 2001), while also allowing for an examination of different types of memory, such as recognition versus free recall (Smith et al., 2014). For example, Jacobs et al. (2015) used a version of the task whereby participants were required to recognise the name associated with a given face out of four potential options. Conversely, Zeineh et al. (2003) used a version of the task in which participants must freely

recall the name associated with a given face. The advantages and relevance of this task to the current research have made it a robust choice of task for the experiments carried out within this thesis. Three different versions of the FNPT were used, which are detailed in the following sections.

2.2.1.1 Video format

Originally, a version of the FNPT which closely resembled that detailed by Zeineh et al. (2003) was used. In this version of the task, participants were asked to watch a video of eight faces paired with eight names and to subsequently recall the names associated with each face. There was an encoding phase, divided into four trials, and a retrieval phase. Each encoding trial consisted of two videos, a study block video shown twice per trial, and a retrieval block video. The retrieval phase consisted of one retrieval block video. Participants were presented with the following message upon beginning the video:

"You are going to see a series of FACES, each with a NAME beside it. You should try to remember which name corresponds to each face. Press the spacebar to begin."

Upon pressing the spacebar, a fixation cross appeared for 0.5 seconds. The fixation cross was followed by the first of the eight faces, paired with a name (see Figure 2.1a). The video continued in this manner: Fixation cross followed by a face/name association. Each face/name combination remained on the screen for approximately four seconds. The faces used were all female, presented in black and white, and had their hair removed. The same eight face-name pairs were used repeatedly across the four encoding trials. The video ended with the following message displayed on the screen:

"End of Study Block. Press the spacebar to continue."

Participants watched the video for a second time before proceeding to the retrieval block video. The following message was presented at the beginning of the retrieval block video:

"You will now see each of the faces you saw before WITHOUT the names beside them. Please say aloud the name that corresponds to each face. Press the spacebar to continue."

As with the study block videos, upon pressing the spacebar, participants were presented with a fixation cross lasting for approximately 0.5 seconds. The video then displayed the first of the eight faces accompanied by a question mark where there had previously been a name (see Figure 2.1b). As with the study block, each face was preceded by a fixation cross, and remained on screen for approximately four seconds. Participants had to recall each name associated with the on-screen face aloud while the experimenter made note of correct responses on a separate sheet of paper. Each video ended with the following message displayed on screen:

"End of Recall Block. Press spacebar to continue."

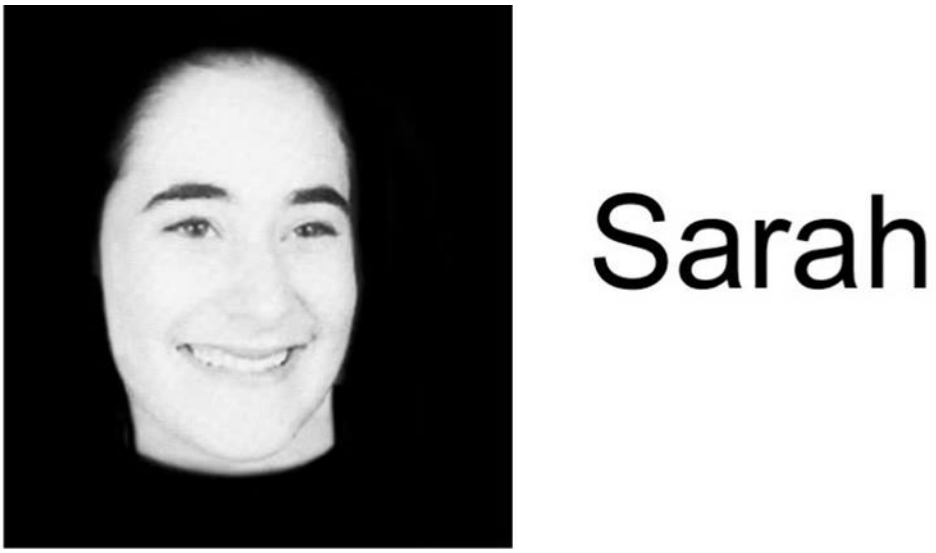


Figure 2.1a: An image of one of the eight faces paired with its corresponding name from the study block.

Figure 2.1b: An image of one of the eight faces from the test block.

At intervals of twenty-four hours, one week, or one month later (depending on experiment), participants would complete the retrieval phase. This involved watching the retrieval block video alone and attempting to recall the names associated with each face (see Figure 2.2b).

2.2.1.2 Presentation format

Upon examining the electrophysiology of the brain, a decision was made to alter the FNPT in light of new circumstances. EEG and ERP analyses require a significant number of stimuli; in other words, more face-name pairs were required for a successful analysis. Additionally, ERP analysis requires the use of triggers to pinpoint exactly when stimuli are presented to a participant and also to pinpoint the exact moment of their response. Furthermore, free recall responses are not ideal when using EEG, as it is very difficult to identify the exact moment at which a response is made unless participants are actively engaged in the responding. As a result, the decision was made to code a new version of the task using Presentation version 23.

In this version of the task, participants were asked to watch a presentation of thirty faces paired with thirty names and to subsequently recognise the correct face-name pairs. Again, there was an encoding phase, divided into four trials, and a retrieval phase. Each trial consisted of two presentations, a study block presentation shown four times per trial, and a retrieval block presentation. At the beginning of each trial, the experimenter started the presentation, which began with the appearance of a fixation cross for 0.5 seconds. The fixation cross was followed by the first of the thirty faces, paired with a name (see Figure 2.2a). The presentation continued in this manner: Fixation cross followed by a face/name association. Each face/name combination remained on the screen for approximately two seconds. The faces used were a mix of male (fifteen) and female (fifteen), presented in full colour on a white background, all wearing neutral expressions. Names were presented above or below the face; this was alternated with each subsequent pair to keep participant's attention. The face-name pairs were sourced from the Glasgow Unfamiliar Face Database (http://www.facevar.com/glasgow-unfamiliar-face-database). The same thirty face-name pairs were used repeatedly across the four encoding trials.

Figure 2.2a: An image of one of the thirty faces paired with its corresponding name from the study block.

Following the study block, participants completed a retrieval block. As with the study block, participants were presented with a fixation cross lasting for approximately 0.5 seconds. The video then displayed the first of one-hundred-and-twenty face-name pairs, sixty of which were "correct" (participants had viewed them in the study block) and sixty of which were "incorrect" (see Figure 2.2b). Participants had to indicate whether they thought a given face-name pair was "correct" or "incorrect" by right- or left-clicking the mouse (the mouse was

labelled so that participants would not forget which button to click). As with the study block, each face-name pair was preceded by a fixation cross, and each pair remained on screen for approximately ten seconds. If participants had not made a judgement at that point, it was considered a "miss". One month later, participants would complete the retrieval phase. This involved watching the first retrieval block presentation alone and attempting to recognise the correct face-name pairs (see Figure 2.3b).

Figure 2.2b: An image of one of the incorrect face-name pairs from the retrieval block.

2.2.1.3 Qualtrics format

Due to the COVID-19 pandemic, all experiments had to be moved online in March 2020. As a result, the aforementioned video and Presentation versions of the FNPT had to be adapted for online administration. This was done using Qualtrics. Two versions of the FNPT were created using Qualtrics: One was an adaptation of the video version (version one), the other an adaptation of the Presentation version (version two).

In general, version one of the Qualtrics task matched the video task very closely; participants were asked to watch a slideshow (created via use of the "timing" function on Qualtrics) of eight faces paired with eight names and to subsequently recall the names associated with each face. Again, each trial consisted of two slideshows, a study block slideshow shown twice per trial, and a retrieval block slideshow. The same eight stimuli were used in both the Qualtrics version and the video version of the tasks (see Figures 2.1a and 2.1b). Participants were also presented with similar messages on-screen; in the Qualtrics version "press the spacebar" was replaced with "click the blue button". No fixation cross was used on Qualtrics and the eight face-name pairs appeared for approximately five seconds each.

The retrieval block slideshow differed somewhat from that used in the video format. Given that participants had to type their response (rather than speaking the names aloud as in the video format), it was decided not to impose a time limit. Again, participants were presented with the face alone and had to type the corresponding name into a text box. The "force response" function was utilised to ensure that participants did not just skip to the next face; in other words, they had to at least provide a guess.

Version two of the Qualtrics task also matched the Presentation task very closely. participants were asked to watch a slideshow (created via use of the "timing" function on Qualtrics) of thirty faces paired with thirty names and to subsequently recognise the correct face-name pairs. Again, each trial consisted of two slideshows, a study block slideshow shown four times per trial, and a retrieval block slideshow. The same thirty stimuli were used in both

the Qualtrics version and the presentation version of the tasks (see Figures 2.2a and 2.2b). No fixation cross was used on Qualtrics and the thirty face-name pairs appeared for approximately two seconds each. The retrieval block slideshow was also very similar to the Presentation version of the task. Participants were presented with one-hundred-and-twenty face-name pairs which they had to recognise as "correct" or "incorrect". Again, no fixation cross was used on Qualtrics. Rather than right- or left-clicking the mouse, participants were asked to indicate "correct" or "incorrect" by clicking the corresponding button on-screen. The "force response" function was used again, so there were no "misses" in the Qualtrics version.

2.2.1.4 Learning condition

Spacing is among the most robust findings in literature regarding learning and memory, and has been proposed as an efficient and ecologically valid strategy for improving our ability to learn novel face-name associations (see Chapter 1) (Landauer & Bjork, 1978; Neuschatz et al., 2005; Rand-Giovannetti et al., 2006; Bredart, 2019). One of the aims of this thesis was to test this idea by examining whether spaced-trained participants were better able to remember novel face-name pairs than massed-trained participants under a number of different conditions. Four of the five experiments detailed within this thesis involved randomly splitting participants into groups based on type of learning undertaken: Spaced or massed.

Participants in the spaced condition learned the face-name pairs over four consecutive days, completing one trial per day. Participants in the massed condition learned the face-name pairs in one single study session, completing all four trials on the same day with no break in between blocks. This is true for each of the four experiments in which spacing was used, regardless of version of task. Furthermore, in order to evaluate short- versus long-term memory, participants were further divided into twenty-four hour, one week, or one month conditions, depending on experiment. Participants in the twenty-four hour condition

completed a retest one day after encoding, participants in the one week condition completed a retest approximately seven days after encoding, and participants in the one month condition completed a retest approximately thirty days after encoding (spaced-trained participants completed the retest one day, one week, or one month after day four of learning) (see Figure 2.3).

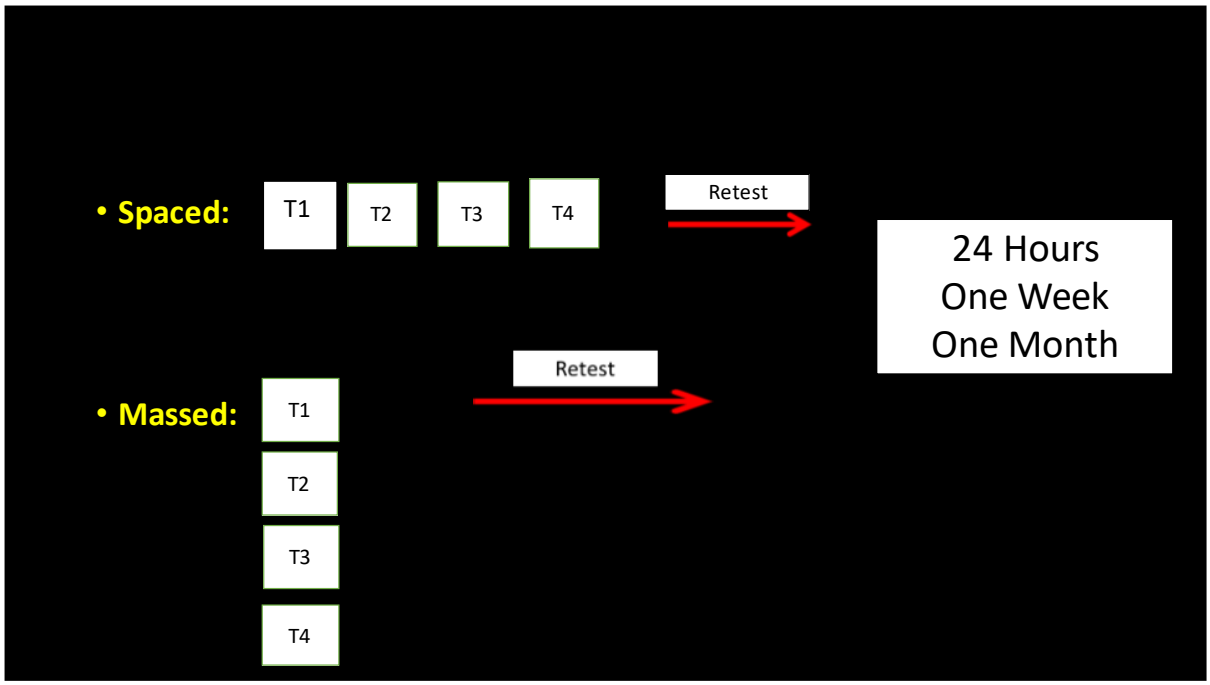


Figure 2.3: A breakdown of the spaced and massed conditions.

2.2.2 The Tower of Hanoi (ToH) task

The Tower of Hanoi (ToH) task acts primarily as a measure of problem solving, planning, fluid intelligence, and working memory (Goel & Grafman, 1995; Welsh & Huizinga, 2001; Zook et al., 2004). In its most simple form, the ToH comprises three pegs and three discs, one small, one medium, and one large. The three discs are stacked in order of size on one of the three pegs. The aim of the task is to move the three discs so that they are arranged in the same fashion on a different peg, however there are a number of rules to be followed. Only one disc may be moved at a time, the top disc must always be moved first, discs may only be placed on

one of the three pegs, and a larger disc can never be stacked on top of a smaller disc. Participants abilities are judged based on number of moves required and time taken to complete the task (Anderson & Douglass, 2001). For the purposes of this thesis, a three-disc, four-disc, and five-disc version of the task were administered (Noyes & Garland, 2003).

Originally, the ToH was administered in-person using a model (participants would have to physically move the discs from peg to peg). More recently, various computer-based versions of the task have become available (Noyes & Garland, 2003; Hinz et al., 2009; Mill et al., 2019). Despite some criticisms suggesting that computerised versions of the ToH are easier and encourage inefficiency (Noyes & Garland, 2003), they are mostly acknowledged to be equivalent to the traditional tasks, and a valid measure of planning ability (Mataix-Cols & Bartres-Faz, 2002; Kotitsa, 2007; Robinson & Brewer, 2016). In fact, Kotitsa (2007) suggests that computerised versions of the ToH are more ecologically valid, given that computers, smartphones, and tablets are such large fixtures of modern living. Furthermore, computerised versions of the ToH allow the task to be performed outside of the confines of a laboratory, which may in itself impact results. The ToH task is used in Chapter 6 of this thesis as we wanted to examine the effects of sleep on a non-associative, non-hippocampal task as a comparator to the FNPT; participants were directed to follow a link which allowed access to an online version of the task (https://www.mathsisfun.com/games/towerofhanoi.html). Participants were asked to complete the three-, four-, and five-disc versions of the task, and to record the number of moves and time taken to complete each version.

2.2.2.1 Scoring the ToH task

In order to prevent over-complicating the statistical analyses involved for the current thesis, a decision was made to give participants a combined score based on their performance on each

of the three versions of the ToH task. This combined score was based on a combination of average time and number of moves for each version as demonstrated in the literature. For the three-disc version, participants who managed to complete the task with seven moves in fifty-four seconds or less were awarded a score of 1 (Fabio & Capri, 2017). Given that participants are specifically instructed to complete the task in as few moves as possible, number of moves was given priority over time taken to complete the task, therefore participants who completed the task with seven moves in more than fifty-four seconds were awarded a score of 2, while participants who completed the task with more than seven moves in less than fifty-four seconds were awarded a score of 3. Participants who completed the task with more than seven moves in more than fifty-four seconds were awarded a score of 4 (see Table 2.1).

Table 2.1: *Scores for the three-disc ToH task.*

Moves	Time (seconds)	Score
7	≤54	1
7	>54	2
>7	≤54	3
>7	>54	4

For the four-disc version, participants who managed to complete the task with fifteen moves in one-hundred-and-forty-one seconds or less were awarded a score of 1 (Mataix-Cols et al., 2002). Participants who completed the task with fifteen moves in more than one-hundred-and-forty-one seconds were awarded a score of 2, while participants who completed the task with more than fifteen moves in less than one-hundred-and-forty-one seconds were awarded a score of 3. Participants who completed the task with more than fifteen moves in more than one-hundred-and-forty-one seconds were awarded a score of 4 (see Table 2.2).

Table 2.2: *Scores for the four-disc ToH task.*

Moves	Time (seconds)	Score
15	≤141	1
15	>141	2
>15	≤141	3
>15	>141	4

For the five-disc version, participants who managed to complete the task with thirty-one moves in one-hundred-and-sixty seconds or less were awarded a score of 1 (Robinson & Brewer, 2016). Participants who completed the task with thirty-one moves in more than one-hundred-and-sixty seconds were awarded a score of 2, while participants who completed the task with more than thirty-one moves in less than one-hundred-and-sixty seconds were awarded a score of 3. Participants who completed the task with more than thirty-one moves in more than one-hundred-and-sixty seconds were awarded a score of 4 (see Table 2.3).

Table 2.3: *Scores for the five-disc ToH task.*

Moves	Time (seconds)	Score
31	≤160	1
31	>160	2
>31	≤160	3
>31	>160	4

Each of these scores was then combined, so that participants received a continuous score of 3 up to 12, with lower scores indicating better performance overall.

2.3 Questionnaires

2.3.1 Sleep-based questionnaires

Among the variables discussed in relation to our ability to accurately recall face-name associations is the effect of sleep. Sleep is thought to be of crucial importance to our overall health and well-being (Wenk, 2017; Zhai et al., 2018; Gulia & Kumar, 2020; Shattuck et al., 2020; Hunter, 2021). Additionally, there is significant evidence to suggest that sleep plays a critical role in memory consolidation and general cognitive ability (Rieth et al., 2010; Maurer et al., 2015; Huang et al., 2016; Chambers, 2017; Wilckens et al., 2018; Kapsi et al., 2020). When it comes to assessing sleep, questionnaires are a commonly used tool. Sleep-based questionnaires are acknowledged to be useful, inexpensive, and easy-to-administer instruments that serve as a non-invasive method of assessing an individual's sleep quality and duration (Spruyt & Gozal, 2011; Riemann et al., 2017; Ibanez et al., 2018). Furthermore, given their subjective nature, sleep questionnaires allow for an individual's own feelings about their sleep and their sleep habits to be taken into account (Ibanez et al., 2018).

In light of the COVID-19 pandemic, and due to ease of administration, three sleep-based questionnaires were administered to participants for the purposes of the experiment detailed in Chapter 6. The first of these questionnaires was not standardised, and was administered for the sole purpose of determining participant's sleeping habits (see Appendix F). This questionnaire was very short, and included questions such as "thinking about a typical night in the last month, what time do you go to sleep?" and "on average, does your bedtime/wake-up time differ on days where you go to work/school versus a day off?" among others. In addition, participants were asked to complete the Sleep Condition Indicator (SCI) and the Karolinska Sleepiness Scale.

2.3.1.1 The Sleep Condition Indicator (SCI)

The Sleep Condition Indicator (SCI) (see Appendix G) is a diagnostic tool, developed in line with the symptoms of insomnia as assessed by the Diagnostic and Statistical Manual of Mental Disorders (DSM) 5 (Espie et al., 2014). The SCI comprises an eight item questionnaire, taking factors such as sleep quality, and night-time and daytime symptoms of insomnia as categorised by the DSM-5 into account. Participants may select one of five possible answers to each question, and are scored accordingly, with higher scores indicating better sleep quality. A score of 16 or less is considered to be indicative of insomnia (Espie et al., 2014; Wong et al., 2017; Ballesio et al., 2018; Espie et al., 2018).

The SCI has been acknowledged as a useful screening tool when evaluating for insomnia (Espie et al., 2014; Wong et al., 2017; Espie et al., 2018; Hellstrom et al., 2019; Lin et al., 2020; Bayard et al., 2021). Other popular scales used to evaluate insomnia include the Pittsburgh Sleep Quality Index (PSQI) and the Insomnia Severity Index (ISI). While the PSQI can give an indication of sleep disturbance, it is somewhat lacking with regard to precise observations of disruption (Espie et al., 2014; Mollayeva et al., 2016). In contrast, the ISI is quite particular, but as a result is better suited to actual, clinical diagnoses (Espie et al., 2014). This thesis seeks to divide participants into good versus poor sleepers for the purpose of evaluating the effect of sleep on learning and consolidation. Given that the PSQI is not specific enough to give an adequate measure of good versus poor sleep, while the ISI is a little too extreme, for the purposes of this research the SCI was chosen as a valid measure of insomnia symptoms. Participants who scored 16 or below were classified as “poor sleepers”, while participants who scored 17 or above were classified as “good sleepers”.

2.3.1.2 The Karolinska Sleepiness Scale (KSS)

The Karolinska sleepiness scale (KSS) provides a subjective measure of participant’s sleepiness at the time of administration (Shahid et al., 2011). The KSS (see Appendix H)

requires researchers to pose the question “please, indicate your sleepiness during the five minutes before this rating through circling the appropriate description”. Participants are then encouraged to choose an option from one to nine, indicating how sleepy they currently feel, with one indicating “extremely alert” and nine indicating “very sleepy, great effort to keep awake, fighting sleep”.

The KSS gives a reasonably good indication of an individual’s own experience of sleepiness in the moment prior to performing a given task. For the purposes of this thesis, the KSS was used to indicate how tired or alert participants felt prior to undertaking cognitive tasks such as the FNPT and the ToH. Used in conjunction with other sleep questionnaires, such as the SCI, the KSS can lend further support to the classification of good versus poor sleepers. Although the KSS can produce different results depending on a number of factors, such as time of administration and circadian rhythm, it has demonstrated high validity (Shahid et al., 2011). Kaida et al. (2006) found a significant, positive correlation between KSS score and EEG and behavioural variables, suggesting that the KSS does act as a reliable indicator of sleepiness. Similarly, Brown et al. (2014) found that KSS score correlated significantly with a number of other sleepiness measures.

2.3.2 Cognitive Questionnaires

2.3.2.1 The Cognitive Failures Questionnaire (CFQ)

The Cognitive Failures Questionnaire (CFQ) is a self-report measure which is designed to assess failures in perception, memory, and motor function as experienced by the individual (Broadbent et al., 1982). In other words, the questionnaire aims to assess the likelihood of making mistakes when carrying out simple, everyday tasks. The CFQ (see Appendix L) comprises a twenty-five item multiple choice questionnaire, whereby participants must rate the degree to which they agree with a given question or statement. Items include questions

such as “do you read something and find you haven’t been thinking about it and must read it again?” and “do you fail to listen to people’s names when you are meeting them?”, among others. Participants are encouraged to answer each question by selecting a numbered response from 0 to 4, whereby 0 equates to “never” and 4 equates to “very often”. Participant scores are added up, with higher scores indicating greater cognitive failures.

The CFQ has been used for a number of years now and has been shown to be valid and reliable (Broadbent et al., 1982; Wallace et al., 2002; Wallace, 2004; Bridger et al., 2013). Though self-report measures of cognition are not ideal, often leading to exaggeration or misinformation on the part of a participant and thus low correlations with objective measures of cognition (Southwell et al., 2018), they remain an important tool nonetheless, particularly when conducting research online. The CFQ has been shown to correlate with related constructs, such as boredom and attention deficit/hyperactivity disorder (Wallace et al., 2002). Furthermore, CFQ scores have also been related to accident proneness, human error, and psychological stress (Bridger et al., 2013), suggesting that it can give a decent measure of an individuals’ experience of cognitive failures, while correlating strongly with other, related factors. In the context of this thesis, the CFQ may act as a decent control task, giving an indication of participants own understanding of their cognitive abilities. Moreover, the CFQ provides an interesting contrast with other, objective measures of cognition, allowing us to examine the correlation between objective and subjective tests, as well as the correlation between personal experience of cognitive failures and other psychological measures.

2.3.3 Mental health-based questionnaires

When studying the effects of sleep, it is important to consider other variables that may directly impact sleep quality and duration. For example, one cannot simply attribute behaviour to

sleep, or lack thereof; it is possible that sleep is actually a mediating variable, and that behaviour is caused by other factors which also impact sleep. Among the most impactful variables with regard to sleep are emotional regulation and mental health (Harvey, 2011; Palmer & Alfano, 2017; Palmer et al., 2018; Vandekerckhove & Wang, 2018). As a result, this thesis uses two mental-health based questionnaires to assess participants for depressive and anxious symptoms. Used in conjunction with the sleep-based measures, these questionnaires allow for a more accurate and all-encompassing interpretation of behaviour.

2.3.3.1 The Depression Anxiety Stress Scale-21 (DASS-21)

The Depression Anxiety Stress Scale-21 (DASS-21) is a shorter version of the DASS-42, and is designed to assess and differentiate between symptoms of depression, anxiety, and stress (Ali et al., 2021). The DASS-21 (see Appendix I) comprises a twenty-one item multiple choice questionnaire, whereby participants must rate the degree to which they agree with a given statement. Items include statements such as "I found it difficult to work up the initiative to do things" and "I felt I was close to panic", among others. Participants are encouraged to indicate the extent to which they identify with each statement by selecting a numbered response from 0 to 3, whereby 0 equates to "never" and 3 equates to "almost always". Participants scores are added up and multiplied by two. The questionnaire includes a severity rating whereby scores are broken down so as to indicate the severity of depression, stress, and anxiety experienced by participants. Higher scores indicate greater feelings of anxiety, depression, and stress.

The DASS-21 has been used successfully for a number of years across a range of cultures (Scholten et al., 2017). This questionnaire is based on the tripartite model, which differentiates between depression, anxiety, and stress symptoms, suggesting that while they are interrelated, and together cause significant distress, each has its own distinct characteristics

that may be measured individually (Ali et al., 2021; Zanon et al., 2021). There has been some criticism of the DASS-21 with regard to its ability to accurately assess each of the three main characteristics, with researchers commenting on the similarities between various depression, anxiety, and stress symptoms (Ali et al., 2021). Furthermore, despite some successful cross-cultural validation studies, researchers argue that further validation is necessary before the DASS-21 can truly be considered generalisable. Given the cultural variation across emotional experience and expression, and indeed, variation across different age groups, it is not clear whether the DASS-21 can accurately distinguish between symptoms of depression, anxiety, and stress across different populations (Gloster, et al., 2008; Oei et al., 2013). The consensus seems to be that, depending on context, the DASS-21 does not always accurately distinguish between depression, anxiety, and stress, however it gives a good indication of overall distress experienced by an individual (Ali et al., 2021; Zanon et al., 2021). The DASS-21 was chosen for this thesis due to its ability to give a reasonable estimate of distress with limited participant burden and without the added complications associated with diagnostic tools.

2.3.3.2 The General Health Questionnaire-12 (GHQ-12)

The General Health Questionnaire-12 (GHQ-12) is a shorter version of the GHQ-60 and is most commonly used to screen for anxiety and depression (Kalliath et al., 2004). The GHQ-12 (see Appendix J) comprises a twelve item multiple choice questionnaire, whereby participants must indicate the extent to which they agree with a given statement. Items include statements such as “have you recently been able to concentrate on what you’re doing?” and “have you recently felt capable of making decisions about things?”, among others. Participants are encouraged to indicate the extent to which they identify with each statement by selecting a numbered response from 0 to 3, whereby 0 equates to “better than usual” and 3 equates to “much less than usual”. Participants scores are added up with higher scores

indicating greater feelings of depression and anxiety. A score of 16 or over suggests mild distress, while a score of 21 or over suggests severe psychological distress.

The GHQ-12 has been acknowledged as a valid measure of psychological distress, and is the most commonly used of all available GHQ versions (Kalliath et al., 2004). Despite originally being conceived as a unidimensional scale, it has been proposed that the GHQ-12 comprises a two- or three-factor solution, including anxiety/depression, social dysfunction, and loss of confidence (Romppel et al., (2013). Though some studies suggest that the GHQ-12 gives a better analysis of psychological morbidity when considered in light of different factors, others maintain that the factors identified are strongly correlated, and thus there is little to be gained by differentiating between them (Martin, 1999; Gao et al., 2004). The fact remains that the unidimensional scale displays decent psychometric properties and can give a reasonable indication of psychological distress (Romppel et al., 2013). For the purposes of this thesis, the GHQ-12 was chosen to be used in tandem with the DASS-21 to give an indication of feelings of depression and anxiety amongst participants.

2.3.4 The Alcohol Use Disorder Identification Test (AUDIT)

Another variable that is intrinsically linked with sleep is substance abuse (Colrain et al., 2014; Van Schrojenstein Lantman et al., 2017; Goodhines et al., 2019; Koob & Colrain, 2020). Substance abuse, emotional and psychological distress, and quality and duration of sleep often operate cyclically; working in tandem, these variables can significantly influence each other to affect behaviour (Miller et al., 2017). The Alcohol Use Disorder Identification Test (AUDIT) measures alcohol abuse and other behaviours associated with harmful drinking (O'Hare & Sherrer, 1999). The AUDIT (see Appendix K) comprises a ten item multiple choice questionnaire, whereby participants must indicate how often (if ever) they engage in certain drinking behaviours. Items include questions such as "how often do you have a drink

containing alcohol?" and "how often during the last year have you been unable to remember what happened the night before because you had been drinking?", among others. Participants are encouraged to answer each question by selecting a numbered response from 0 to 4, whereby 0 generally equates to "never" and 4 generally equates to "daily or almost daily". Participants scores are added up, with scores of 8 or higher indicating harmful alcohol use.

The AUDIT is acknowledged as being a valid and reliable measure when assessing problem drinkers (O'Hare & Sherrer, 1999; Selin, 2003). However, criticisms suggest that psychometric evaluation of the AUDIT has been in line with diagnoses of alcohol dependence rather than alcohol abuse, as is intended (O'Hare & Sherrer, 1999; Boschloo et al., 2010). Furthermore, some researchers suggest that depressive or anxious symptoms may contribute to inaccurate scores due to symptom overlap (Boschloo et al., 2010). The general consensus seems to be that, although the AUDIT does not necessarily measure alcohol abuse depending on circumstance, and although it requires adaptation across populations (particularly with regard to questions of consumption), it can give a successful indication of alcohol dependence under most circumstances through detection of high-volume, potentially problematic, drinking (Selin, 2006; Boschloo et al., 2010; Higgins-Biddle & Babor, 2018). The AUDIT was chosen for this thesis due to its ability to give a reasonable estimation of problem drinking, which may affect sleep patterns, even in conjunction with symptoms of depression and anxiety (Higgins-Biddle & Babor, 2018).

2.4 Electroencephalography

Electroencephalography (EEG) refers to a neural approach that involves measuring the electrical activity of neurons (Schacter et al., 2016). Electroencephalography is one of the older techniques used to probe brain activity, stemming from Berger's discovery of low-level electrical brain activity in the early twentieth century (Shipton, 1975). Electrical brain activity is recorded via an electroencephalogram through the placement of electrodes on the scalp. The EEG has the ability to significantly amplify the electrical signals produced by synaptic transmission, thus providing a visual output of the brain's underlying electrical activity (Schacter et al., 2016). EEG can provide much information regarding the neural correlates of behaviour, such as evaluating and diagnosing disorders and aiding further discoveries regarding the nature of sleep and cognition (Berka et al., 2004; Lau-Zhu et al., 2019).

2.4.1 An overview of electroencephalography

The EEG electrodes record the combined voltage generated by post-synaptic potentials (PSPs) from multiple neurons, occurring simultaneously. PSPs create a flow of electrical current that, when generated by similarly oriented neurons, can be detected by scalp electrodes. Generally, this current is generated by pyramidal cells (Luck, 2014). Following sensory, motor, or cognitive events, specific voltages are generated. Changes in these voltages which are time-locked to specific events and averaged across participants are referred to as event-related potentials (ERPs). ERPs are analysed based on latency and amplitude of a given waveform, and may be classified as sensory (early waves, indicative of physical response to a given stimulus) or cognitive (later waves, indicative of information processing) (Sur & Sinha, 2009).

Each ERP waveform consists of a number of positive and negative peaks. These peaks are labelled in relation to direction and timing. For example, the P50 component refers to a positive peak at fifty milliseconds post event, while the N170 component refers to a negative

peak at one-hundred-and-seventy milliseconds post event (Luck, 2014). Different components tend to be associated with specific responses. For example, research indicates that the P300 component can reflect attention. The oddball paradigm requires participants to view a number of different stimuli, one of which is presented sporadically in comparison to the others. Participants are asked to respond to this infrequent stimulus only, and in doing so, tend to produce greater P300 peaks (Sur & Sinha, 2009). A reduction in P300 amplitude is associated with a number of disorders, including addiction and antisocial behaviour (Patrick et al., 2006). Similarly, the N170 component is thought to be indicative of face processing. The N170 peak is largest when presented with face stimuli, such as a photograph, and tends to be most pronounced over the visual cortex (Luck, 2014). Furthermore, research has indicated an anomalous N170 in autistic children (Dawson et al., 2002).

There are a number of advantages to conducting EEG research, despite more recent advances in the field of neuroimaging (Luck, 2014). EEG tends to be more conducive to participant comfort: It is safe for all participants, regardless of implants or metal in the body, as opposed to functional Magnetic Resonance Imaging (fMRI), which poses serious safety risks to individuals with metal or implants in the body. Furthermore, EEG allows for easy monitoring of distress, and is less likely to induce claustrophobia compared to fMRI (Harrison & Connolly, 2013). EEG is inexpensive, and due to recent advances, may be conducted in most locations. Moreover, EEG does not require participants to be positioned in any particular way, unlike fMRI (Stemmer & Connolly, 2011). EEG also allows for the removal of motion artifacts so that data rarely needs to be excluded. In contrast, fMRI may be rendered useless due to large motion artifacts (Harrison & Connolly, 2013). Arguably the biggest contribution of EEG is its ability to provide temporal information far beyond fMRI or Positron Emission Tomography (PET) (Luck, 2014). Both fMRI and PET measure regional cerebral blood flow, which takes time. As a result, EEG is better suited to recording millisecond-based

measurements of brain activity (Harrison & Connolly, 2013). Conversely, due to their recording of regional cerebral blood flow, both PET and fMRI are better suited to measures of spatial resolution, particularly with regard to examination of sub-cortical regions. In comparison, due to the dispersal of electrical current, and the distance of electrodes, spatial resolution is very difficult to calculate with accuracy in EEG (Luck, 2014). Nevertheless, the access to high-resolution temporal data and ease of administration make EEG a useful research tool. For the purposes of this thesis, EEG was conducted to investigate the neural correlates of spacing.

2.4.2 Hardware and software

EEG was recorded using a Biosemi ActiveTwo system with a 32 electrode cap using a 10-20 layout. Thirty-two active sintered Ag-AgCl electrodes made contact with the scalp through an electrolyte gel link (SignaGel, Parker Laboratories Inc., NJ, USA) which formed a connection between the scalp and the cap in which electrodes were inserted (see Figure 2.4). Use of this electrode material amplifies EEG at the scalp, thus ensuring minimal interference from external noise and a performance preferable to that of passive electrodes at most impedances (Laszlo et al., 2014). Wet electrodes aid in further noise reduction, and are considered more comfortable for participants compared to dry electrodes (Mathewson et al., 2016; Oliveira et al., 2016). A further four flat-type Active-electrodes were placed on the face to record electrooculogram signals in order to aid the detection of blinks (see Figure 2.5).

Data were recorded continuously throughout the task in a room enclosed by a Faraday cage using a battery-powered amplifier so as to reduce the impact of electrical mains noise on the signal (see Figure 2.6). Data were relayed to computers in an adjoining room. EEG signals were observed and recorded on a Dell machine with a Windows 7 operating system. A second Dell machine with a Windows 7 operating system was used to administer the FNPT via

Presentation to the Faraday cage. Only the computer monitor was present within the Faraday cage; the computer hard-drive was situated in the adjacent room. EEG data were sampled at a rate of 1024 Hz, with a pass band filter from 0.16 Hz to 100 Hz.

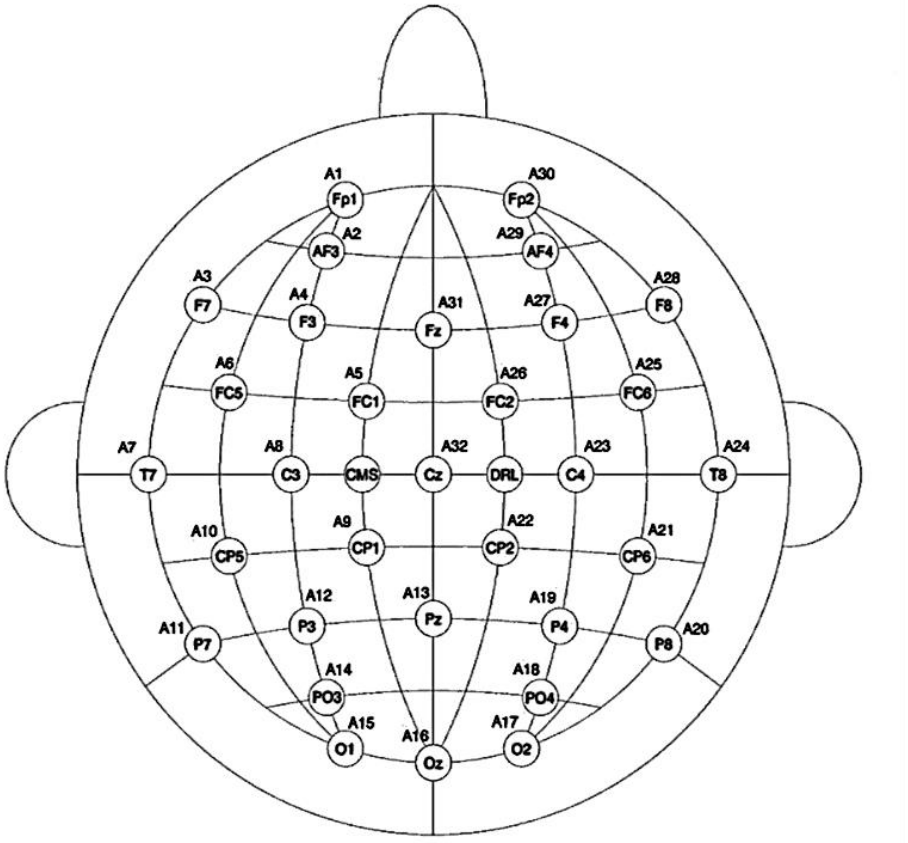


Figure 2.4: *BioSemi 32 electrode cap using a 10-20 layout. Adapted from BioSemi website: http://www.biosemi.com/pics/cap_32_layout_medium.jpg.*

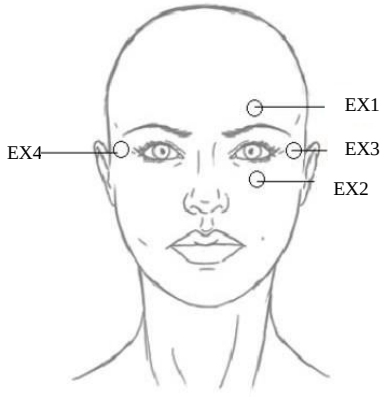


Figure 2.5: *Positioning of four EXG electrodes used to detect blinks.*

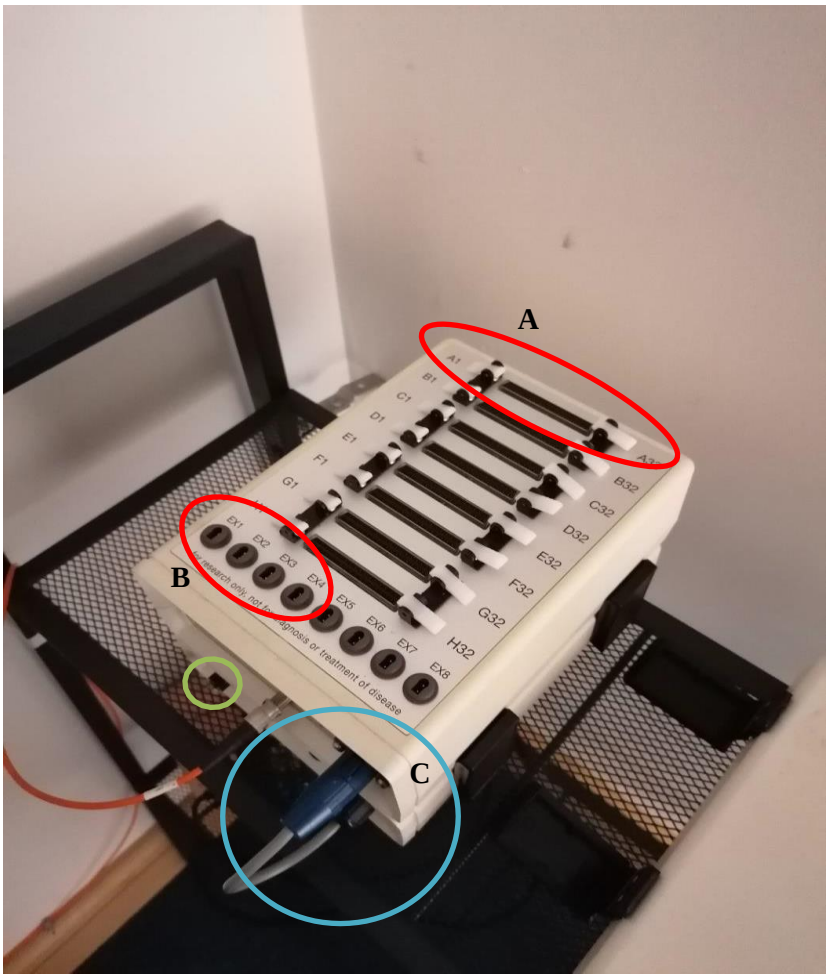


Figure 2.6: *The Biosemi ActiveTwo System used to record EEG. A = 32 electrode ribbon plugin, B = EXG electrodes plugin, and C = battery plugin.*

2.4.3 Experimental procedure

After giving informed consent, participants were seated in a preparation area. Head measurements were taken and a corresponding, electrode-positioning cap which was fastened beneath the chin with a Velcro strap was chosen. The cap was positioned so that central electrode locations were aligned vertically between the nasion and inion. Conductive, electrolyte gel was inserted into each electrode location using a syringe. The tip of the syringe was used to move hair aside. At this point, control tasks were conducted to allow the gel to soak through participant's hair, creating a stronger link between scalp and electrode.

Following the administration of the control tasks, four electrooculographic electrodes were placed around the eyes: Electrodes were placed above and below the right eye, and at the corner of each eye. Electrooculographic electrodes were held in place using small pieces of face tape. Pin electrodes were then inserted into their corresponding locations on the cap. Participants were then moved into the Faraday Cage. They were seated in front of a presentation screen with a keyboard and a mouse. The scalp ribbon and electrooculographic electrode cables were connected to an AD-box which digitises sensor signals at a 24 bit sampling resolution. These digital outputs are then sent to a receiver via an optical fibre cable. This receiver also obtained triggers from the Presentation software on the presenting monitor. The electrode optical data and trigger outputs were sent to the recording computer running the BioSemi ActiView acquisition programme. After the completion of hardware setup, direct current offset of each recording electrode was examined using the ActiView programme and additional gelling was performed where necessary. Once problematic channels were brought to a satisfactory standard, the FNPT was administered.

2.4.4 Data processing and averaging

The EEG data were analysed off-line using Brainstorm software (version 3.210714) (Tadel et al., 2011; Tadel et al., 2019). Since we did not use a reference electrode, we re-referenced our signal to an average of the electrodes (de Cheveigne & Nelkin, 2019). Data were examined manually to determine and remove bad channels or segments. A band-pass filter using a High-pass filter of 0.1Hz and a Low-pass filter of 100Hz was applied. Data were then re-referenced again to ensure that there was no dramatic change following application of the filter. We ran an Independent Component Analysis (ICA) (Lee et al., 1999; Banellis et al., 2020) with thirty-one components on the raw data using the EEGLAB *runica* infomax function

callable within Brainstorm. Based on this analysis, obvious blink and facial movement artefacts were removed.

Stimulus-locked ERP epochs were imported and averaged in Brainstorm. Each epoch began 200ms before stimulus presentation as baseline correction interval. The baseline of -200ms was used as a neutral mean voltage and was subtracted from the mean ERP voltage, to control for random pre-stimulus fluctuations. Each epoch ended at 800ms post-stimulus (Guo et al., 2005). Triggers deemed to be "correct" (that is, triggers where participants correctly identified or dismissed a given face-name pair) were isolated and epoched. ERPs were averaged for each individual participant across all "correct" triggers for each condition (spaced or massed), at each electrode site. Grand averages were then calculated across all participants in a group for each condition (spaced versus massed). ERPs extracted from four midline scalp locations (Fz, Pz, Cz, and Oz) were selected for comparative analysis via visual inspection of these averaged waveforms. These sites were chosen because close examination of ERP results obtained from all other scalp locations indicated that a midline analysis provided a good overview of all results. Furthermore, this procedure has been adopted by similar experiments (see Guo et al., 2005; Hammer et al., 2013). Mean amplitudes and peak latencies were the dependent variables for all statistical comparisons.

2.4.5 COVID-19 precautions

Due to the ongoing COVID-19 pandemic, a number of safety precautions were put in place to reduce the risk of participants or researchers contracting the virus. Participants were required to scan a QR code on their phones upon entering and leaving the laboratory. The QR code brought them to a short form whereby participants had to fill out contact details and record time of entrance and exit. This form was used as a means of contact tracing.

Participants and researchers were required to wear facial coverings throughout the experiment. Researchers also wore gloves while applying equipment. All EEG equipment, computers, and communal spaces were thoroughly cleaned and disinfected between each use. Used caps were cleaned immediately and not used again for a minimum of three days to minimise transmission. Contact between participants and researchers was kept to a minimum. Researchers were only directly in contact with participants while applying and setting up EEG equipment. Participants were isolated in the Faraday cage while carrying out the tasks.

2.5 Statistical Analysis

Data were analysed using Microsoft Excel and the IBM SPSS statistical package (versions 23, 26, and 28). Demographics and data pertaining to control tasks were compared between groups using independent t-tests. Between-group comparisons were made using independent t-tests and analyses of variance (ANOVAs). Post-hoc analyses were carried out under conditions where a main effect was observed. The strength and direction of the linear relationship between variables was investigated using Pearson product-moment correlation coefficients. Relationships between variables were further explored using standard linear regressions. A significance level of 0.05 was set for all analyses, with a Bonferroni type adjustment utilised where multiple t-tests were conducted to compare between groups. Multiple analyses of a given dependent variable increase the risk of inflated Type I errors. Bonferroni corrections lower the risk of this occurrence by dividing the original significance level (0.05) by the number of comparisons conducted, thus providing a more moderate value by which to determine statistical significance. Details of exact statistical analyses are provided in each chapter.

2.6 Ethical Approval and Participant Recruitment

The American Psychological Association and Psychological Society of Ireland codes of ethical conduct were observed throughout. Ethical approval was obtained from Maynooth University Ethics Board for all experiments (see experimental chapters for individual ethics references). Two main population samples were recruited for the purpose of this thesis: Cognitively healthy young adults and cognitively healthy older adults (aged fifty-five and over).

Participants for each experiment outlined in this thesis were recruited from Maynooth University, Dublin city centre, Navan, and the Wilkinstown-Kilberry area. Participants responded to advertisements posted on campus, in local shops, and announcements made on campus and at local community meetings (for example, the Wilkinstown Active Retirement group). Some participants for experiments outlined in Chapters 5, 6, & 7 were recruited using a participant pool, whereby psychology students at Maynooth University were encouraged to participate in up to three hours of ongoing research in order to obtain credits towards their degree (students who did not wish to participate in research were able to submit a written assignment instead).

For each experiment, participants were informed that volunteers were required to participate in a study investigating the effects of distributed practice on associative memory, or the effects of sleep on memory and cognition. Those who responded to the initial request were provided with an information sheet in advance of the experiment, explaining the procedure in detail, including what was expected of participants, the psychological and behavioural measures involved, and how long the procedure would take. Individuals partaking of the EEG experiment were fully briefed on the procedure, including a summary of what it measures, an explanation of each step involved in the process, and a warning that gel would be placed on the scalp and their hair would need to be washed afterwards. Each experiment

was also explained verbally. Participants were also given a list of exclusion and inclusion criteria to determine whether participation was appropriate.

All participants were over eighteen and consented to taking part. Consent forms were signed in person, or administered online, whereby participants had to indicate that they fully understood what they were consenting to. Participants were informed that they could pull out at any time prior to anonymisation. Participants were made aware that data were anonymised for privacy, and that data would be stored separately to consent forms. If anyone expressed concern over the results of any behavioural tests or questionnaires, participants were advised to contact their general practitioner, or another medical professional. Participants were informed that none of the measures utilised in this thesis were used for diagnostic purposes. Participants were fully debriefed following participation, and any questions were answered by the researcher. Approval and reference numbers for each experiment are provided in the relevant chapters.

Chapter 3

The effects of distributed practice on short- and long-term memory

Abstract

The spacing effect is a robust phenomenon that has been demonstrated across a number of domains. However, research investigating the effects of distributed practice on more ecologically valid concepts, such as learning face-name associations, is incomplete. Furthermore, the short- and long-term effects of spacing when learning face-name associations are not clear. This study aimed to establish the existence of a spacing effect when completing the Face-Name Pairs task at short- and long-term retrieval intervals (twenty-four hours, one week, and one month). The results suggest that spacing is beneficial when learning face-name associations at longer intervals of one month, but not at shorter intervals. Furthermore, though there was no significant difference between performance of spaced- and massed-trained participants at twenty-four hours and one week, spaced-trained participants experienced significantly less forgetting across all three intervals. These results support the robustness of the spacing effect when learning more abstract concepts, particularly at longer retrieval intervals, and suggest that spacing is beneficial with regard to reducing forgetting across both short- and long-term intervals.

3.1 Introduction

In recent years, it has been widely acknowledged that spaced learning holds a distinct advantage over massed learning (Vlach et al., 2008; Benjamin & Tullis, 2010; Kapler et al., 2015; Delaney et al., 2018). The spacing effect has been widely reproduced across many domains (Goverover et al., 2009; Breckwoltd et la., 2016; Wang et al., 2017). For example, Kapler, et al. (2015) found that undergraduate students who reviewed lecture material after an interval of eight days (spaced learning) performed better on tests than those who reviewed the content after only one day. Similarly, research has shown that spaced learning also benefits the retention of practical skills at two-weekly and one-yearly intervals in surgical trainees (Spruit et al., 2014). The findings are so robust that Kapler et al. (2015) have suggested that repeated sessions should be considered as an educational standard.

Despite this, individuals consistently rely on massed schedules of learning over spaced, even going so far as to formally judge massed learning as better than spaced when presented with alternative evidence (Kornell & Bjork, 2007; Kornell, 2009; Son & Kornell, 2009). This may be due to the fact that massed learning seems less time-consuming than spaced (Baddeley & Longman, 1978). It is possible that with a greater understanding of spaced learning and what makes it so advantageous, this perception may change. However, research alluding to why spaced learning yields such advantage over massed learning has been rather limited. Recently, Smolen et al. (2016) have attempted to address this by discussing a number of possible cognitive theories, for example, the encoding variability theory (the further apart study intervals are spaced, the more likely an individual is to associate learning with various contexts, thus creating a more powerful memory), the study-phase retrieval theory (spaced learning allows for more retrieval than massed learning, thus reinforcing a memory), and deficient-processing theory (massed learning does not allow for some of the processes required to make a strong memory in the way that spaced learning does) (Melton, 1970; Toppino, 1991;

Braun & Rubin, 1998). There may be some merit to these theories but thus far there is limited testing to support or deny them.

The key difference between spaced and massed learning is scheduling. When "cramming", there is no schedule as such - individuals simply study everything in one go. When it comes to spacing however, learning is conducted at different intervals in time. There is some evidence to suggest that these intervals and their timing are the key to understanding why spaced learning is so advantageous (Karpicke & Bauernschmidt, 2011). Some researchers have sought to optimise spacing by manipulating the intervals between learning sessions. For example, Landauer and Bjork (1978) proposed expanded retrieval, a form of learning where study sessions are spaced at increasing intervals. Camp (1989) later expanded on this theory with spaced retrieval training, a form of training in which intervals between study sessions are adjusted depending on the learner's performance. There is significant support for both techniques, particularly when training people with dementia (for example, Camp et al., 1996; Brush & Camp, 1998). However, given that most studies do not include a comparison of different spacing techniques, it is difficult to say with certainty whether expanded retrieval and spaced retrieval training are superior to other forms of spacing (Logan & Balota, 2005). In one study, Hochhalter et al. (2005) compared a number of spacing techniques, including expanded retrieval, spaced retrieval training, and random spacing, among others. Their results indicate that no one schedule of distributed learning is preferable to another. In fact, more people seemed to benefit from random spacing than any other, though this finding was not significant (Hochhalter et al., 2005). Similarly, Cull (2000) did not find any significant difference between different types of scheduling. Pyc & Rawson (2007) suggest that timing of intervals, and by extension, the number of learning sessions, may be important when implementing schedules such as dropout (this schedule involves only studying items that need to be learned on successive trials; for example, if an individual demonstrates

successful learning of one item out of four, that item will be dropped from further study sessions to allow focus on the three items that still need to be learned), but not when it comes to general methods of distributed learning. Again, this suggests that manipulation, timing, and number of learning sessions does not have any particular effect: What matters is that practice is distributed rather than accumulated.

Despite the robustness of the effect, spacing research has been criticised recently, with some suggesting that laboratory-based tasks are too simple and therefore not indicative of the complex cognitive abilities required in real-world settings (Rohrer & Pashler, 2010; Kapler et al., 2015). Much of the research investigating distributed practice focuses on simple vocabulary and mathematical tasks, learning of nonverbal sequences, names of objects, and/or word pairs (Cull, 2000; Hochhalter et al., 2005; Logan et al., 2005) or acquisition of practical medical skills (Dempster, 1986; Price Kerfoot et al., 2010; Spruit et al., 2014). Furthermore, though spacing has been demonstrated at longer intervals (Price Kerfoot et al., 2010; Spruit et al., 2014), there has been somewhat limited research with regard to the long-term effects of spaced versus massed training schedules when learning more abstract concepts, with most studies performing retests within a week of learning. This begs the question of whether the effects of spaced learning are evident and preserved over time when learning more abstruse concepts, such as face-name associations. This is an important consideration, as retention of names becomes a key difficulty with Alzheimer's disease and other disorders (Hromas & Bauer, 2019). Furthermore, successful retrieval of face-name associations is directly relevant to most individuals on a daily basis.

Reason & Lucas (1984) and Cohen & Faulkner (1986) demonstrated that individuals find it more difficult to recall names than occupations or hobbies and that retrieval blocks are more common with regard to names than any other words. Cohen (1990) concluded that in general, names are only well-remembered when they have meaning; names that lack personal

significance are inconsequential and often, individuals have nothing or no one with whom they may be associated, thus making them harder to recall then other semantic concepts. Tsao (1948) proposed that the spacing effect is more pronounced when learning meaningless, sometimes nonsense materials (as opposed to more meaningful stimuli, for example, learning nonsense syllables versus learning prose). Applying this research to face-name associations suggests that spacing should be effective. A number of techniques to help improve retention of face-name associations have been proposed: The face-name mnemonic (Carney et al., 1997) and semantic encoding strategies (Morris et al., 2005) among others (Helder & Shaughnessy, 2008). However only some research has examined whether spacing might be of benefit. Carpenter & DeLosh (2005) found that participants were better at recalling face-name pairs following the utilisation of a spaced, tested schedule when compared to those in the massed condition, suggesting that spacing is beneficial when learning face-name associations. Interestingly, they also found that expanded retrieval schedules did not yield better results than uniform schedules, suggesting that, as with other types of learning, different schedules do not yield different results (Carpenter & DeLosh, 2005).

With regard to long-term effects, Simanton & Hansen (2012) evaluated the ability of medical students to retain relevant knowledge across four years depending on the use of different educational models. Their results suggest that clinical application and spaced training schedules may lead to better retention of medical knowledge over a four-year period. These results complement those of Spruit et al. (2014). Similarly, Price Kerfoot et al. (2010) divided urology residents into online spaced training and web-based teaching (massed) schedules, whereby students received information to be studied at scheduled daily intervals, or all together in one single email. Participants were then tested periodically over a forty-five-week period. Results indicated that although participants in the massed condition tended to perform better in the short-term (weeks fourteen to sixteen), participants in the spaced

condition demonstrated significantly better long-term retention of material (weeks eighteen to forty-five). These findings suggest that spacing may not be particularly beneficial in the short-term but can lead to significant long-term retention over greater periods of time (Price Kerfoot et al., 2010). This could also explain why many individuals believe that massed learning is preferable to spaced.

To further investigate the effects of spacing and the role of intervals with regard to learning and memory, the current study uses the Face-Name Pairs task to examine participants' ability to retain face-name associations following the utilisation of different schedules of learning. The Face-Name Pairs task was administered to 118 participants who had to recall eight different face-name associations following intervals of twenty-four hours, one week, and one month. Participants were further divided into two conditions – spaced or massed. It is hypothesised that although memory recall will diminish with time, those that are spaced-trained will show better memory performance overall and that this effect will be more prominent as time goes on.

3.2 Methods

3.2.1 Participants

Power calculations were done to estimate the number of participants required. Using fixed effects ANOVAs and an effect size of 0.3 with power of 0.9, $p = 0.05$, and 6 groups estimates 119 participants. The sample consists of 118 participants, 60 males and 58 females, recruited from Maynooth University, Dublin city centre, Navan, and the Wilkinstown-Kilberry area. Participants were aged between 18 and 25 (mean = 23.22 years, SD = 8.501). An exclusion and inclusion criteria were applied, so all participants were healthy, cognitively healthy, and had normal or corrected-to normal vision. No participant had a known history of drug or substance abuse, and no other relevant medical conditions.

3.2.2 Materials

Three control tasks were used to ensure that both training groups were similar in terms of IQ, executive functioning, and general memory ability: The National Adult Reading Test (NART; Nelson, 1982) gave an estimate of verbal IQ, the Trail Making Tasks (TMT; Reitan & Wolfson, 1992) tested executive functioning, and the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1941) evaluated memory and learning strategies. The Face-Name Pairs task was used to assess associative memory and was carried out using a Sony laptop. The task was presented through a series of short, forty second videos. There were eight videos in total, four study block videos and four retrieval block videos. Each of the four study block videos consisted of eight different faces paired with eight different names. After each block, recall was assessed. The four retrieval block videos consisted of the eight different faces without their corresponding name. Participant's scores were recorded by the administrator on a separate sheet of paper (see Chapter 2).

3.2.3 Procedure

Participants were initially presented with a consent form to be read and signed (see Appendix M). The consent form stressed that all results would be anonymised and kept completely confidential. The experiment took place in a quiet room, free of distractions. Participants were asked to complete the NART, TMT, and RAVLT prior to partaking in the experiment. Each test was explained in full, and results were given upon completion if requested.

Participants were randomly assigned to the twenty-four hour, one week, or one month groups, and then to the spaced or massed conditions (see Table 3.1 for details and breakdown by gender). Due to the longevity involved with both the one week and one month groups, a number of prospective participants dropped out prior to the commencement of the experiment. As a result, there were significantly more participants in the twenty-four hour group. Each condition included four study block trials and one retrieval trial. Participants in the spaced condition completed the four trials over four consecutive days. Participants in the massed condition completed the four trials on one day. Those in the twenty-four hour condition completed the retrieval trial twenty-four hours after completing the study block, those in the one week condition completed the retrieval trial one week after completing the study block, and those in the one month condition completed the retrieval trial one month after the study block (see Figure 3.1).

Table 3.1: *Group and gender breakdown for each condition.*

	24 Hours	One Week	One Month
Spaced			
Male	14	7	10
Female	17	8	5
	31	**15**	**15**
Massed			
Male	13	8	8
Female	14	7	7
	27	**15**	**15**
Total number	**58**	**30**	**30**

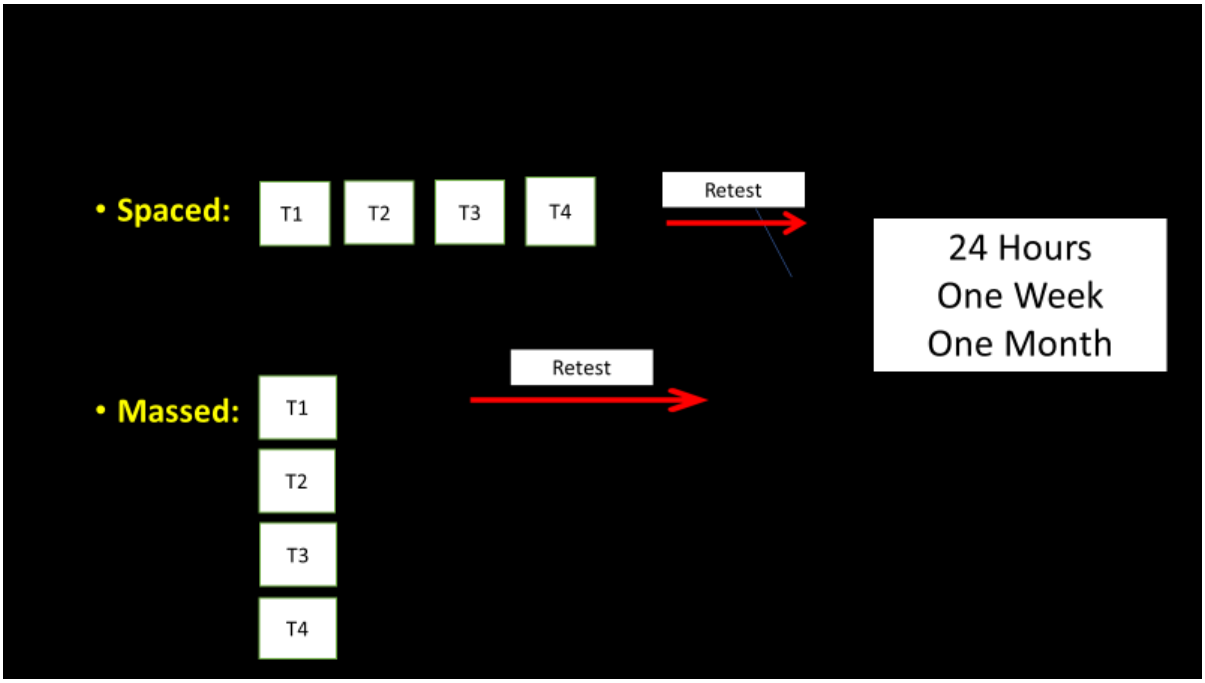


Figure 3.1: A breakdown of the spaced and massed conditions.

3.2.4 Encoding

Participants were informed as to the nature of the experiment: They were asked to watch a video of eight faces paired with eight names and were to try to recall the names associated with each face. It was explained that each trial consisted of two videos, a study block video shown twice per trial, and a retrieval block video (see Chapter 2 for details). Once the study block was complete, participants were immediately tested on their ability to recall the face-name associations. Participants were asked to watch a retrieval block video, which consisted of the eight faces alone. Participants were prompted to recall the associated name out loud.

3.2.5 Retrieval

At intervals of twenty-four hours, one week, or one month later (depending on group), participants would complete a retrieval trial. This involved watching the retrieval block video alone and attempting to recall the names associated with each face out loud (see Chapter 2 for details).

3.2.6 Design

A mixed between-within factorial design was employed for both the encoding and retrieval phases. The independent variables were condition (spaced or massed learning) and time interval (twenty-four hours, one week, or one month). The dependent variable was mean correct score (how many face-name pairs participants could remember on a given trial). The between-subjects measure was condition (spaced or massed and twenty-four hours, one week, and one month) and the within-subjects measure was difference (if any) between trials during the encoding phase and difference (if any) between trial four and the retrieval trial. Between

group comparisons were used to examine the massed and spaced groups on each of the control tasks (NART, TMTs, and RAVLT).

3.2.7 Statistics

Microsoft Excel and an IBM SPSS statistics software programme (version 23) were used to calculate the results. Means and standard errors of the mean were calculated through Microsoft Excel. Independent t-tests were used to compare the means of the control tasks and demographics. An initial 2 X 4 mixed between factorial ANOVA was conducted to investigate whether learning had occurred and to show whether a difference existed between the massed and spaced conditions. Following this, three further 2 X 4 mixed between-within factorial ANOVAs were conducted in order to evaluate initial learning experience separately for each retrieval interval group (twenty-four hours, one week, and one month). A two-way between-groups ANOVA was conducted to examine whether participants could remember each face-name pair and to show whether a difference existed between groups for each retrieval time. The Tukey HSD test was used for between group *post-hoc* comparisons and Bonferroni corrected t-tests were used for further within-group comparisons. Two one-way repeated ANOVAs were conducted to examine the forgetting curve for each condition. A number of paired samples t-tests were conducted to further analyse unusual results. Results were determined as statistically significant when $p < 0.05$. To aid visualisation a star system of significance was used where * = $p < 0.05$, **= $p < 0.01$ and ***= $p<0.001$.

3.2.8 Ethics

The American Psychological Association and Psychological Society of Ireland codes of ethical conduct were observed throughout. Participants were provided with an information sheet in advance of the experiment, explaining the procedure in detail. All participants were

over 18, consented to taking part, and were informed that they could pull out at any time. Data were anonymised for privacy. All experiments were approved by Maynooth University ethics committee (reference SRESC-2017-097).

3.3 Results

To ensure that both spaced- and massed-trained groups were matched across age and control tasks, we used a MANOVA to compare participants from both groups with respect to age and scores on the NART, TMTs, and RAVLT (see Table 3.2). The results indicate that there was no significant difference between the spaced and massed groups on the combined dependent variables ($F(6, 106) = 0.749$, $p = 0.611$). There was also no significant difference between groups when the results were considered separately: Age ($F(1, 111) = 0.207$, $p = 0.650$), NART score ($F(1, 111) = 0.115$, $p = 0.735$), TMTa score ($F(1, 111) = 0.342$, $p = 0.560$), TMTb score ($F(1, 111) = 0.038$, $p = 0.846$), TMTb-a score ($F(1, 111) = 0.282$, $p = 0.596$), RAVLT score ($F(1, 111) = 2.051$, $p = 0.155$). This suggests that participants were cognitively-matched and that further results were not affected by these variables.

Table 3.2: *Mean age, NART, TMT, and RAVLT scores (standard error of the mean) for both spaced and massed conditions, and their p values.*

	N	M/F	Age	NART	TMTa	TMTb	TMTb-a	RAVLT
Spaced	61	31/30	23.59	24.27	25.00	45.88	20.84	52.71
(SD)			(9.314)	(12.466)	(5.737)	(15.798)	(16.015)	(7.620)
Massed	57	29/28	22.86	23.47	24.18	46.44	22.30	50.60
(SD)			(7.684)	(12.388)	(8.892)	(14.955)	(13.062)	(8.088)
p values	-	-	0.650	0.735	0.560	0.846	0.596	0.155

3.3.1 Encoding Phase

An initial 2 X 4 mixed between-within factorial ANOVA was conducted to compare learning across the four trials for both the spaced- and massed- trained conditions. There was a

substantial main effect of Trial (F (3, 114) = 164.176, p < 0.001, partial eta squared = 0.812), but no effect of Group (F (1, 116) = 2.322, p = 0.130, partial eta squared = 0.020). There was no significant interaction between trial and group (F (3, 114) = 0.393, p = 0.758, partial eta squared = 0.010) (see Figure 3.3).

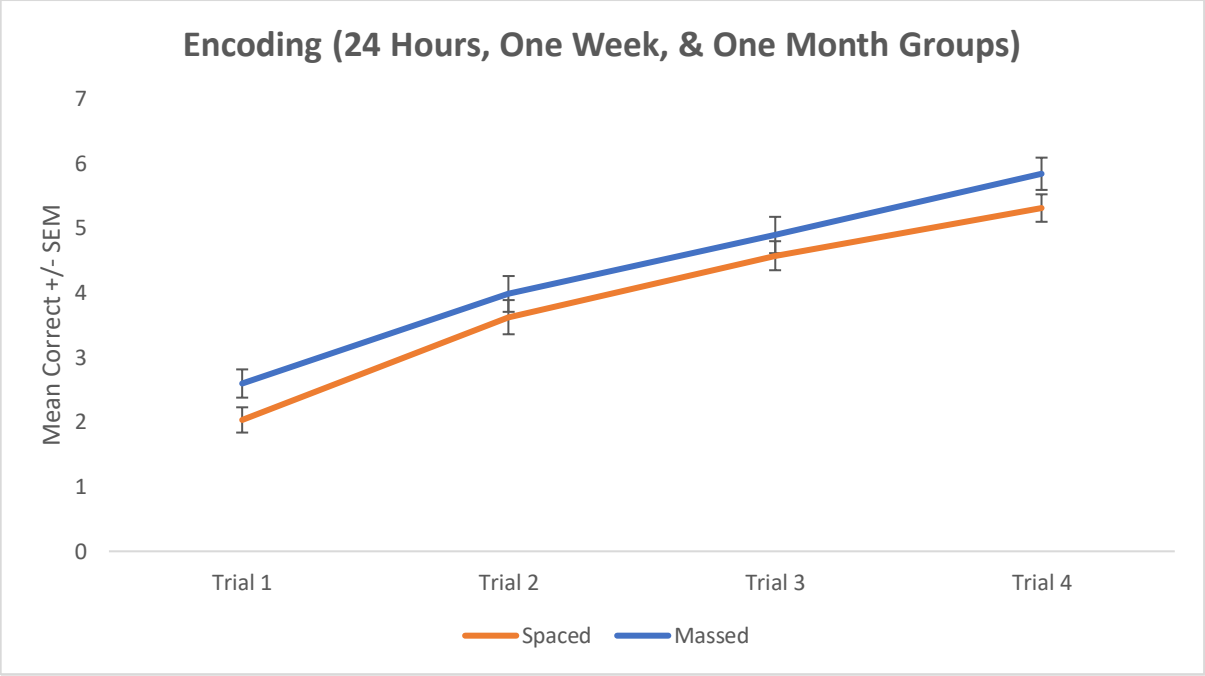


Figure 3.3: Mean encoding score and standard error of the mean for both spaced and massed groups at twenty-four hours, one week, and one month.

To ensure that all three groups learned in a similar fashion before we split based on retrieval interval, and to ensure that any difference in recall was due to the time lapse between learning and retrieval rather than poor learning, we carried out three further 2 X 4 mixed between-within factorial ANOVAs. The results indicated that there was a significant main effect of Trial for the twenty-four hour (F (3, 54) = 98.030, p < 0.001, partial eta squared = 0.845), one week (F (3, 26) = 63.928, p < 0.001, partial eta squared = 0.881), and one month groups (F (3, 26) = 28.538, p < 0.001, partial eta squared = 0.767). Effect sizes were large across all three intervals, suggesting that participants in the twenty-four hour, one week, and one month

groups all improved significantly across trials. There was no effect of condition (massed versus spaced) for the twenty-four hour (F (1, 56) = 0.114, p = 0.737, partial eta squared = 0.002), one week (F (1, 28) = 0.686, p = 0.415, partial eta squared = 0.024), and one month groups (F (1, 28) = 2.498, p = 0.125, partial eta squared = 0.082). There was no significant interaction between trial and group for the twenty-four hour (F (3, 54) = 0.865, p = 0.465, partial eta squared = 0.046), one week (F (3, 26) = 2.410, p = 0.090, partial eta squared = 0.218), and one month groups (F (3, 26) = 2.158, p = 0.117, partial eta squared = 0.199) (see Figure 3.4).

Figure 3.4: Mean encoding and standard error of the mean for both spaced and massed groups at twenty-four hours, one week, and one month.

3.3.2 Retrieval Phase

A two-way between groups ANOVA was conducted to explore the difference between the ability of those in the spaced and massed conditions to recall the face-name pairs following an interval of twenty-four hours, one week, or one month. The results indicate a moderate main effect of Condition (spaced/massed) (F (1, 112) = 9.464, p = 0.003, partial eta squared = 0.078) and a substantial main effect of retrieval interval (F (2, 112) = 14.673, $p < 0.001$, partial eta squared = 0.208). There was no significant interaction effect (F (2, 112) = 0.619, p = 0.540). *Post-hoc* comparisons using the Tukey HSD test indicated that the mean correct face-name pairs for the twenty-four hour group was significantly different from the one week group (p = 0.044) and from the one month group ($p < 0.001$), and that the mean correct face-name pairs for the one week group was significantly different from the one month group (p = 0.025) (see Figure 3.5). Three Bonferroni corrected t-tests were conducted to further explore the differences in retrieval between each group. The results indicate that there was no significant difference between the spaced and massed groups performance on the retest at twenty-four hours (t(56) = 1.706, p = 0.094, cohen's d = 0.892), and one week (t(28) = 1.045, p = 0.305, cohen's d = 0.382). However, there was a significant difference between the spaced and massed groups performances on the retest at one month (t(28) = 3.108, p = 0.004, cohen's d = 1.135).

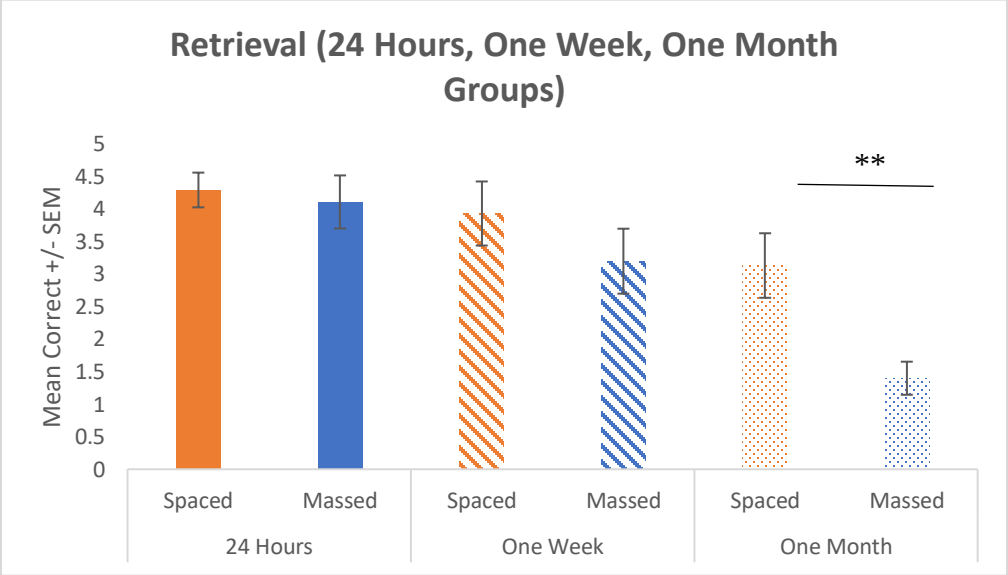


Figure 3.5: Mean retrieval score and standard error of the mean for both the spaced and massed groups at twenty-four hours, one week, and one month.

3.3.3 Forgetting

Two one-way ANOVAs were conducted to examine whether there were any differences between the performance of participants in the spaced and massed conditions respectively at the three different time intervals. The results for the **spaced group** indicated that there was a significant difference between performance at each of the three intervals (F (2, 58) = 5.110, p = 0.009). *Post-hoc* comparisons using the Tukey HSD test indicated that performance for the spaced group was not significantly different at twenty-four hours and one week (p = 0.183) but was significantly different at twenty-four hours and one month (p = 0.009). There was no significant difference between performance at one week and one month (p = 0.505) (see Figure 3.6).

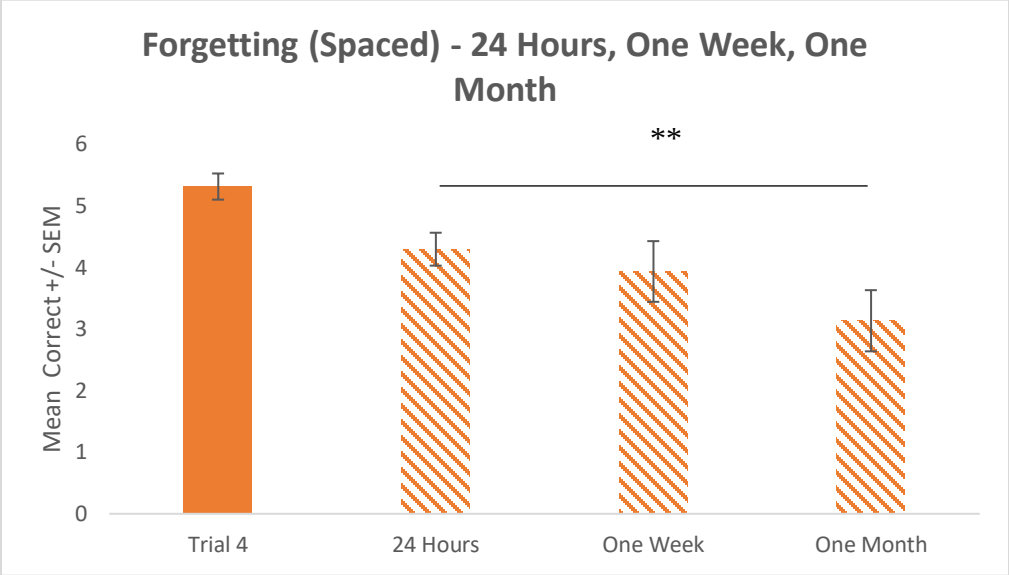


Figure 3.6: Mean retrieval and standard error of the mean for the spaced group at twenty-four hours, one week, and one month.

Conversely, the results of the **massed group** indicated that there was a significant difference between performance at each of the three intervals (F (2, 54) = 10.482, $p < 0.001$). *Post-hoc* comparisons using the Tukey HSD test indicated that performance for the massed group was significantly different at twenty-four hours and one month ($p < 0.001$), and significantly different at one week and one month ($p = 0.026$). There was no significant difference between performance at twenty-four hours and one week ($p = 0.281$) (see Figure 3.7).

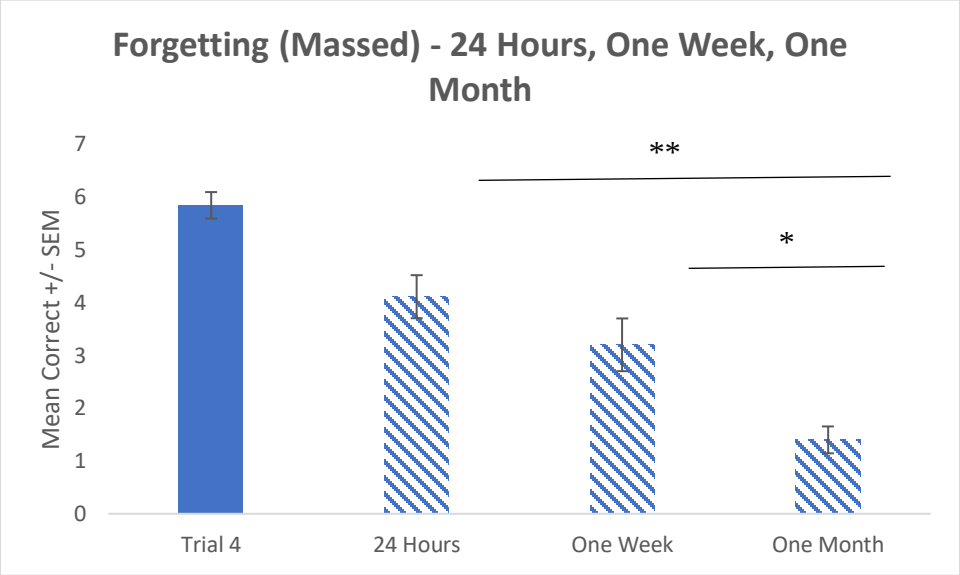


Figure 3.7: Mean retrieval and standard error of the mean for the massed group at twenty-four hours, one week, and one month.

A number of paired samples t-tests were conducted to further explore the extent to which participants "forgot" information between trial four and the retest. The results of the **spaced** t-tests indicate that there was no significant difference between trial four and retest scores at twenty-four hours (t (30) = 0.490, p = 0.627, cohen's d = -0.526), however, there was a significant difference between trial four and retest scores at one week (t (14) = 4.583, p < 0.001, cohen's d = 1.183) and one month (t (14) = 3.926, p = 0.002, cohen's d = 1.014). The results of the **massed** t-test indicate that there was a significant difference between trial four and retest scores at twenty-four hours (t (26) = 3.262, p = 0.003, cohen's d = 0.628), one week (t (14) = 9.025, p < 0.001, cohen's d = 2.330), and one month (t (14) = 12.808, p < 0.001, cohen's d = 3.307).

3.4 Discussion

The results from the encoding phase suggest that all participants learned over the course of the four trials, regardless of whether learning was spaced or massed. Participants' performance improved steadily across all four trials with the most noticeable difference occurring between trials one and four. Those in the massed group tended to have a slightly higher mean accuracy across all three conditions but this was not significant. Few studies tend to give results of the encoding phase, but these findings seem to be in line with those of Spruit et al. (2014). Their findings indicate that participants in the massed condition tended to have a higher mean accuracy (which was not significant) when learning basic laparoscopic tasks. Similarly, the new theory of disuse implies that massed participants should do better than spaced participants on encoding trials (Bjork & Bjork, 2006). This is because spaced-trained participants must actively retrieve material on subsequent study sessions, which can be difficult depending on lag length. In contrast, massed-trained participants tend not to engage in retrieval, or at least not to the same extent, due to shorter lags between subsequent study sessions. Therefore, it is reasonable to expect that, at shorter intervals, such as during encoding, massed-trained participants would do better than spaced-trained participants.

The results from the retrieval phase indicate that there was no significant difference between the performance of the spaced and massed conditions on the retest at twenty-four hours. However, the massed group performed significantly worse on the retest versus trial four. In other words, the massed group experienced immediate forgetting at twenty-four hours. This suggests that although the massed group gained better encoding scores on average, the spaced group were better able to retain what they had learned at twenty-four hours. It is possible that this is due to the schedule of learning implemented (in this experiment, those in the spaced group were tested every twenty-four hours for four consecutive days as part of the encoding phase).

At one week, both the massed and spaced conditions performed worse on the retest than at trial four, but again, both groups recalled at a similar level. The results from those tested at one month indicate that both the spaced and massed conditions performed significantly worse on the retest than at trial four, but the spaced group remembered significantly more than the massed group. Furthermore, when spaced learning occurs, memory performance is preserved at longer time intervals, whereas when massed learning occurs, retrieval drops sharply at longer time intervals. Based on these results, when massed learning occurs, memory performance is initially maintained for short periods, but as time goes by it drops significantly. This is in line with the original hypotheses, and many of the aforementioned studies (Vlach, et al., 2008; Goverover, et al., 2009; Benjamin et al., 2010; Kapler, et al., 2015; Breckwoltd, et al., 2016; Wang, et al., 2017; Delaney, et al., 2018). In particular, these results are similar to those of Price Kerfoot et al. (2010), who found that participants in the massed condition performed better than those in the spaced condition at shorter time intervals, but at longer time intervals, those in the spaced condition retained significantly more information than those in the massed condition.

However, it should be noted that these findings may be impacted by uneven numbers across retrieval groups. Given the difficulty associated with finding participants who were willing to return at longer intervals, it is possible that those participants who did return at one month were better motivated than the average participant, and thus more likely to pay attention to the face-name associations and subsequently benefit from a strong spacing effect. Given that there was no difference in retrieval at one week, however, and given that there were similar numbers across one week and one month retrieval groups, it is likely that this explanation alone does not fully account for these results. Of course, uneven groups also have a number of statistical implications, such as unequal variance and low power (Pallant, 2013). However,

these issues may be overcome with suitable post-hoc analyses, including Bonferroni corrected t-tests and Tukey-Kramer tests (Shingala & Rajyaguru, 2015).

These findings may have some implications with regard to spacing. It is interesting that there is no significant difference between the performance of those in the spaced and massed groups at twenty-four hours and one week. This finding would suggest that at shorter intervals, the schedule of learning makes little to no difference in terms of overall performance when learning face-name associations. If these results are generalisable across other abstract concepts, this could potentially lend some insight as to why individuals are inclined to trust cramming over spacing (Kornell, 2009). If, at twenty-four hour or weekly intervals, participants actually perform just as well having learned in one sitting, it is easy to understand why people might find this option more desirable when compared to spacing (Baddeley et al., 1978; Son et al., 2009). These findings also raise the question of why spaced learning is so advantageous at longer intervals. As previously mentioned, other researchers have suggested that type of spacing (for example, time between intervals and number of sessions) could impact the results (Karpicke et al., 2011). However, comparisons have shown that, if anything, random spacing appears to be the most effective (Cull, 2000; Hochhalter et al., 2005). The fact that many of the aforementioned studies use different spacing methods to produce the same results (spaced learning is preferable to massed) lends credibility to this idea. In that case, perhaps optimum spacing lies in assessment of the information to be learned. For example, in studies such as those of Price Kerfoot et al. (2010) and Spruit et al., (2014), participants had to learn medical definitions and procedures, as well as studying clinical scenarios. Arguably, such items require a greater learning capacity than object names or word pairs. The spacing schedules implemented by these researchers reflect this: Spaced participants of Price Kerfoot et al. (2010) learned twenty items over a period of three to five weeks, depending on the difficulty of a given module, with training sessions occurring every

twenty-four hours. Similarly, spaced participants of Spruit et al. (2014) learned one item per week over a period of three weeks. In contrast, Sobel et al. (2011) taught children English word definitions. Spaced participants learned four items over two separate sessions spaced one week apart. This type of spacing took place over a shorter period of time and involved considerably less learning sessions, but equally, there were considerably less items to be learned compared to the medical studies. The current experiment more closely resembles that of Sobel et al. (2011). In this experiment, participants had to learn eight items (face-name pair associations) over four sessions spaced twenty-four hours apart. Our results were also similar to Sobel et al. (2011): In both experiments, there was no significant difference between initial performance, but at one month the spaced groups retained significantly more information than the massed groups. This suggests that when designing a spaced intervention, one should consider the nature of the items to be learned.

It is still unclear why spaced learning yields such an advantage in general, particularly at one month. Due to the specific nature of recalling face-name associations, however, one might propose that spaced and massed learning simply mirror real-life name-learning situations. For example, in general individuals are far more likely to remember the name of someone whom they see over the course of five days at a training programme than they are to remember the name of someone whom they see over the course of five hours at a dinner party (Cohen et al., 1986). This could be due to a decrease in proactive interference (previously learned material interferes with the learning of new material of a similar nature) following spaced learning (Pollatsek & Bettencourt, 1976; Smith & Kimball, 2010). Similarly, it could be due to participants in the spaced condition having a greater opportunity to make novel associations between face-name pairs, or due to the fact that participants in the spaced condition sleep between learning sessions (Smolen et al., 2016).

In conclusion, this experiment has demonstrated that spaced learning is more advantageous than massed learning when attempting to retain face-name pair associations, particularly at longer intervals of one month. This study has also shown that when implementing a spaced schedule of learning, memory is better preserved at all intervals, while implementing a massed schedule of learning causes memory performance to drop dramatically. These findings are mostly concurrent with previous studies. Now that it has been established that spacing optimises retrieval of face-name associations in younger adults, it raises the question of whether the same is true for cognitively healthy older adults, and if so, can spacing be used to help combat natural memory decline with age?

Chapter 4

The effects of distributed practice on short- and long-term memory in older adults

Abstract

It is known that memory, particularly the ability to remember face-name associations, declines with age. Recent research has attempted to optimise conditions under which cognitively healthy older adults might retain information. Literature would suggest that the spacing effect, widely acknowledged to be beneficial to younger adults, is preserved with age. This study attempted to investigate the effects of age on spacing and the role of intervals with regard to learning and memory in older adults using the Face-Name Pairs task. The results suggest that older adults are impaired at learning compared to younger adults, that the spacing effect influences both older and younger adults at longer intervals, and that spaced-trained participants display similar forgetting patterns at longer intervals, irrespective of age. These results may have some implications with regard to improving the conditions under which optimum retention occurs for cognitively healthy older adults, as well as providing insight into the effect of age on our ability to learn and remember face-name associations.

4.1 Introduction

Age-related diseases are causing increasing problems in Western societies (Lin et al., 2013; Tieland et al., 2017; Gomes et al., 2019). It is known that age can affect various forms of memory, such as verbal learning, simple associations, and the recognition of faces and names (Prull et al., 2000; Ozen et al., 2010; Humphries et al., 2015; Hromas & Bauer, 2019). For example, D'Argembeau and Van der Linden (2010) found that older adults had more difficulty recalling unfamiliar faces compared to younger adults, while Martschuk and Sporer (2018) noted that younger participants performed better than older participants across a number of different face recognition measures. However, age is not always indicative of memory performance. Chalfonte and Johnson (1996) found no difference between the ability of older and younger participants to remember individual objects and colours. However, when asked to recall object/colour associations, older adults performed significantly worse than younger adults. Similarly, Grady (2012) acknowledges that while episodic, verbal, and working memory deteriorate with age, semantic memory is largely preserved.

Age-related performances can be affected by type of information and the way in which information is presented (Rahhal et al., 2002). For example, Barresi et al. (1998) found that while both younger and older adults were better able to recall occupations than surnames, older adults in particular were disproportionately better at learning occupations as opposed to surnames. They proposed that this is due to use of different neural systems when encoding names and occupations. Similarly, James (2006) proposed that by measuring tip-of-the-tongue states (an inability to produce well-known information despite believing that retrieval is possible and even likely) independent of other recall errors, specific information regarding age-related deteriorations might be uncovered. In this experiment, older and younger participants were presented with fifty-eight photographs of well-known celebrities from various decades and asked to name the person, as well as providing particular biographical

information such as occupation. By measuring tip-of-the-tongue errors, James (2006) found a specific deficit in older adult's ability to accurately retrieve proper names when compared to their ability to retrieve other biographical information. This seems to confirm that type of information presented is very important with regard to age-related performances; it is possible that due to different organisations in encoding and retrieval, some types of information are more readily available than others.

It has also been suggested that older adults have the ability to engage a wider span of brain regions than younger adults when performing cognitive tasks (Grady, 2012). This additional activity may compensate for other brain regions that have been impaired with age (Grady et al., 1994). For example, Davis et al. (2007) found that older adults showed reduced activity in the occipital lobe but increased activity in the prefrontal cortex when compared to younger adults completing the same task. Similarly, Spreng et al. (2010) conducted a meta-analysis which shows that older adults consistently demonstrate greater activity in frontal regions, but also demonstrate considerably less activity in the visual cortices when compared to younger adults. The compensation-related utilisation of neural circuits hypothesis (CRUNCH) was proposed to explain this activity (Reuter-Lorenz & Cappell, 2008). CRUNCH suggests that, depending on the cognitive demands of a given task, older adults may engage or under-utilise additional brain regions, resulting in better or poorer performance when compared to younger adults (Nashiro et al., 2018). This hypothesis implies that age-related differences in brain activity can be explained by task difficulty alone. However, this does not appear to be the case. Davis et al. (2007) found a clear posterior-anterior shift in ageing (PASA) pattern, despite controlling for differences that may occur due to task difficulty. This confirms that visible differences in neural activity between older and younger adults are most likely a direct result of ageing rather than any other variable.

Theories and experiments detailing the neural underpinnings of learning and memory can provide some explanation for age-related performances with regard to *type* of information presented. When considering *how* information is presented, questions of whether age-related performances might be improved are raised. With regard to younger adults, it is widely acknowledged that the spacing effect (see Chapter 3) is among the more advantageous forms of scheduling (Delaney et al., 2018). Though most studies examining the spacing effect include younger participants, there are some studies that use cognitively healthy older adults. One such study is that of Bercovitz et al. (2017), who taught older and younger adults word pairs, with those in the massed condition practicing immediately after training and those in the spaced condition practising twenty-four hours later. They concluded that, although younger adults remember more than older adults overall, there is evidence of the spacing effect in both participant groups at ten-day intervals. Glenberg (1976) suggests that the spacing effect can be more or less effective depending on retrieval interval. Glenberg's (1976) results show that though increased spacing allows for better recall performance at long retrieval intervals, the effect is not present at shorter retrieval intervals. The average participant age is not disclosed in this research, but Balota et al. (1989) ran similar studies comparing the performance of younger and older adults at longer and shorter retrieval intervals. The results indicate that, like younger adults, older participants were influenced by the spacing effect, particularly at longer intervals. Crowder (1976) suggests that such effects may be due to encoding variability theory (the further apart study intervals are spaced, the more likely an individual is to associate learning with various contexts, thus creating a more powerful memory) (see Chapter 1). If this is the case, encoding variability theory may further explain why older adults perform more poorly in comparison to younger adults. Rabinowitz et al. (1982) found that younger participants performed better than older participants on cued memory tasks when the cue was specific, however there was no age difference when cues were general. Similarly, Smith et al.

(1998) found greater age differences in memory performance when participants were presented with context cues as opposed to semantic cues. This suggests that older adults cannot utilise context-specific cues the way that younger adults can when recalling information. There is something of a contradiction here - if encoding variability theory is indeed responsible for the spacing effect, one might assume that it would not be present in older participants. More recent research suggests a hyper-binding effect, whereby older adults are more susceptible to distracting information, and form associations between it and target information (Campbell et al., 2010; Powell et al., 2018). In other words, due to potential disruption of frontal regions with ageing, older adults actually associate too much information, thus hindering their ability to accurately recall target information.

In summary, research to date seems to suggest that spacing is beneficial to older adults as well as younger adults, though it is not clear if this effect translates to abstract concepts, such as face-name associations (Balota et al., 1989; Bercovitz et al., 2017). It has been established that older adults tend to perform worse than younger adults on various memory tasks, but particularly with regard to face-name associations (D'Argembeau et al., 2010; Martschuk et al., 2018). Encoding variability theory may account for this deterioration in performance but would also predict that older adults do not experience the spacing effect (Crowder, 1976). This begs the question of whether the effects of the previous experiment (see Chapter 3) can be observed in older adults: Can the performance of older adults can be improved by spacing when doing exercises such as the Face-Name Pairs task (FNPT)? To further investigate the effects of age on spacing and the role of intervals with regard to learning and memory, the current study uses the FNPT to examine the ability of older and younger participants to retain face-name associations following the utilisation of different schedules of learning. The FNPT was administered to 141 participants (59 older and 82 younger) who had to recall eight different face-name associations following intervals of twenty-four hours and

one month. Participants were further divided into two conditions – spaced or massed. It is hypothesised that (1) older adults will perform worse than younger adults in all conditions, (2) that spacing effects will be observed in older adults, and that there will be a difference between performance at recent and remote intervals.

4.2 Methods

4.2.1 Participants

Power calculations were done to estimate the number of participants required. Using fixed effects ANOVAs and an effect size of 0.3 with power of 0.9, $p = 0.05$, and 8 groups estimates 119 participants. The sample consists of 141 participants, 67 males and 74 females, recruited from Maynooth University, Dublin city centre, Navan, and the Wilkinstown-Kilberry area of county Meath. Participants were split into older adults and younger adults. Based on the World Health Organisation (World Health Organisation, 2015) we classified older adults as those aged 55+. In our sample, older adults were aged between 55 and 87 (mean = 64.63 years, SD = 9.004). Those classified as younger adults were aged between 18 and 29 (mean = 21.85 years, SD = 2.294). An exclusion and inclusion criteria were applied, so all participants were healthy, cognitively healthy, and had normal or corrected-to normal vision. No participant had a known history of drug or substance abuse, and no other relevant medical conditions.

4.2.2 Materials

Similar to Chapter 3, four control tasks were used to ensure that both training groups were similar in terms of IQ, executive functioning, and general memory ability and to ensure that older participants were cognitively healthy. These tasks included the National Adult Reading Test (NART; Nelson, 1982) which gives an estimate of verbal IQ; the Trail Making Tasks A and B (TMT; Reitan & Wolfson, 1992) which test executive functioning; the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1941) which evaluates memory and learning strategies; and the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) tests general cognition and for mild cognitive impairment. The FNPT was used to assess associative memory (see Chapter 2 for details).

4.2.3 Procedure

Participants were initially presented with a consent form to be read and signed (see Appendix N). The consent form stressed that all results would be anonymised and kept completely confidential. The experiment took place in a quiet room, free of distractions. Participants were asked to complete the NART, TMT, RAVLT, and MoCA prior to partaking in the experiment. Each test was explained in full, and results were given upon completion if requested.

Participants were randomly assigned to the twenty-four hour or one month groups, and then to the spaced or massed conditions (see Table 4.1 for details and breakdown by gender). Each condition included four study blocks and one retrieval trial block. Participants in the spaced condition completed the four trial blocks over four consecutive days. Participants in the massed condition completed the four trial blocks on one day. Those in the twenty-four hour condition completed the retrieval trial twenty-four hours after completing the study block and those in the one month condition completed the retrieval trial one month after the study block (see Figure 4.1).

Table 4.1: *Number of participants in each condition and group (including gender breakdown).*

	24 Hours	**One Month**
Spaced		
Older adults	**14** (9 female/5 male)	**15** (7 female/8 male)
Younger adults	**22** (11 female/11 male)	**15** (10 female/5 male)
	36	**30**
Massed		
Older adults	**15** (9 female/6 male)	**15** 8 female/7 male
Younger adults	**23** (11 female/12 male)	**22** (12 female/10 male)
	38	**37**
Total number	**74**	**67**

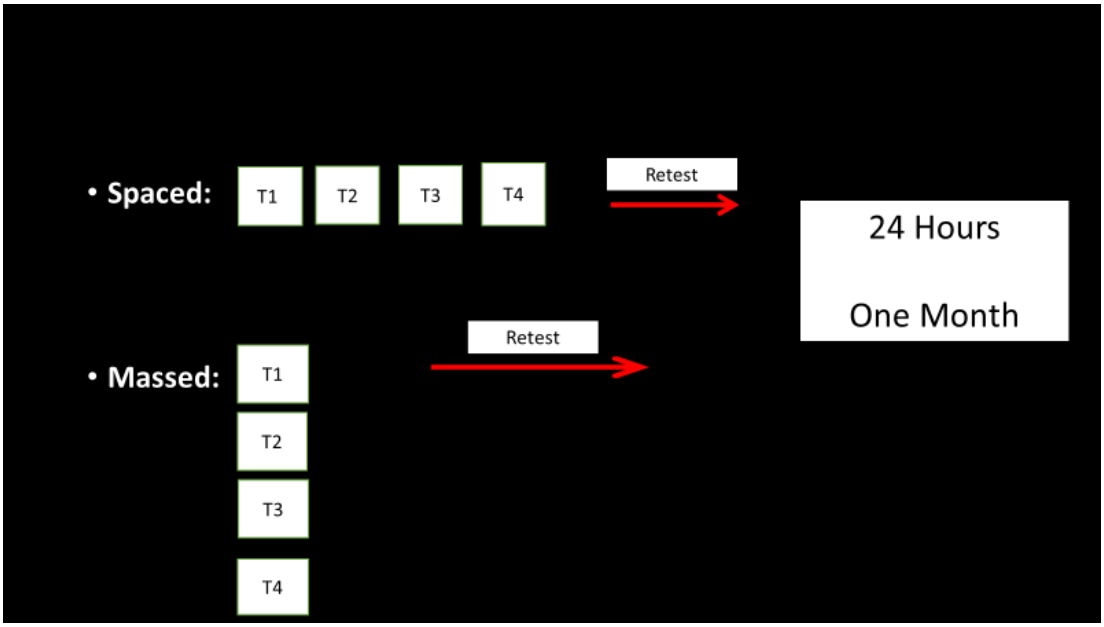


Figure 4.1: A visual representation of the spaced and massed conditions. For the massed group, all four trials were given on the same day. For the spaced group, one trial was given each day for four days.

4.2.4 Encoding

See Chapter 2 for details on encoding. In brief, participants were asked to watch a video of eight faces paired with eight names twice. Participants were then required to recall each of the eight names when presented with the face alone. This was repeated four times.

4.2.5 Retrieval

At intervals of twenty-four hours or one month later participants were required to recall the correct name associated with each face. This involved a single trial of eight faces.

4.2.6 Statistics

Microsoft Excel and an IBM SPSS statistics software programme (version 23) were used to calculate the results. Means and standard errors of the mean were calculated through Microsoft Excel. A number of independent t-tests were used to compare the means of the control tasks and demographics. An initial 2 X 4 mixed between factorial ANOVA was conducted to investigate whether learning had occurred and to show whether a difference existed between the massed and spaced conditions. Following this, four further 2 X 4 mixed between-within factorial ANOVAs were conducted to examine whether there was a difference between age and conditions at each retrieval time. A 2 X 2 X 2 factorial ANOVA was conducted to examine whether participants could remember each face-name pairs and to show whether a difference existed between age and condition for each retrieval time. Two further 2 X 2 factorial ANOVAs were conducted to further examine whether there was a difference between age and groups at each retrieval time. A number of Bonferroni-corrected t-tests were conducted to further explore the difference between the spaced and massed groups and to examine forgetting for each age group and condition.

4.2.7 Ethics

The American Psychological Association and Psychological Society of Ireland codes of ethical conduct were observed throughout. Participants were provided with an information sheet in advance of the experiment, explaining the procedure in detail. All participants were over eighteen, consented to taking part, and were informed that they could pull out at any time. Data were anonymised for privacy. All experiments were approved by Maynooth University ethics committee (reference SRESC-2017-097).

4.3 Results

To ensure that both younger and older spaced- and massed-trained participants were matched across control tasks, we used two MANOVAs to compare participants from both groups with respect to scores on the NART, TMTs, and RAVLT (see Table 4.2). The results of the *younger* MANOVA indicate that there was no significant difference between the spaced and massed conditions on the combined dependent variables ($F(6, 28) = 1.008$, $p = 0.440$). There was also no significant difference between groups when the results were considered separately: NART score ($F(1, 33) = 0.484$, $p = 0.492$), TMTa score ($F(1, 33) = 2.8$, $p = 0.104$), TMTb score ($F(1, 33) = 1.125$, $p = 0.297$), TMTb-a score ($F(1, 33) = 0.157$, $p = 0.694$), RAVLT score ($F(1, 33) = 1.947$, $p = 0.172$), MoCA score ($F(1, 33) = 0.061$, $p = 0.807$). The results of the *older* MANOVA indicate that there was no significant difference between the spaced and massed conditions on the combined dependent variables ($F(5, 52) = 1.376$, $p = 0.249$). There was also no significant difference between groups when the results were considered separately: NART score ($F(1, 56) = 2.555$, $p = 0.116$), TMTa score ($F(1, 56) = 0.1$, $p = 0.753$), TMTb score ($F(1, 56) = 2.483$, $p = 0.121$), TMTb-a score ($F(1, 56) = 3.333$, $p = 0.073$), RAVLT score ($F(1, 56) = 0.065$, $p = 0.8$), MoCA score ($F(1, 56) = 0.656$, $p = 0.422$). This suggests that participants were cognitively-matched and that further results were not affected by these variables.

Table 4.2: *Mean age, NART, TMT, RAVLT and MoCA scores (standard error of the mean) for both spaced and massed conditions, and their p values.*

	N	M/F	Age	NART (No Errors)	TMTa (Secs)	TMTb (Secs)	TMTb-a (Secs)	RAVLT No correct (Sum 1-5)	MoCA (Score)
Young Spaced (SD)	37	21/16	22.32 (2.11)	15.59 (3.362)	32.2 (15.85)	38.4 (13.8)	18.8 (9.55)	48.8 (8.349)	28.6 (0.894)
Young Massed (SD)	45	22/23	21.47 (2.39)	13.63 (5.468)	24.83 (7.737)	45.22 (13.25)	20.88 (11.043)	56.73 (12.17)	28.43 (1.455)
p values	-	-	-	0.492	0.104	0.297	0.694	0.172	0.807
Older Spaced (SD)	29	13/16	65.17 (10.1)	11.36 (6.623)	31.54 (12.55)	81.54 (54.07)	48.68 (46.71)	47.75 (8.077)	27.13 (1.807)
Older Massed (SD)	30	13/17	64.1 (7.99)	9.13 (3.646)	32.47 (9.980)	65.45 (13.92)	32.49 (12.955)	47.10 (11.040)	27.57 (1.633)
p values	-	-	-	0.116	0.753	0.121	0.073	0.8	0.422

4.3.1 Encoding Phase

An initial 4 X 4 mixed between-within factorial ANOVA was conducted to compare learning across the four trials for both the spaced- and massed- trained conditions and for both the younger and older groups. There was a significant main effect of Trial (F (3, 135) = 84.323, $p < 0.001$, partial eta squared = 0.652) and a significant effect of Group (F (3, 137) = 39.135, $p < 0.001$, partial et squared = 0.461). There was a significant interaction between trial and group (F (9, 328.705) = 3.019, p = 0.002, partial eta squared = 0.062) (see Figure 4.2). Bonferroni-corrected t-tests indicate that the mean number of correct responses on trial four were significantly higher that trials one, two, and three ($p < 0.001$, cohen's d = -1.301, cohen's d = -0.665, cohen's d = -0.342), suggesting that all groups learned the task. *Post-hoc* comparisons using the Tukey HSD test indicated that there was a small but significant difference between the performance of the young spaced and massed groups (p = 0.022), a significant difference between the performance of the young and old groups overall ($p <$ 0.001), but no significant difference between the performance of the old spaced and old massed groups (p = 0.973).

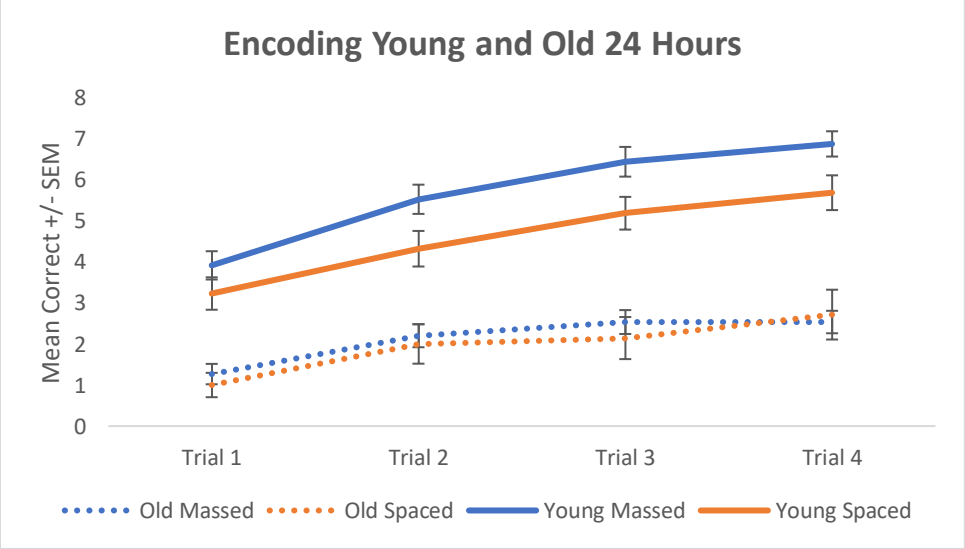


Figure 4.2: Mean encoding score and standard error of the mean for both spaced and massed and old and young groups at twenty-four hours and one month.

To ensure that all four groups learned in a similar fashion before we split based on retrieval interval (24 hour or one-month recall), and to ensure that any difference in recall was due to the time lapse between learning and retrieval rather than poor learning, we carried out four further 2 X 4 mixed between-within factorial ANOVAs. The results indicated that there was a significant main effect of Trial for *young participants* (Figure 4.3, top panel)to be re-tested at twenty-four hours (F (3, 41) = 52.634, $p < 0.001$, partial eta squared = 0.794) and one month (F (3, 33) = 37.606, $p < 0.001$, partial eta squared = 0.183). There was a significant effect of Condition (spaced versus massed) at twenty-four hours (F (1, 43) = 5.797, $p = 0.020$, partial eta squared = 0.119), but no effect of Condition at one month (F (1, 35) = 2.841, $p = 0.101$, partial eta squared = 0.075). There was no significant interaction between trial and condition at twenty-four hours (F (3, 41) = 0.763, $p = 0.522$, partial eta squared = 0.053) or one month (F (3, 33) = 2.471, $p = 0.079$, partial eta squared = 0.183).

There was a significant main effect of Trial for *older participants* (Figure 4.3 bottom panel) to be tested at twenty-four hours (F (3, 25) = 13.578, $p < 0.001$, partial eta squared = 0.620) and one month (F (3, 26) = 9.176, $p < 0.001$, partial eta squared = 0.514). There was no effect of Condition at twenty-four hours (F (1, 27) = 0.148, $p = 0.704$, partial eta squared = 0.005) or one month (F (1, 28) = 0.938, $p = 0.341$, partial eta squared = 0.032). There was no significant interaction between trial and condition at twenty-four hours (F (3, 25) = 0.392, $p = 0.760$, partial eta squared = 0.045) or one month (F (3, 26) = 1.538 $p = 0.228$, partial eta squared = 0.151). We were satisfied that all groups learned the task in a similar fashion.

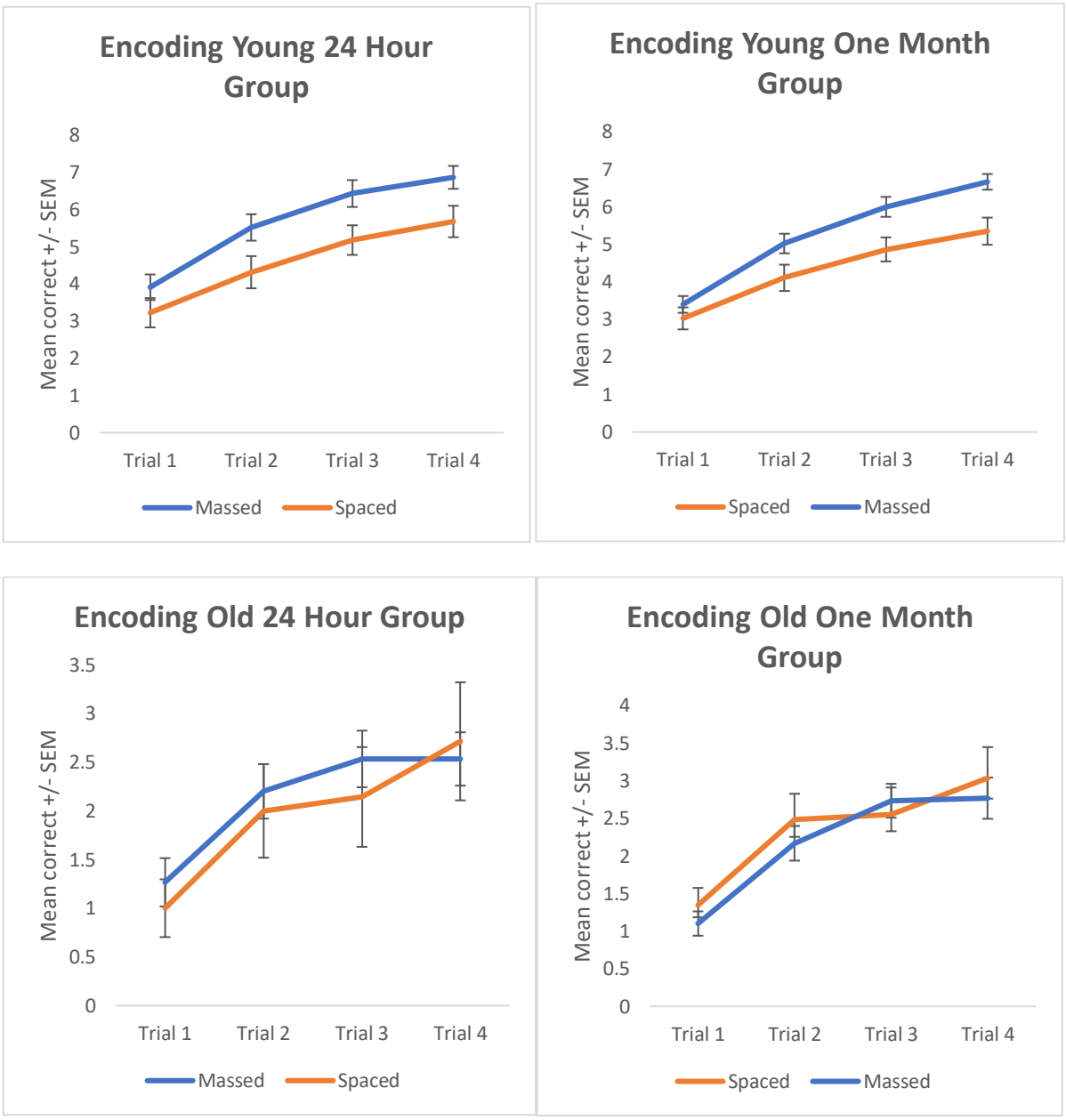


Figure 4.3: Mean encoding and standard error of the mean for both spaced and massed and young and old groups at twenty-four hours and one month.

4.3.2 Retrieval Phase

An initial 2 X 2 X 2 factorial ANOVA was conducted to explore the difference between the ability of those in the spaced and massed conditions and the ability of younger and older participants to recall the face-name pairs following an interval of twenty-four hours or one

month. There was a significant main effect of Time (F (1, 132) = 20.246, p < 0.001, partial eta squared = 0.133), a significant effect of Age (F (1, 132) = 48.087, p < 0.001, partial eta squared = 0.267), and an effect of Group (F (1, 132) = 4.667, p = 0.033, partial eta squared = 0.034). There was a significant interaction between age and time (F (1, 132) = 3.954, p = 0.049, partial eta squared = 0.029), but no significant interaction between group and age (F (1, 132) = 0.912, p = 0.341, partial eta squared = 0.007), no significant interaction between group and time (F (1, 132) = 3.846, p = 0.052, partial eta squared = 0.028), and no significant interaction between group, time, and age (F (1, 132) = 0.714, p = 0.400, partial eta squared = 0.005) (see Figure 4.4).

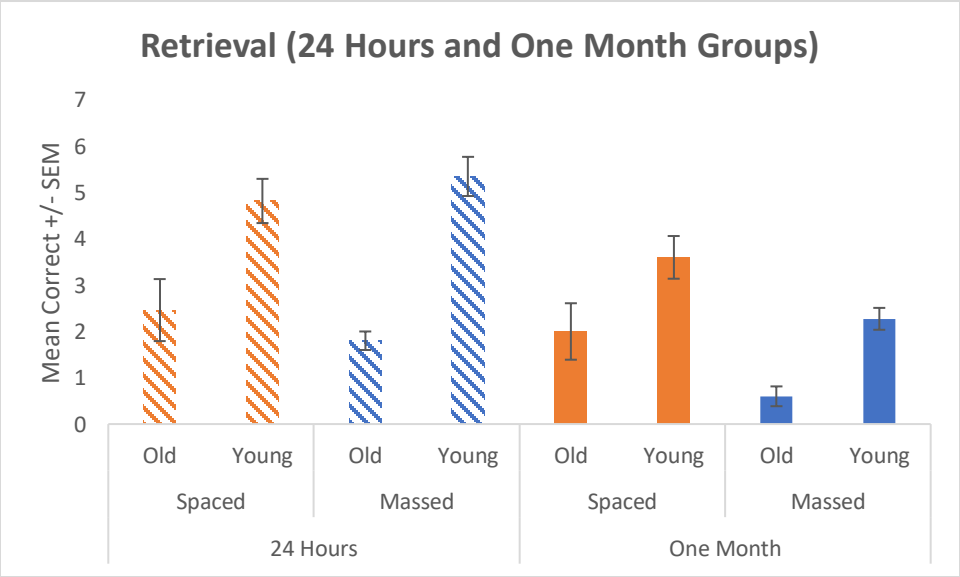


Figure 4.4: Mean retrieval score and standard error of the mean for both the spaced and massed and young and old groups at twenty-four hours and one month.

To examine the differences in retrieval in more depth, we carried out two further 2 X 2 factorial ANOVAs. **Recall at twenty-four hours** indicated that there was a significant main effect of Age (F (1, 69) = 37.197, p < 0.001, partial eta squared = 0.350), with older adults recalling less names compared to younger adults. However, there was no effect for Condition

(F (1, 69) = 0.019, p = 0.892, partial eta squared < 0.001) and no interaction effect between Age and Condition (F (1, 69) = 1.514, p = 0.223, partial eta squared = 0.021). **Recall at one month** also showed a significant effect of Age (F (1, 63) = 13.373, p = 0.001, partial eta squared = 0.175), with older adults again showing poor recall. There was a significant effect of Condition (F (1, 63) = 9.287, p = 0.003, partial eta squared = 0.128), with those in the *spaced group recalling significantly more than those in the massed group* (irrespective of age group). There was no interaction between Age and Condition (F (1, 63) = 0.007, p = 0.935, partial eta squared < 0.001) (see Figure 4.4).

4.3.3 Forgetting

Our results suggest that participants in the spaced condition (irrespective of age) recalled more compared to those in the massed condition and that this effect was only observed at one-month recall. As such, we would expect a greater forgetting effect (between the final learning trial compared to the recall trial) for the massed group compared to the spaced group, particular at the one-month recall. Figure 4.5a shows a large and significant forgetting effect for both the younger (t (21) = 9.970, p < 0.001) and older groups (t (14) = 7.159, p < 0.001) in the massed condition (left panel). Interestingly, the rate of decline is significantly worse for the younger compared to the older adults (mean slope for younger adults is -4.18 +/- 0.4 and for older adults is -2.4 +/- 0.33, t (35) = 3.074, p = 0.004, right panel).

Figure 4.5b also shows a significant forgetting effect for both the younger (t (14) = 3.67, p < 0.001) and older groups (t (14) = 5.29, p < 0.001) in the spaced condition (left panel). In contrast to the massed condition, the rate of decline for both age groups (mean slope for younger adults is -1.266 +/- 0.33 and for older adults is -1.33 +/- 0.25) is similar with no significant difference (t (28) = -0.156, p = 0.877, right panel). Overall, the rate of decline is

significantly worse for the massed condition overall compared to the spaced condition ($F(1,63) = 28.4$, $p < 0.001$).

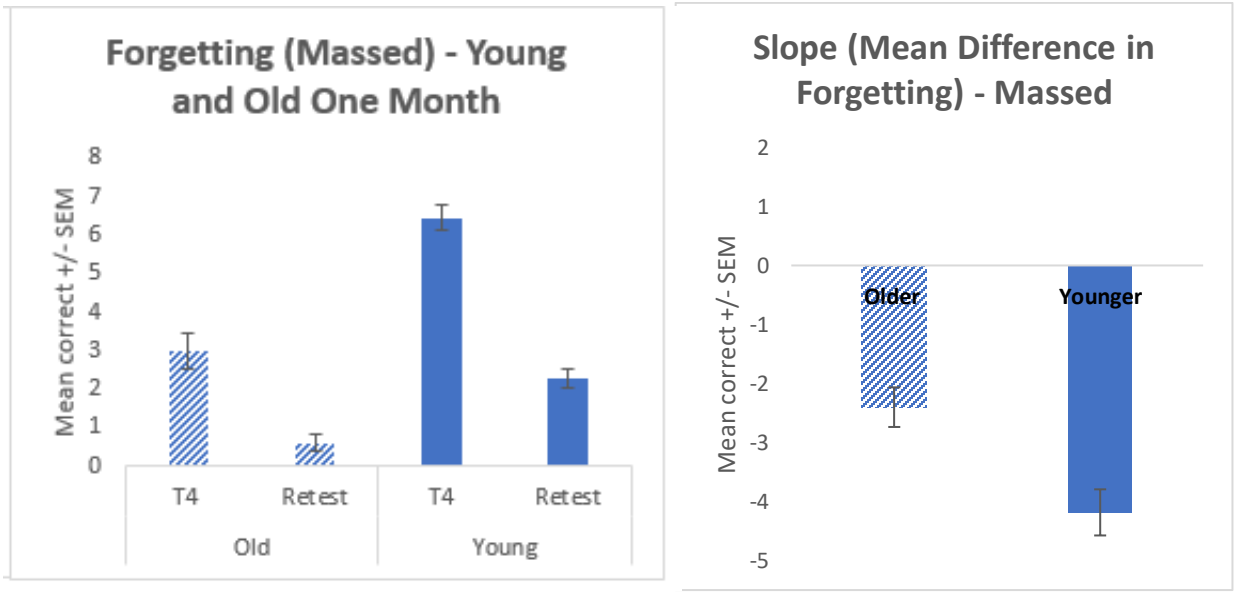


Figure 4.5a: Mean retrieval, slope, and standard error of the mean for the old and young massed groups at one month.

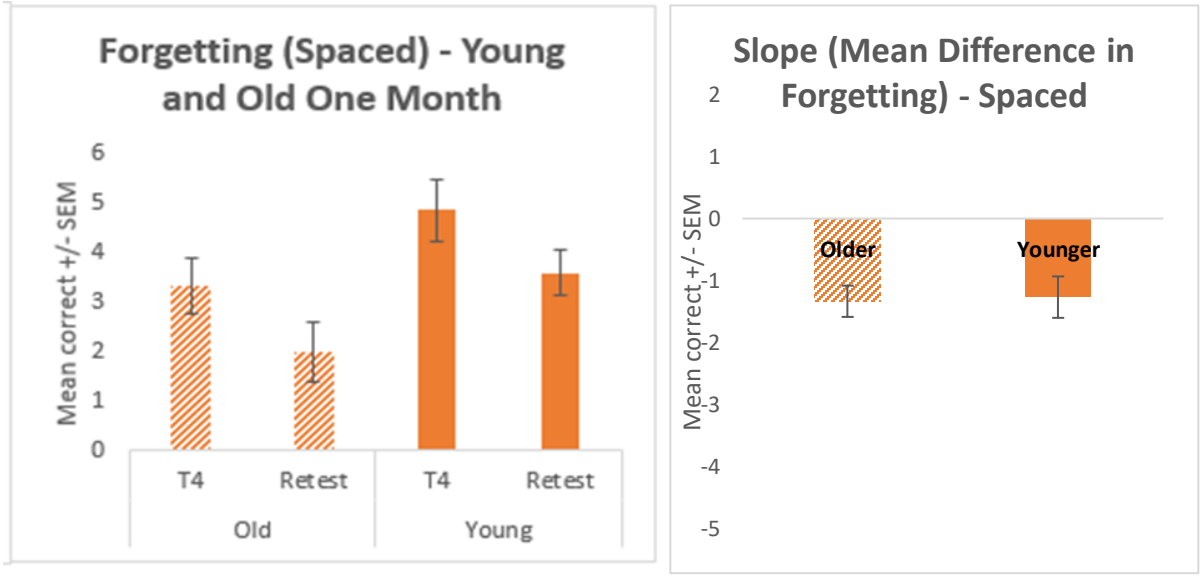


Figure 4.5b: Mean retrieval, slope, and standard error of the mean for the old and young spaced groups at one month.

In summary, older adults are impaired at learning the Face-Name Pairs task compared to younger adults. The spacing effect is not apparent at short intervals of twenty-four hours. However, massed learning evokes poorer recall compared to spaced learning in both younger and older adults at longer intervals of one month. At one month, massed-trained younger adults demonstrate sharper forgetting compared to massed-trained older adults. In contrast, spaced-trained participants display similar forgetting patterns at one month, irrespective of age.

4.4 Discussion

The results from the encoding phase suggest that all participants learned over the course of the four trials, regardless of age (old or young) and type (spaced or massed) of learning, however younger participants learned significantly more than older participants. This is in line with similar studies, for example Bercovitz et al. (2017), who found that though both young and old participants were able to successfully learn word pairs, younger adults were significantly better at it. Participants' performance improved steadily across all four trials with the most noticeable difference occurring between trials one and four. Those in the massed group tended to have a slightly higher mean accuracy across both age groups and conditions but this was only significant in the case of young participants that were subsequently tested at twenty-four hours. This may be explained by the new theory of disuse (Bjork & Bjork, 2006) (see Chapter 3). Spruit et al. (2014) found that when learning basic laparoscopic tasks, massed-trained participants tended to have a slightly higher mean accuracy, however this was not significant. Similarly, Simone et al. (2013) found that massed-trained younger adults tended to perform slightly better than their spaced-trained peers during encoding, but again this was not significant.

The results from the retrieval phase indicate that there was no significant difference between the performance of the spaced and massed groups on the retest at twenty-four hours. However, the older group performed significantly worse than the younger group. In other words, the spacing effect was not evident for either age group at twenty-four hours, but younger participants learned significantly more than older participants. This complements the previous study (see Chapter 3) and is in line with research regarding younger adults out-performing older adults on face-name measures (D'Argembeau et al., 2010; Martschuk et al., 2018). The results of the younger participants are particularly interesting; although participants in the massed group learned significantly better than those in the spaced group,

they did not perform significantly better on the retest. This suggests that spaced-trained participants may be better able to retain what they have learned.

At one month, both younger and older adults who were spaced-trained performed significantly better than their massed-trained peers, and again, younger participants learned significantly more than older participants. These results are in accordance with the original hypotheses and the existing literature (Balota et al., 1989; Benjamin & Tullis, 2010; Bercovitz et al., 2017). As demonstrated in the previous study, younger adults appear to benefit from spacing at longer rather than shorter intervals (see Chapter 3). The current results show that the same is true of older adults. The aforementioned studies suggest that although older adults tend to perform poorly compared to younger adults, they exhibit similar patterns of retrieval. This appears to be the case. Interestingly, upon analysing the slopes of forgetting at one month, we found no significant difference between that of the spaced-trained older and younger adults. Furthermore, massed-trained younger adults demonstrated sharper forgetting than their older peers, suggesting that one's ability to retrieve face-name associations is not affected by age.

These results may have some implications with regard to improving conditions under which older adults achieve optimum retention. It is clear based on the current results that the spacing effect exists for and is advantageous to older adults at longer intervals of one month. Additionally, these results suggest that cognitively healthy older adults do not struggle any more than younger adults with retrieval. In fact, massed-trained young participants experienced significantly more forgetting at one month. This is in line with existing literature, for example, Price Kerfoot et al. (2010) found that young, massed-trained participants experienced a significant drop in retrieval at longer time intervals compared to spaced-trained participants (see Chapter 3). This begs the question of why massed-trained older adults did not experience the same drop in retrieval? In line with theories such as CRUNCH and PASA,

it is possible that these advantages are due to the activation of different brain regions during retrieval (Davis et al., 2007; Reuter-Lorenz et al., 2008; Spreng et al., 2010).

Furthermore, why do younger adults consistently perform better? Our results would suggest that the difficulty for older adults lies in their ability to acquire new information. This is in line with studies such as those conducted by Barresi et al. (1998), who suggested that older adults are significantly poorer at recalling surnames when compared to younger adults due to potential atrophy of the neural system used to encode names. Similarly, McGillivray & Castel (2010) suggest a number of factors that can disproportionately affect the ability of older adults to encode names, including interference and hyper-binding.

Although they perform significantly worse than younger adults, spacing appears to enhance the ability of cognitively healthy older adults to remember face-name pairs long-term. Li & Yang (2020) found that young spaced-trained participants showed significantly greater hippocampal activity when recognising face-scene pairs compared to massed-trained participants. This activity was particularly pronounced at one-month intervals. Given the involvement of the hippocampus in creating long-term memories, this could explain why distributed practice is so advantageous (Scoville & Milner, 1957; Bercovitz et al., 2017; Delaney et al., 2018). It would be worth examining whether the same is true of older adults. Similarly, Callan & Schweighofer (2010) used fMRI to demonstrate significant activity in the frontal operculum while utilising spaced schedules. There was no corresponding activity for massed-trained participants. Given that the average participant age for the experiment of Callan et al. (2010) is thirty-two, it is difficult to say whether the same is true of older adults. However, if the assumptions of Spreng et al. (2010) are correct, it is possible that this activity does occur in older adults and may be amplified by their use of compensation techniques (Nashiro et al., 2018).

These findings could potentially be explained by encoding variability theory (Crowder, 1976; Maddox, 2016). Due to the delay between study intervals, spaced-trained participants have the opportunity to associate greater context with learned material, thus potentially making it easier to retrieve said material under various circumstances. Given that older adults are known to struggle when presented with context-specific cues, this could explain why younger adults perform so much better (Rabinowitz et al. 1982; Smith et al. 1998). However, encoding variability theory would suggest that older adults should not benefit from spacing at all, which is clearly not the case. Why, then, is spacing preserved with age? The aforementioned findings of Callan & Schweighofer (2010) are consistent with deficient processing theory, the idea that spaced-trained individuals are more attentive to subsequent presentations when compared to massed-trained individuals. Due to the involvement of working memory at each stage in learning, massed-trained individuals are more inclined to believe themselves familiar with the material and therefore less attentive on consecutive presentations. In contrast, spaced-trained participants are inclined to feel less familiar with the material which leads to more vigilant encoding with each presentation (Cepeda et al., 2006) (see Chapter 1). If this increased frontal activity is also present in older adults, this would explain the presence of the spacing effect, as well as aligning with other neuroimaging studies, for example, PASA (Davis et al., 2007). Additionally, it is possible that due to over-activation or compensation-related brain activity, older adults are not able to distinguish between relevant and irrelevant contextual information the way young adults can, thus forming associations between target information and distractors (Campbell et al., 2010; Powell et al., 2018). With regard to the retrieval of face-name associations in particular, there are other contextual factors to be considered in this instance, for example, own-age bias (Martschuk et al., 2018). The faces used in the current experiment are all belonging to young adults, therefore it is possible that older participants tended to perceive the faces as more similar to each other than younger

participants, who belong to the same age group and may be more discerning. This own-age bias could explain why older participants performed so poorly in this experiment (Quattrone & Jones, 1980).

In conclusion, this experiment has demonstrated that the spacing effect is relevant to cognitively healthy older adults when attempting to retain face-name pair associations, particularly at longer intervals of one month. Furthermore, older adults perform significantly worse than younger adults under all conditions. However, spaced-trained individuals display similar patterns of forgetting at one month, regardless of age. These findings are mostly concurrent with previous studies.

Chapter 5

Distributed practice in an online versus in-person task

Abstract

The outbreak of the COVID-19 pandemic has resulted in significant change across the board. In particular, laboratory-based research has been adversely affected, with all non-essential laboratory research discontinued for a time. Furthermore, the pandemic has necessitated a shift towards online learning in educational institutions worldwide. This raises concerns over the reliability and validity of both research and other services that have been adapted for online application. Can existing research be replicated online? Are individuals receiving the same level of service through online mediums? We sought to answer these questions by examining whether the spacing effect could be replicated in an online setup using the Face-Name Pairs task. The results suggest that although participants learn and recall better in an online setup compared to in-person, the spacing effect was not as robust and did not confer any real advantage. These results are discussed in terms of advantages and disadvantages of online versus in-person procedures and the implications for online studies.

5.1 Introduction

The recent outbreak of the coronavirus SARS-CoV-2 (COVID-19) has had an extraordinary impact on research. Due to ongoing national lockdowns, laboratory work was forced to an abrupt halt, resulting in the suspension, termination, and discontinuation of many important experiments (Weiner et al., 2020; Alam et al., 2021). Additionally, due to current public safety measures, researchers are unable to convene with participants face-to-face unless maintaining essential and/or life-saving care, or conducting research directly related to COVID-19 (GlobalData Healthcare, 2020; Ranganathan et al., 2020). As a result, researchers working with human participants have had to consider alternative methods of recruitment and supervision of research participants, for example, moving experiments online (Goldsack et al., 2020; Sohrabi et al., 2021). Such changes in the nature of human participation begs a number of questions: Is remote research preferrable to research carried out in-person? Can current laboratory-based research be successfully adapted and distributed online? Are the results of remote experiments comparable to in-person experiments? Can in-person research be replicated remotely?

There are a number of advantages to conducting research online. For example, online experiments can benefit from a greater number and wider range of participants, allowing for more robust and generalisable datasets (Langer & Beckman, 2005; Comley & Beaumont, 2011b). Remote research can also prove less time-consuming for researchers and allow greater flexibility for participants (Comley & Beaumont, 2011a), i.e. allowing participants to select their own time and place to take part in a study. Furthermore, online methods are becoming increasingly relevant in a digital world (Germain et al., 2018). That being said, remote experiments also raise a number of issues, such as ethical concerns, sample bias, and a heightened possibility of misunderstandings when explaining a task (Comley & Beaumont, 2011a; Bridges, 2016; Germain et al., 2018). Over the years, a number of studies have adapted

traditional qualitative methods for online use with reasonable success, although there are ongoing methodological concerns (Seymour, 2001; Morison et al., 2015; Seko et al., 2015; Kurtz, 2017). Similarly, there have been successful attempts to move quantitative research online, but again, there are ongoing methodological and ethical concerns (Comley & Beaumont, 2011a; Comley & Beaumont, 2011b; Page Hocevar & Flanagin, 2017; Claypoole et al., 2018). For example, it is very difficult to exactly replicate quantitative tasks when adapting them for online use, and if an experimenter was originally present, a significant influencer has now been removed. Furthermore, if a participant becomes distressed while carrying out a task online, it is difficult for researchers to follow traditional ethical protocols.

With regard to distributed learning, there is ever-expanding literature based around spacing practice and its relationship with online education. There is much research to suggest that the spacing effect is evident in distance/online learning as well as face-to-face, and can in fact be optimised by the use of online techniques (Carvalho et al., 2020; Jost et al., 2021). For example, Marzouk et al. (2016) suggest that spaced learning of definitions can be optimised using online tools, including using a glossary that prompts students to reflect on the context in which they last encountered a specific definition and scheduling optimal review times based on close monitoring of student's online study activity. Similarly, Fulton et al. (2013) found that the spacing effect is evident at shorter and longer retrieval intervals when taking an online statistics course and suggested that students and distribution of practice could benefit from frequent deadlines imposed through the online course.

Conversely, in a post-pandemic world where most educational institutions have been forced to adopt at least a mixed-method or, in some instances, fully online approach, it is clear that there can be disadvantages to distanced learning (Surkhali & Garbuja, 2020). For example, Zeng (2020) suggests that virtual learning relies too heavily on access to internet and electronics, as well as taking a toll on the mental and physical health of students and teachers.

Furthermore, Versteijlen et al. (2017) indicate that the success of online learning is heavily dependent on student engagement. Many researchers believe that while there are benefits to online learning, there will always be a necessity for face-to-face education, particularly depending on the material to be taught (Kemp et al., 2014; Vaida, 2020).

There is an ongoing replication crisis relevant to psychological research, whereby researchers often struggle to reproduce the results of past studies (Maxwell et al., 2015; Morawski, 2019). With this in mind, it is important to investigate whether this replication crisis extends to adapting experiments for online participation. There is evidence to suggest that some online replications are successful. For example, Claypoole et al. (2018) managed to successfully replicate the results of Thomson et al. (2016), suggesting that laboratory vigilance tasks can be adapted for online use. However, they also provide a number of cautions, implying that the results are dependent on type and length of task, among other factors (Claypoole et al., 2018). Conversely, there have been a number of failed attempts at online replication. Cusak, Vezenkova et al. (2012) failed to replicate the results of Burgmer and Englich (2012) both directly and after adapting a word-search task (originally created by Chen et al. (2001), used in Burgmer and Englich's second experiment) for online use. Similarly, Plant (2016) suggests that the ongoing replication crisis may be a direct result of a move to computer-based tasks, particularly when attempting to replicate timing with millisecond accuracy. Furthermore, it is suggested that when adapting tasks, researchers must interpret results with care. In the case of interpreting results that indicate a successful replication, one has an obligation to ensure to the best of their ability that the results are actually in line with a successful replication and not merely coincidence (Plant, 2016). These findings suggest that it is possible to successfully adapt certain tasks for online use, but success of replicating existing in-person experiments using online methods may be dependent on the type of task and the effects one is trying to measure.

In addition, one must consider the difference in participant sample when advertising an experiment online versus in-person. Online experiments tend to require less commitment from participants and can be administered anywhere in the world thus allowing a far greater reach. As a result, online experiments often have higher populations compared to in-person experiments (Langer & Beckman, 2005; Comley & Beaumont, 2011b). When attempting to replicate an existing study, this increase in participants may lead to more valid, generalisable, and robust results. However, it is also possible that a dataset collected online will come with a number of associated issues. For example, the use of crowdsourced databases such as MTurk (Amazon's Mechanical Turk) has raised questions about the validity of data collected in this manner. While it is recommended that researchers include response validity indicators when using Mturk and similar databases (Mason & Suri, 2011; Chmielewski & Kucker, 2020) and there is ample evidence to suggest that data collected via MTurk are equivalent to data collected in-person (Behrend et al., 2011; Kees et al., 2017; Chmielewski & Kucker, 2020), concern remains. Chmielewski & Kucker (2020) found a significant decrease in data quality resulting in a failure to replicate well-established findings. Similarly, Cusak et al. (2012) draw attention to the possibility of participants recruited through MTurk becoming overly familiar with certain tasks and the possibility of bots contaminating data. This implies that researchers should use caution when adapting existing tasks for online use and be aware of any significant differences in the population when interpreting the results of subsequent replications.

In summary, the recent outbreak of COVID-19 has forced researchers to adapt accordingly. In many cases, this involves adapting existing experiments so that they may be conducted online rather than in-person (Ranganathan et al., 2020; Alam et al., 2021; Sohrabi et al., 2021). There are a number of benefits and pitfalls to consider when conducting research online. For example, online research is more convenient and allows for a more inclusive and generalisable dataset, however it is heavily dependent on access to technology and raises a

number of controllability and ethical concerns (Comley & Beaumont, 2011a; Comley & Beaumont, 2011b; Surkhali & Garbuja, 2020; Zeng, 2020). Furthermore, it is important to investigate whether well-established findings can be replicated when experiments and tasks are adapted for online use, given the different medium and potential access to a greater participant pool (Comley & Beaumont, 2011b; Plant, 2016; Chmielewski & Kucker, 2020).

Given the direct effect of COVID-19, a number of changes were made to the current research project. Most significantly, the Face-Name Pairs task (FNPT) administered in previous experiments was adapted for use online via Qualtrics. This begs the question of whether the results of the previous experiments (see Chapters 3 and 4) can be replicated when the task is administered remotely rather than in-person? To investigate, the current study uses an adaptation of the FNPT (administered via Qualtrics) to examine the ability of participants to retain face-name associations following the utilisation of different schedules of learning. The FNPT was administered to three-hundred-and-fifty-eight participants who had to recall eight different face-name associations following intervals of twenty-four hours and one month. Participants were further divided into two conditions – spaced or massed. In line with the previous experiments, it is hypothesised that although memory recall will diminish with time, those that are spaced-trained will show better memory performance overall and that this effect will be more prominent as time goes on.

5.2 Methods

5.2.1 Participants

Power calculations were done to estimate the number of participants required. Using fixed effects ANOVAs and an effect size of 0.3 with power of 0.9, $p = 0.05$, and 4 or 6 groups estimates 119 participants. The sample consists of 358 participants, 155 males and 203 females. Some participants were recruited via an online advertisement posted across various social media platforms (including Facebook and Twitter, among others). The advertisement explained the nature of the study and required participants to contact the researcher in order to express an interest. Other participants were recruited from Maynooth University as part of a Research Participation module. Yet other participants were recruited by word of mouth. Participants were aged between 18 and 72 (mean = 26.76, SD = 11.504). An exclusion and inclusion criteria were applied, so all participants were healthy, cognitively healthy, and had normal or corrected-to normal vision. No participant had a known history of drug or substance abuse, and no other relevant medical conditions. This was self-assessed. If participants responded "yes" to any of the exclusion criteria they were unable to move through the survey.

5.2.2 Materials

A number of questionnaires were administered online via Qualtrics to assess various cognitive and psychological factors. Three sleep-based questionnaires were used to discern good and poor sleepers: The Karolinska Sleepiness Scale (see Appendix H) was used to measure participant's alertness in the moment (Shahid et al., 2011), the Sleep Condition Indicator (SCI) (see Appendix G) was used to measure sleep quality, and a third questionnaire was used to determine each participant's average sleep schedule (Espie et al., 2014). The self-reported Cognitive Failures Questionnaire (CFQ) (see Appendix L) was used to assess everyday lapses of attention, memory, and cognition (Broadbent et al., 1982). Three further questionnaires

were used to measure psychological factors associated with sleep: The Alcohol Use Disorders Identification Test (AUDIT) (see Appendix K) was used to determine alcohol consumption (Reinert & Allen, 2007), and the Depression, Anxiety, Stress Scale 21 (DASS 21) (see Appendix I) (Lovibond & Lovibond, 1995) and the General Health Questionnaire 12 (GHQ 12) (see Appendix J) (Kalliath, O'Driscoll, & Brough, 2004) were used to test for behaviours associated with depression and anxiety.

The Tower of Hanoi task (ToH) was used to test executive functioning (Shallice, 1982). This task involved stacking coloured blocks according to an image provided. Participants were required to visit a third-party site which timed them and recorded the number of moves required to complete the task. Upon completion, participants were asked to record their timing and number of moves via Qualtrics. Participants were scored based on number of moves and time taken to complete the task (see Chapter 2 for details). Given that the aim of this chapter was to establish the existence of a spacing effect when administering the FNPT online, the aforementioned questionnaires and tasks are not analysed in the current chapter.

The FNPT was used to assess associative memory and was carried out using Qualtrics. The task was presented through a series of short presentations. There were eight presentations in total, four study block presentations and four retrieval block presentations. Each of the four study block presentations consisted of eight different faces paired with eight different names. After each block, recall was assessed. The four retrieval block presentations consisted of the eight different faces without their corresponding name. See Chapter 2 for more details.

5.2.3 Procedure

Upon reading an information sheet and agreeing to participate, participants were given a Qualtrics link via email. Participants were initially presented with a digital consent form (see Appendix O). The consent form stressed that all results would be anonymised and kept

completely confidential. Confidentiality was ensured by assigning each participant an ID number. This ensured that participants were identifiable across trials, but not in any significant way.

Participants were randomly assigned to the twenty-four hour or one month groups, and then to the spaced or massed conditions (see Table 5.1 for details and breakdown by gender). Each condition included four study blocks and one retrieval trial block. Participants in the spaced condition completed the four trial blocks over four consecutive days. Participants in the massed condition completed the four trial blocks on one day. Those in the twenty-four hour condition completed the retrieval trial twenty-four hours after completing the study block and those in the one month condition completed the retrieval trial one month after the study block (see Figure 5.1).

Participants assigned to the spaced condition completed the KSS, SCI, general sleep questionnaire, CFQ, and ToH on day one, and the DASS-21, AUDIT, and GHQ-12 on day five. Participants assigned to the massed condition completed the KSS, general sleep questionnaire, and ToH on day one, and the SCI, CFQ, DASS-21, AUDIT, and GHQ-12 on day two. Each test and questionnaire was explained in full. All participants were given an option to review the consent form on subsequent days if desired.

Table 5.1: *Group and gender breakdown for each condition.*

	24 Hours	One Month
Spaced		
Male	35	32
Female	60	49
	98	**81**
Massed		
Male	48	37
Female	42	52
	90	**89**
Total Number	**188**	**170**

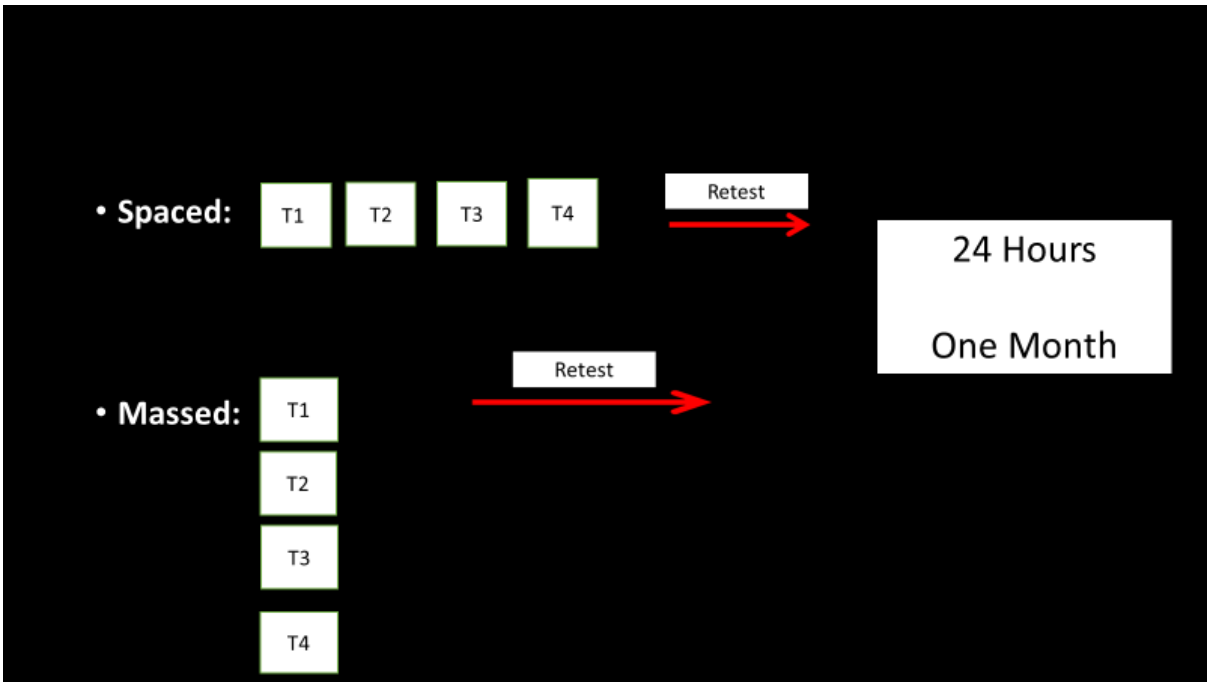


Figure 5.1: A visual representation of the spaced and massed conditions. For the massed condition, all four trials were given on the same day. For the spaced condition, one trial was given each day for four days.

5.2.4 Encoding

See Chapter 2 for details on encoding. In brief, participants were asked to watch a slideshow of eight faces paired with eight names twice. Participants were then required to recall and type in each of the eight names when presented with the face alone. This was repeated four times.

5.2.5 Retrieval

At intervals of twenty-four hours or one month later participants were required to recall and type in the correct name associated with each face (see Chapter 2). This involved a single trial of eight faces.

5.2.6 Statistics

Microsoft Excel and an IBM SPSS statistics software programme (version 23) were used to calculate the results. Means and standard errors of the mean were calculated through Microsoft Excel. Independent t-tests were used to compare the means of the control tasks and demographics. An initial 2 X 4 mixed between factorial ANOVA was conducted to investigate whether learning had occurred and to show whether a difference existed between the massed and spaced conditions. A two-way between-groups ANOVA was conducted to examine whether participants could remember each face-name pair and to show whether a difference existed between groups (massed and spaced) for each retrieval time (24hrs and 1-month). Bonferroni corrected t-tests were used for further within-group comparisons. Pearson correlations were used to assess gender and age effects.

5.2.7 Ethics

The American Psychological Association and Psychological Society of Ireland codes of ethical conduct were observed throughout. Participants were provided with an information

sheet in advance of the experiment, explaining the procedure in detail. All participants were over eighteen, consented to taking part, and were informed that they could pull out at any time. Data were anonymised for privacy. All online experiments were approved by Maynooth University ethics committee (reference BSRESC-2019-2378730).

Given the interest received in this experiment due to online administration, it was decided to allow for the inclusion of significantly more participants than power calculations suggested were needed. Doing so raises a number of potential ethical and methodological issues. Given that this experiment did not involve serious risk or any great number of resources, and given that all participants engaged voluntarily and without coercion, it was decided to allow for the greater sample size, as, generally speaking, larger sample sizes are more reliable and generalisable (Faber & Fonseca, 2014). Though increased sample sizes may cause statistical problems, upon careful consideration, it was decided that this would not be an issue for the present experiments as this is only true in the case of very large samples (Faber & Fonseca, 2014).

5.3 Results

5.3.1 Encoding Phase

An initial 2 X 4 mixed between-within factorial ANOVA was conducted to compare learning across the four trials for both the spaced- and massed- trained conditions. There was a significant main effect of Trial (F (3, 354) = 292.655, $p < 0.001$, partial eta squared = 0.713), but no effect of Condition (F (1, 356) = 0.856, $p = 0.356$, partial eta squared = 0.002). There was a significant interaction between trial and group (F (3, 354) = 3.947, $p = 0.009$, partial eta squared = 0.032) (see Figure 5.3). Bonferroni corrected t-tests indicate that massed participants performed significantly better than spaced participants on trial four (t (341.972) = -2.071, $p = 0.039$, cohen's d = -0.219).

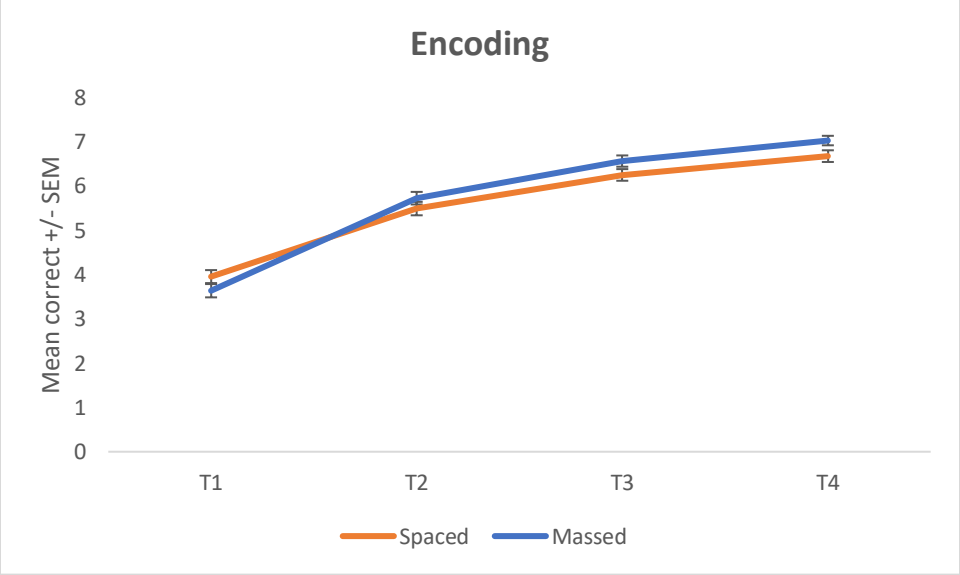
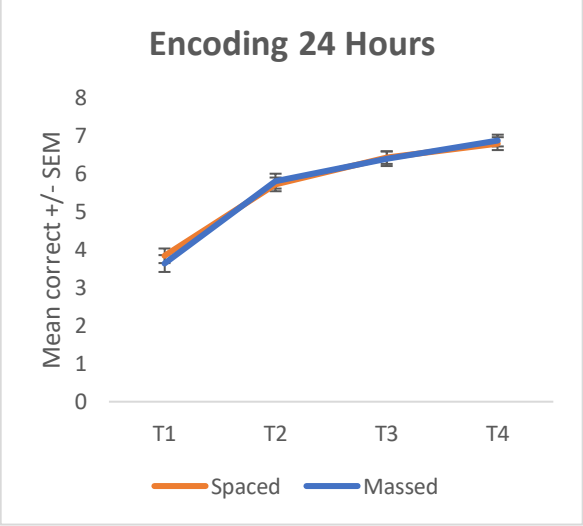


Figure 5.3: Mean encoding score and standard error of the mean for both spaced and massed groups overall.

To ensure that both groups learned in a similar fashion before we split based on retrieval interval, and to ensure that any difference in recall was due to the time lapse between learning and retrieval rather than poor initial learning, we carried out two further 2 X 4 mixed between-within factorial ANOVAs. The results indicated that there was a significant main

effect of Trial at twenty-four hours (F (3, 184) = 164.338, p < 0.001, partial eta squared = 0.728) and one month (F (3, 166) = 128.248, p < 0.001, partial eta squared = 0.699). There was no overall effect of condition (massed versus spaced) at twenty-four hours (F (1, 186) = 0.006, p = 0.938, partial eta squared = 0.0001) and one month (F (1, 168) = 1.958, p = 0.164, partial eta squared = 0.012). There was no significant interaction between trial and group at twenty-four hours (F (3, 184) = 0.535, p = 0.659, partial eta squared = 0.009), however there was a significant interaction between trial and group at one month (F (3, 166) = 5.383, p = 0.001, partial eta squared = 0.089). Four t-tests were conducted to further examine the differences between the spaced and massed groups on each of the four trials at one month. The results indicate that there was no significant difference between the spaced and massed groups performance on trial one (t (168) = 1.508, p = 0.133, cohen's d = 0.232) and trial two (t (168) = - 1.323, p = 0.095, cohen's d = -0.203). However, there was a significant difference between the spaced and massed groups performances on trial three (t (168) = - 2.621, p = 0.010, cohen's d = -0.402) and trial four (t (147.101) = - 2.549, p = 0.012, cohen's d = -0.397) (see Figure 5.4). This suggests that the overall interaction effect noted above was driven by a small difference between the groups among the one-month participants.



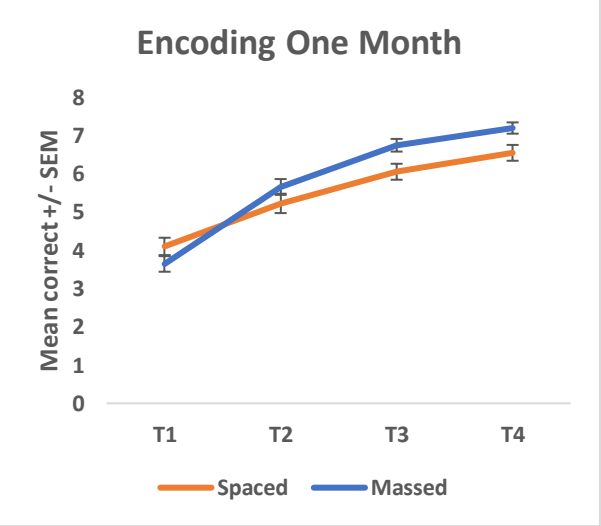


Figure 5.4: Mean encoding and standard error of the mean for both spaced and massed groups at twenty-four hours and one month

5.3.2 Retrieval Phase

A two-way between groups ANOVA was conducted to explore the difference between the ability of those in the spaced and massed conditions to recall the face-name pairs following an interval of twenty-four hours or one month. The results indicate a main effect of Condition (spaced/massed) that was just significant (F (1, 354) = 4.079, p = 0.044, partial eta squared = 0.011), with spaced-trained participants scoring slightly more than massed-trained participants overall, and a significant main effect of retrieval interval (F (1, 354) = 175.653, p < 0.001, partial eta squared = 0.332), with recall at one-month significantly less than twenty-four hours as would be expected. There was no significant interaction effect (F (1, 354) = 0.126, p = 0.723) (see Figure 5.5).

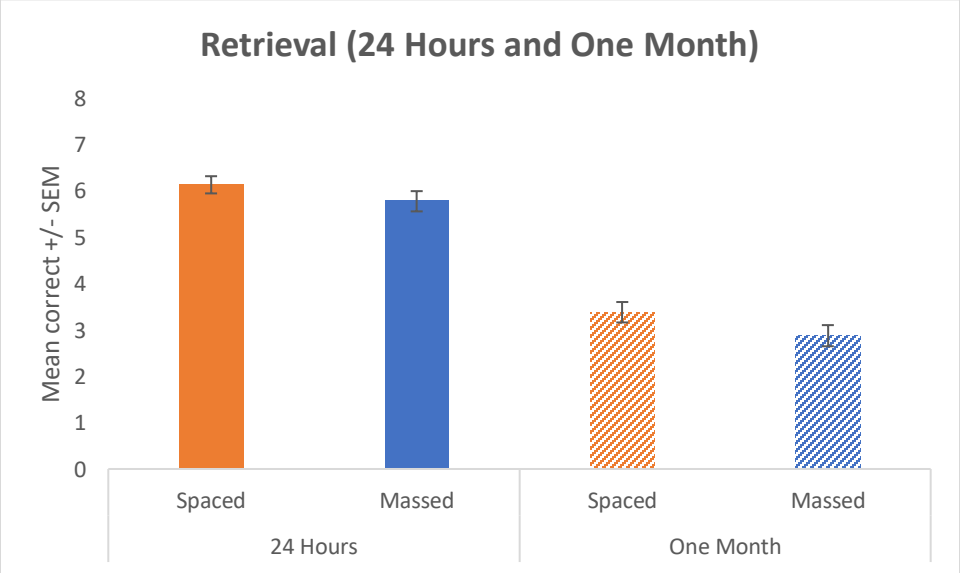


Figure 5.5: Mean retrieval score and standard error of the mean for both the spaced and massed groups at twenty-four hours and one month.

5.3.3 Direct comparison between in-person and online experiments during learning and retrieval

To illustrate the differences between the two mediums of learning (online versus in-person), we decided to compare participants across learning groups. This comparison included the participant sample collected for the current chapter (online group) and the participant sample collected for Chapter 3 (in-person group; see Chapter 3 for details). Using a 2 X 2 X 4 mixed factorial ANOVA for the learning phase (Figure 5.6), we found an overall significant effect for Trial (F (3, 1326) = 3.44, $p < 0.001$, partial eta squared = 0.438), with participants on trial 4 (mean = 6.1, standard deviation = 1.7) learning significantly more compared to trial one (mean = 3, standard deviation = 2.0); Bonferroni corrected t-test, $p < 0.001$). No overall significant difference between Condition (spaced versus massed) was observed (F (1, 442) = 2.44, p = 0.119, partial eta squared = 0.006). There was however an overall significant difference in the experimental condition (online vs in-person; F (1, 442) = 96.7, $p < 0.001$, partial eta squared = 0.18), with participants in the online condition (mean = 5.6, standard deviation = 1.4) learning more than those in-person (mean = 3.9, standard deviation = 2.8).

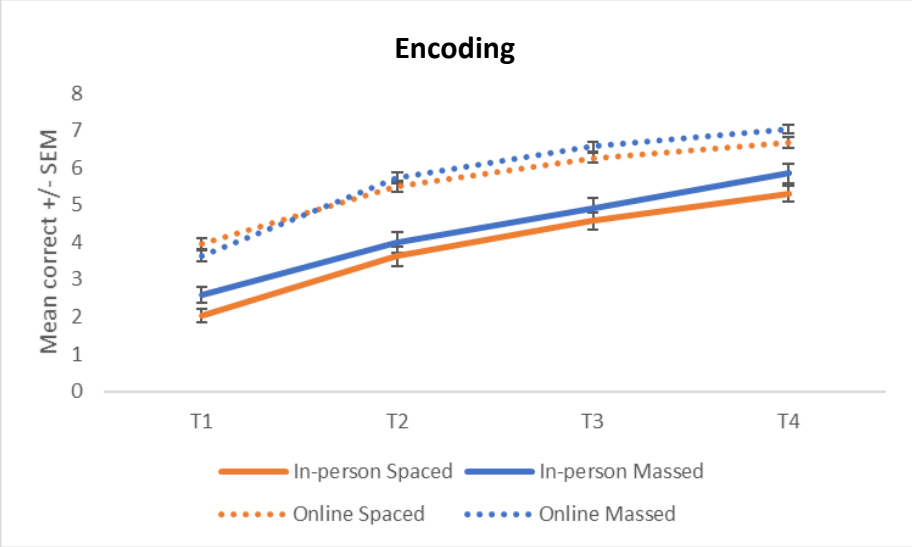


Figure 5.6: Mean number of correct names (and SEM) for both spaced and massed and in-person and online groups across the four learning blocks.

For the retrieval phase we conducted a three way between groups ANOVA. We found an overall significant effect for retrieval interval (twenty-four hour versus one month; (F (1, 438) = 107.4, p < 0.001, partial eta squared = 0.197)), with participants recalling on average less names after one month (mean = 2.9, standard deviation = 2) compared to twenty-four hours (mean = 5.6, standard deviation = 2). There was also a significant effect for Condition (spaced versus massed; (F (1, 438) = 12.6, p < 0.001, partial eta squared = 0.028)), with participants in the spaced condition recalling more names (mean = 4.8, standard deviation = 2.3) compared to those in the massed condition (mean = 4.1, standard deviation = 2.5). Importantly, there is also an overall significant difference in the mode of experimentation (online vs in-person; (F (1, 438) = 20.5, p < 0.001, partial eta squared = 0.045), with participants online recalling on average more names (mean = 4.6, standard deviation = 2.4) compared to those in-person (mean = 3.8, standard deviation = 2.2) (see Figure 5.7).

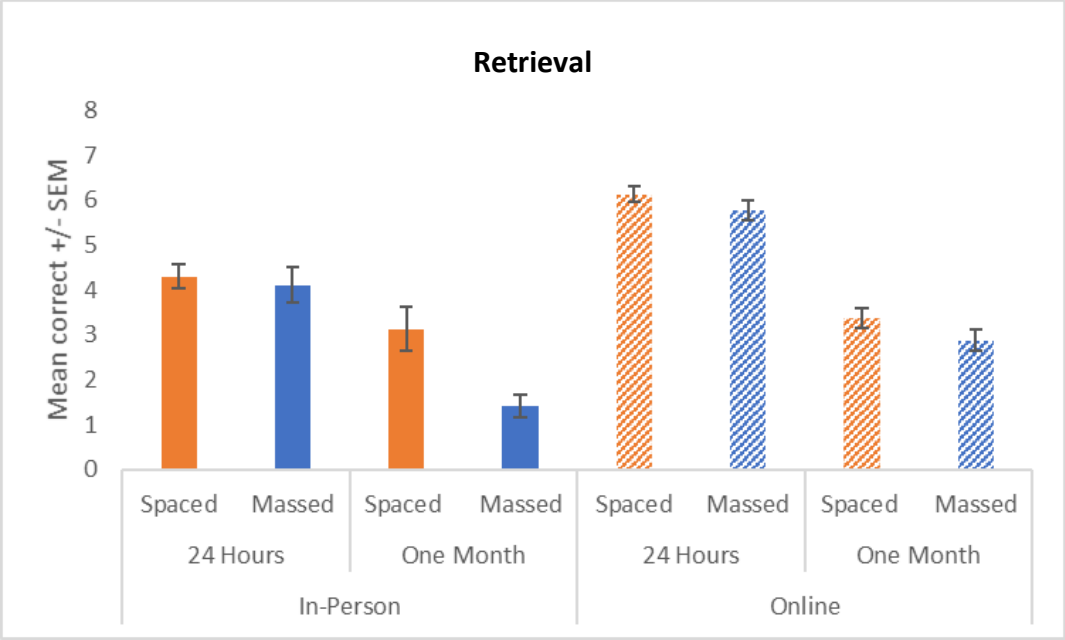


Figure 5.7: Mean retrieval scores (and SEM) for both spaced and massed conditions and in-person and online groups when retested at twenty-four hours and one month post learning.

5.3.4 Age and Gender

One difficulty with online experiments is that experimental control is often lost. In this respect, we noticed that there was a significant age and gender difference with respect to our participants. For example, the massed group was slightly older than the spaced group (mean = 29.4 and 24.1, respectively; t (468) = - 3.020, p = 0.003, cohen's d = -0.326). In addition, there were more females in the spaced group whereas the massed group was more balanced in this respect (see methods). Correlating age with retrieval scores, we found a small but overall significant negative correlation (r = -0.117, p = 0.028), with age having more of an impact in the spaced group (r = -0.264, p = 0.001) compared to the massed one (r = 0.011, p =0.887).

When we examined whether gender had an impact on memory performance, we found an overall significant effect (F (1, 350) = 17.99, p < 0.001, partial eta squared = 0.049), with females showing better recall than males at both twenty-four hour (mean = 6.3, standard deviation = 1.8 and mean = 5.5, standard deviation = 2, respectively) and one month intervals (mean = 3.6, standard deviation = 2.1 and mean = 2.5, standard deviation = 1.7, respectively). No Gender x Condition (spaced/massed) effect was observed (F (1, 350) = 0.301, p = 0.584, partial eta squared = 0.001).

A one-way between-groups ANCOVA was conducted to investigate whether the slight overall spacing effect is still present when age and gender are statistically controlled for. The results indicated that age and gender did not effect this finding (age: F (1, 353) = 2.677, p = 0.103; gender: F (1, 353) = 0.716, p = 0.398).

5.4 Discussion

The results from the encoding phase suggest that all participants learned over the course of the four trials, regardless of whether learning was spaced or massed. Participants' performance improved steadily across all four trials with the most noticeable difference occurring between trials one and four. Those in the massed condition tended to have a slightly higher mean accuracy: This was only significant for trials three and four in the one-month group. These findings are similar to those in Chapters 3 and 4. In Chapter 3, results indicated that those in the massed condition tended to have a slightly higher mean accuracy overall, but this was not significant. In Chapter 4, results indicated that younger participants assigned to the massed condition also had a significantly higher mean accuracy (but this was in those that were assigned to the twenty-four hour recall group). These ambiguous results are reflected in the literature where massed-trained participants tend to outperform their spaced-trained peers during encoding, but often these results are not significant (Simone et al., 2013; Spruit et al., 2014). Therefore, it suggests that while there is a general trend for participants to learn better in a massed schedule (both in person and online) the effects are not that strong or robust

The results from the retrieval phase indicate that there was no significant difference between the performance of the spaced and massed groups on the retest at twenty-four hours. These results complement the previous studies (see Chapters 3 and 4), suggesting that the spacing effect is not evident at twenty-four hour intervals. Also, in line with the results of Chapters 3 and 4, massed-trained participants did not outperform spaced-trained participants on the retest despite slightly better encoding scores.

Importantly, there was no significant difference between the performance of those in the spaced and massed conditions at one month. These results contradict those of Chapters 3 and 4, where spaced-trained participants performed significantly better than massed-trained participants at one-month intervals, and findings from the literature (Simanton & Hansen,

2012; Spruit et al., 2014; and discussed in more depth in the previous chapters). These findings raise a number of questions about why the experiment failed to replicate such well-established findings. It is important to note that there were some key methodological differences between this experiment and those discussed in Chapters 3 and 4. Where possible, the procedures used here were copied exactly, however this was not always feasible given the change in medium. Previously, the FNPT was administered in video format. During encoding, participants had five seconds to study each face-name pair. Upon adapting the task for use via Qualtrics, the face-name pairs were displayed as a slideshow instead, using a timing function to ensure that each pair was on-screen for five seconds. It is possible that the timing on Qualtrics did not exactly match the timing of the video, as suggested by Plant (2016), however given that this experiment does not rely on millisecond timing, it is likely that any differences during encoding were very minor and we do not believe that this would impact the results.

Of greater note were the differences during retrieval. Previously during the retrieval phase, faces were presented in video format. Participants had five seconds in which to recall each associated name before the video would move on to present the next face. Participants were also required to say the name aloud while the researcher recorded their answers. Realistically, this was not possible through Qualtrics. In the current experiment, participants were required to type in the name. As this could be rather difficult to accomplish within five seconds, it was decided that participants would not be limited by time. Instead, the next face was presented only after the participant had typed in a name. Furthermore, in an attempt to avoid participants skipping through the task, the "force response" function was implemented. In other words, if participants did not know the name associated with a particular face, they had to provide a guess if they wished to proceed with the experiment. This is important as in the previous experiments, participants were not required to guess.

These differences would certainly explain why participants had a higher mean retrieval score than in the previous experiments, regardless of condition; more time to think about their answer and being forced to provide a guess both lend themselves to better performance on the task. However, this does not explain why there is no discernible spacing effect. The spacing effect has been well established in literature (Vlach et al., 2008; Benjamin & Tullis, 2010; Kapler et al, 2015; Delaney et al., 2018) and is evident in distanced, online learning too (Fulton et al., 2013; Marzouk et al., 2016; Carvalho et al., 2021). This would suggest that spacing should occur even when the task is adapted for Qualtrics.

It remains unclear why spacing is so advantageous compared to massed learning, however there are a number of plausible theories, for example, encoding variability theory or deficient processing theory, among others (see Chapter 1 for details) (Smolen et al., 2016). Given the difference in controlled environment between this experiment and those conducted in Chapters 3 and 4, it is possible that these behaviours did not occur, or occurred in a reduced capacity, and as a result there is no discernible differences between those in the spaced and massed conditions. In the previous experiments, the FNPT was conducted in a laboratory setting with a researcher present. In the current study, participants were at liberty to complete the task in any setting and without the added pressure of a researcher recording their answers. As a result, it is possible that some participants performed better in an uncontrolled environment, while others may have been distracted or interrupted while partaking of the task. Such deviances may have led to an improvement in the performance of massed participants with a corresponding decline in the performance of spaced participants, thus eliminating the spacing effect in this sample. This is in line with Versteijlen et al. (2017), who suggest that engagement is a key component of successful spacing when learning online.

Furthermore, although spacing is well established across many types of learning, it is worth mentioning that there is relatively limited research as to whether spacing is as effective

when learning abstract concepts such as names. There are some studies to suggest that the spacing effect does occur when learning face-name associations (Carpenter & DeLosh, 2005; Hawley et al., 2008; Maddox et al., 2020). However, the samples of the aforementioned studies are considerably smaller than that of the current experiment (12, 139, and 96, respectably). Furthermore, the samples of the experiments detailed in Chapters 3 and 4 are also significantly smaller than the current study. It is possible that previous studies are underpowered, therefore leading to incorrectly rejecting the null hypothesis (Anderson et al., 2017). This could further explain why some online experiments fail to replicate lab-based research. As previously discussed, conducting experiments online can lead to a greater number and wider range of participants, which may in turn lead to a more powerful statistical analysis (Stevens, 1996; Langer & Beckman, 2005; Comley & Beaumont, 2011b) but the downside is the lack of experimental control.

In conclusion, this experiment has failed to replicate the spacing effect observed at one month in previous studies. This raises a number of questions about the potential for online research. Although there are a number of benefits, including larger, more generalisable datasets and ease of administration and use, there are also a number of potential pitfalls, particularly with regard to replicating established findings and adapting lab-based experiments. Moreover, these results have implications for other services that are being adapted in light of the recent pandemic, such as online education or therapy.

Chapter 6

The effects of sleep on memory and cognition

Abstract

Sleep has been shown to affect both memory and cognition, with observations apparently being dependent on both type of sleep and type of task. However, there are some discrepancies in findings, which have led researchers to suggest that the effects of sleep have been grossly overexaggerated in the literature. Furthermore, sleep has been posited as a potential explanation of the spacing effect. Researchers suggest that the lag between spaced study sessions allows for sleep, which may contribute to improved consolidation. In the absence of a pronounced spacing effect, this experiment sought to investigate the effects of sleep on a number of cognitive and psychological measures. Participants were divided into good versus poor sleepers based on their score on the Sleep Condition Indicator, and compared across an array of tasks and questionnaires, including the Face-Name Pairs and Tower of Hanoi tasks, the Cognitive Failures Questionnaire, the Depression, Anxiety, Stress Scale-21, the General Health Questionnaire-12, and the Alcohol Use Disorders Identification Test. Results indicate that objective measures of cognition are not affected by poor sleep, however poor sleepers received significantly higher scores on subjective measures of cognition and psychological measures. Furthermore, there were a number of gender and age effects. These results have implications for the effects of sleep on elements of cognition.

6.1 Introduction

It is widely acknowledged that sleep is of crucial importance to our overall health and well-being (Wenk, 2017; Zhai et al., 2018; Gulia & Kumar, 2020; Shattuck et al., 2020; Hunter, 2021). Moreover, sleep is thought to play a critical role in memory consolidation and general cognitive ability (Rieth et al., 2010; Maurer et al., 2015; Huang et al., 2016; Chambers, 2017; Wilckens et al., 2018; Kapsi et al., 2020). For example, Ellenbogen et al. (2007) found that relational memory is bolstered by sleep, while Gillen-O'Neel et al. (2013) found that late-night studying at the expense of sleep tends to negatively impact student's academic performance. Similarly, Walker (2009) suggests that the role of sleep in memory processing may extend to improving general knowledge and creativity, while Deak & Stickgold (2010) discuss how young adults whose sleep has been restricted over a fourteen day period perform progressively worse in attention, working memory, and cognitive throughput tasks. Though there is still no clear-cut explanation regarding the function of sleep, there are some distinct physiological and behavioural benefits, including improved day-to-day functioning and cell repair (Siegel, 2003).

Given the aforementioned studies regarding improved memory as a function of sleep, one might hypothesise that distributed practice is preferable because of the potential for sleep in between learning sessions, depending on interval. There is some evidence of this in the literature. For example, Spruit et al. (2017) found that spaced trained medical students and students who were given nap breaks between learning sessions significantly outperformed students who were traditionally massed trained and massed trained with breaks. Similarly, Bell, Kawadri et al. (2014) found that spaced trained participants who were presented with an opportunity to sleep were better able to retain Swahili-English word pairs compared to massed trained participants. With regard to learning face-name associations, Maurer et al. (2015) found that giving participants the opportunity to sleep between trials led to improved

recognition of face-name associations. Similarly, Whitmore et al. (2022) found that memory for face-name associations improves when those memories are reactivated during sleep.

However, the type of and way in which memory is affected by sleep depends on a number of factors (Smith & Rose, 2000; Siegel, 2001). Plihal & Born (1997) suggest that REM and non-REM sleep have specific effects on different types of memory: Declarative memory is improved during slow-wave sleep while procedural memory is improved during REM sleep. More recent research expands on this theory, confirming that non-REM sleep has pronounced effects on explicit memory while both slow-wave and REM sleep produce improvements in implicit memory (Chambers, 2017). In general, sleep appears to have a stronger association with improvements in procedural memory, as these studies tend to have more robust controls in place (Smith, 2001; Rieth et al., 2010). Rieth et al. (2010) found no sleep-specific improvements on both explicit and implicit motor tasks and suggested that the use of sleep-deprived control groups may give the appearance of a heightened sleep effect. Such findings imply that while sleep is not unimportant in consolidation of memories, it's effects may be somewhat overexaggerated in the literature.

Though much emphasis is placed on the specific role of sleep with regard to memory, sleep is acknowledged as affecting other elements of cognition too. Walker (2009) suggests that more so than enhancing individual memories, sleep may be necessary to integrate memories and create associations between different concepts, thus improving our general knowledge and understanding. In line with this, Bernier et al. (2013) found that children who got more sleep as infants demonstrated a greater affinity for complex cognitive tasks, such as abstract reasoning, problem-solving, and concept-formation, while Della Monica et al. (2018) found that good sleep contributes to response time and accuracy across the lifespan. Poor sleep is often acknowledged as being a key mediating factor with regard to causes of cognitive failures (Dalgaard et al., 2014; Xanidis & Brignell, 2016). For example, Hong et al. (2020)

found that poor sleep quality caused by mobile phone addiction leads to poorer cognitive function, while Simpson et al. (2005) listed disturbed sleep as an influential factor with regard to workplace injuries and accidents, and decreased performance. In particular, poor sleep is associated with greater failures on self-report measures of cognition (Simpson et al., 2005; Willert et al., 2005; Dalgaard et al., 2014; Xanidis & Brignell, 2016; Hong et al., 2020). Furthermore, the literature suggests a direct link between sleep quality and ability to perform cognitive tasks that require an affinity for planning and problem solving, such as the Tower of Hanoi task (Ashworth et al., 2013; Vermeulen et al., 2019). Nielsen et al. (2014) observed improvements in ability to complete the Tower of Hanoi task following slow-wave sleep. Similarly, Schiff & Vakil (2015) found that older children's performance on the Tower of Hanoi task improved following a night of sleep.

When considering the effects of sleep, one cannot attribute improvements or lapses in memory and cognition to sleep quality alone, rather it is often considered a mediating factor that explains the relationship between other variables. Among the most discussed variables connected to sleep, memory, and cognition are emotional regulation (Palmer & Alfano, 2017; Vandekerckhove & Wang, 2018) and alcohol use (Goodhines et al., 2019; Koob & Colrain, 2020). Inadequate sleep has long been acknowledged as both a symptom of and, in some cases, a precursor to anxiety, depression, and mood disorders (Harvey, 2011; Palmer & Alfano, 2017). According to Palmer et al. (2018) adolescents who report greater sleep problems are more likely to be at risk of developing psychiatric disorders, particularly mood and anxiety disorders. Similarly, Wan Yunus et al. (2020) found that exercise interventions can potentially improve sleep quality in university students, thus reducing their likelihood of experiencing stress, anxiety, and depression. As with cognitive failures, poor sleep is particularly associated with depression, stress, and anxiety symptoms when those symptoms are self-reported rather than objectively measured (Nanthakumar et al., 2017). Zou et al.

(2020) found evidence supporting a bidirectional relationship between sleep and mental health problems in college-going males using self-report measures, while Mahfouz et al. (2020) noted that students who were physically inactive were more likely to rate their sleep quality as poor, and more likely to report feelings of stress. Similarly, Belingheri et al. (2020) found that perceived stress (as measured by GHQ-12 scores) was one of only two risk factors associated with poor sleep quality in nursing and medical students. Studies evaluating the relationship between sleep duration, sleep quality, and mental health in Spain and the UK found that participants who reported lower sleep duration and poor sleep quality were also more likely to report poor mental health, especially women (Tang et al., 2017; Brace et al., 2021).

Furthermore, there is a direct association between poor sleep and alcohol use disorders (Koob & Colrain, 2020). This is to be expected, given that the neural underpinnings of sleep-wake regulation are affected by alcohol (Colrain et al., 2014). Van Schrojenstein et al. (2017) found a significant correlation between sleep duration and alcohol consumption in adults, while infants affected by foetal alcohol spectrum disorders (FASDs) are known to experience sleep disruptions as a result (Inkelis & Thomas, 2018). Sleep quality, mood regulation, and alcohol consumption are all directly related and may affect our ability to function typically on a daily basis (Miller et al., 2017). Goodhines et al. (2019) found that undergraduate students experiencing sleep problems are likely to self-medicate with alcohol, thus compounding the problem. Stanton et al. (2020) observed a number of psychological changes in Australian adults following the onset of the COVID-19 pandemic, including increased alcohol intake and poorer sleep quality which were directly associated with symptoms of depression, stress, and anxiety, particularly in young women. Given the recurrent nature and interconnectedness of these variables, it is difficult to distinguish one from another with regard to determining potential causes of lapses in memory and cognition. The literature suggests that a number of variables, most prominent of which may be sleep, emotional regulation, and alcohol use, work

in tandem to produce certain effects, such as improvements or failures of memory and cognition (Palmer & Alfano, 2017; Goodhines et al., 2019).

While we originally hoped that we might be able to examine the interaction between different training schedules (spaced versus massed) and sleep, results from our online experiment (Chapter 5) suggested that though there was a slight overall spacing effect, it was not as prominent as in previous experiments, nor was there a difference between conditions at the two retrieval intervals (twenty-four hours and one month). As such, we collapsed both groups and focused on examining the effects of sleep on short-term (twenty-four hours) and long-term (one month) consolidation of memory using the hippocampal-dependent Face-Name Pairs task (FNPT), and also a more frontal based planning task, the Tower of Hanoi (ToH). The decision was made to retain the twenty-four hour and one month groups both to provide a measure of short- versus long-term memory, and, in particular, to examine whether any sleep effects are more pronounced at long-term intervals, as suggested by the literature (Ketz et al., 2018; Sawangjit et al., 2018; Lambert et al., 2020). We hypothesised that those classified as good sleepers would perform better at both tasks compared to poor sleepers. If the hippocampus is involved in consolidation through the sleep process, we might see good sleepers performing better on the FNPT compared to the ToH. In addition, as sleep impacts on other psychological measures, we suggest a strong relationship between those that are good sleepers and performance on the Cognitive Failures Questionnaire (CFQ), the Depression, Anxiety, Stress Scale-21 (DASS 21), the General Health Questionnaire-12 (GHQ 12), and the Alcohol Use Disorders Identification Test (AUDIT).

6.2 Methods

6.2.1 Participants

Power calculations were done to estimate the number of participants required. Using mixed factorial ANOVAs and an effect size of 0.3 with power of 0.9, $p = 0.05$, and 2 groups estimates 46 participants. The sample consists of 358 participants, 155 males and 203 females. It is worth noting that this is the same data set presented in Chapter 5 (see Chapter 5 for details on recruitment procedures). Participants were aged between eighteen and seventy-two (mean = 26.87, SD = 11.504). An exclusion and inclusion criteria were applied, so all participants were healthy, cognitively healthy, and had normal or corrected-to normal vision. No participant had a known history of drug or substance abuse, and no other relevant medical conditions.

6.2.2 Materials

A number of questionnaires were administered online via Qualtrics to assess various cognitive and psychological factors (see Chapter 5 for details). These included the Karolinska Sleepiness Scale (KSS) (see Appendix H) (Shahid et al., 2011), the Sleep Condition Indicator (SCI) (see Appendix G) (Espie et al., 2014), a questionnaire used to determine each participant's average sleep schedule, the Cognitive Failures Questionnaire (CFQ) (see Appendix L) (Broadbent et al., 1982), the Alcohol Use Disorders Identification Test (AUDIT) (see Appendix K) (Reinert & Allen, 2007), the Depression, Anxiety, Stress Scale 21 (DASS 21) (see Appendix I) (Lovibond & Lovibond, 1995), and the General Health Questionnaire 12 (GHQ 12) (see Appendix J) (Kalliath, O'Driscoll, & Brough, 2004). The Tower of Hanoi task (ToH) was used to test executive functioning (Shallice, 1982) (see Chapters 2 and 5 for details).

The Face-Name Pairs task (FNPT) was used to assess associative memory and was carried out using Qualtrics. The task was presented through a series of short presentations.

There were eight presentations in total, four study block presentations and four retrieval block presentations. Each of the four study block presentations consisted of eight different faces paired with eight different names. After each block, recall was assessed. The four retrieval block presentations consisted of the eight different faces without their corresponding name (see Chapter 2 for more details).

6.2.3 Procedure

Upon reading an information sheet and agreeing to participate, participants were given a Qualtrics link via email. Participants were initially presented with a digital consent form (see Appendix O). The consent form stressed that all results would be anonymised and kept completely confidential.

Participants were randomly assigned to the twenty-four hour or one month groups. There were 188 participants in the twenty-four hour group and a further 170 in the one month group (see Table 5.1 for details and breakdown by gender). Each condition included four study blocks and one retrieval trial block of the Face-Name Pairs Task. Those in the twenty-four hour condition completed the retrieval trial twenty-four hours after completing the study block and those in the one month condition completed the retrieval trial one month after the study block (see Figure 5.1).

Participants assigned to the spaced condition completed the KSS, SCI, general sleep questionnaire, CFQ, and ToH on day one, and the DASS-21, AUDIT, and GHQ-12 on day five. Participants assigned to the massed condition completed the KSS, general sleep questionnaire, and ToH on day one, and the SCI, CFQ, DASS-21, AUDIT, and GHQ-12 on day two. Spaced and massed participants completed the sleep and cognitive measures on different days in order to make the experiment more convenient for massed-trained participants. That is, given that massed-trained participants had to complete the experiment

across only two days, it was decided to divide the various tests accordingly so that they spent minimum time participating on each of the two days. Each test and questionnaire was explained in full. All participants were given an option to review the consent form on subsequent days if desired.

6.2.4 Encoding

See Chapter 2 for details on encoding. In brief, participants were asked to watch a slideshow of eight faces paired with eight names twice. Participants were then required to recall and type in each of the eight names when presented with the face alone. This was repeated four times.

6.2.5 Retrieval

See Chapter 2 for details. At intervals of twenty-four hours or one month later participants were required to recall and type in the correct name associated with each face. This involved a single trial of eight faces.

6.2.6 Statistics

Microsoft Excel and an IBM SPSS statistics software programme (version 28) were used to calculate the results. Means and standard errors of the mean were calculated through Microsoft Excel. Independent t-tests were used to compare means and demographics. A number of linear regressions were conducted to assess the ability of SCI score to predict performance on the Face-Name Pairs task, ToH, CFQ, DASS-21, GHQ-12, and AUDIT. Pearson correlations were used to assess the relationship between dependent variables.

6.2.7 Ethics

The American Psychological Association and Psychological Society of Ireland codes of ethical conduct were observed throughout. Participants were provided with an information sheet in advance of the experiment, explaining the procedure in detail. All participants were over eighteen, consented to taking part, and were informed that they could pull out at any time. Data were anonymised for privacy. All experiments were approved by Maynooth University ethics committee (reference BSRESC-2019-2378730).

6.3 Results

6.3.1 Sleep Condition Indicator, sleep habits, and the Karolinska Sleepiness Scale

Participants were divided into good versus poor sleepers based on their SCI score (those who scored sixteen or less were considered poor sleepers (73 total; mean score = 12.49, standard deviation = 3.266); those who scored over sixteen were considered good sleepers (285 total; mean score = 24.5, standard deviation = 4.068) as recommended by the authors of the test (Espie, et al., 2014; Wong et al., 2017; Espie et al., 2018). Participants were further divided into twenty-four hour and one month groups for recall of face-name pairs. For the purposes of this experiment, the KSS and sleep habits questionnaires were used as complementary measures in addition to the SCI. The SCI was used to divide participants into good versus poor sleepers, and the other questionnaires were used to add further support to this categorisation.

Sleep habits were assessed for the twenty-four hour and one month groups separately to ensure that good versus poor sleepers across both groups exhibited similar patterns. At twenty-four hours, a Rayleigh test indicated that both poor sleepers (34 total, mean = 00.46, SD = 23.946; $z = 28.551$, $p < 0.001$) and good sleepers (154 total, mean = 00.07, SD = 17.875; $z = 139.718$, $p < 0.001$) were significantly clustered at bedtime. A Watson-Williams F-test indicated that there was a significant difference between the bedtimes of poor and good sleepers (F (1, 186) = 6.934, $p = 0.009$) (see Figure 6.1).

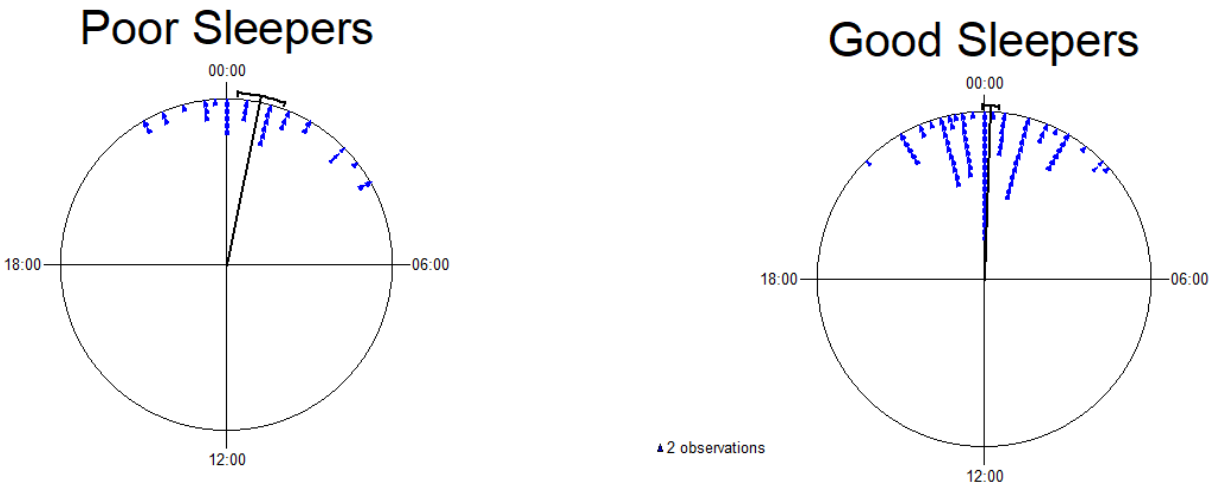


Figure 6.1: Mean bedtime for poor and good sleepers in the twenty-four hour group.

At one month, a Rayleigh test indicated that both poor sleepers (47 total, mean = 00.59, SD = 24.734; $z = 39.009$, $p < 0.001$) and good sleepers (123 total, mean = 00.09, SD = 19.625; $z = 109.383$, $p < 0.001$) were significantly clustered at bedtime. A Watson-Williams F-test indicated that there was a significant difference between the bedtimes of poor and good sleepers (F (1, 168) = 11.589, $p < 0.001$) (see Figure 6.2).

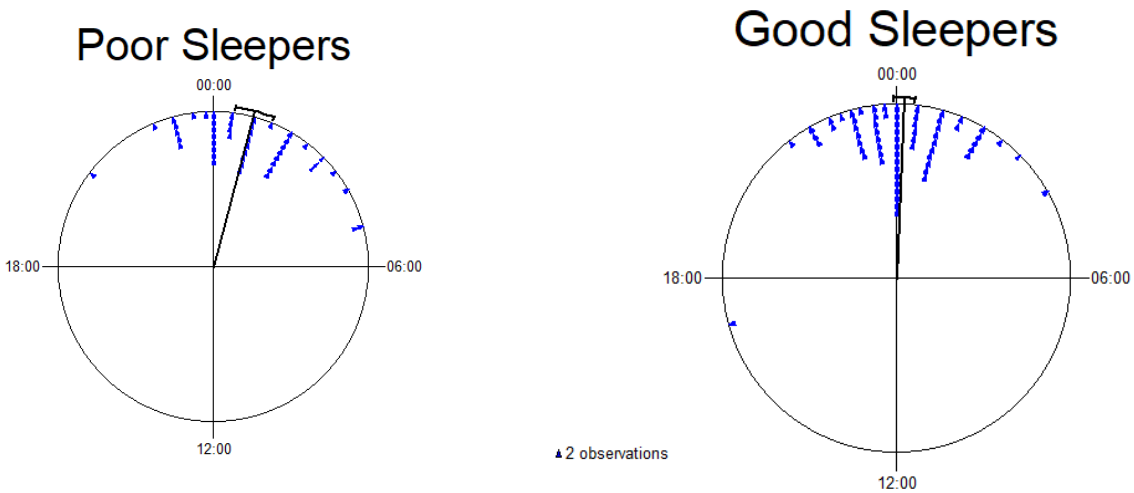


Figure 6.2: Mean bedtime for poor and good sleepers in the one month group.

At twenty-four hours, a Rayleigh test indicated that both poor sleepers (34 total, mean = 08.13, SD = 31.113; z =25.317, $p < 0.001$) and good sleepers (154 total, mean = 08.36, SD = 25.383; z =126.556, $p < 0.001$) were significantly clustered at wake up time. A Watson-Williams F-test indicated that there was no significant difference between the wake up times of poor and good sleepers (F (1, 186) = 1.258, p = 0.263) (see Figure 6.3).

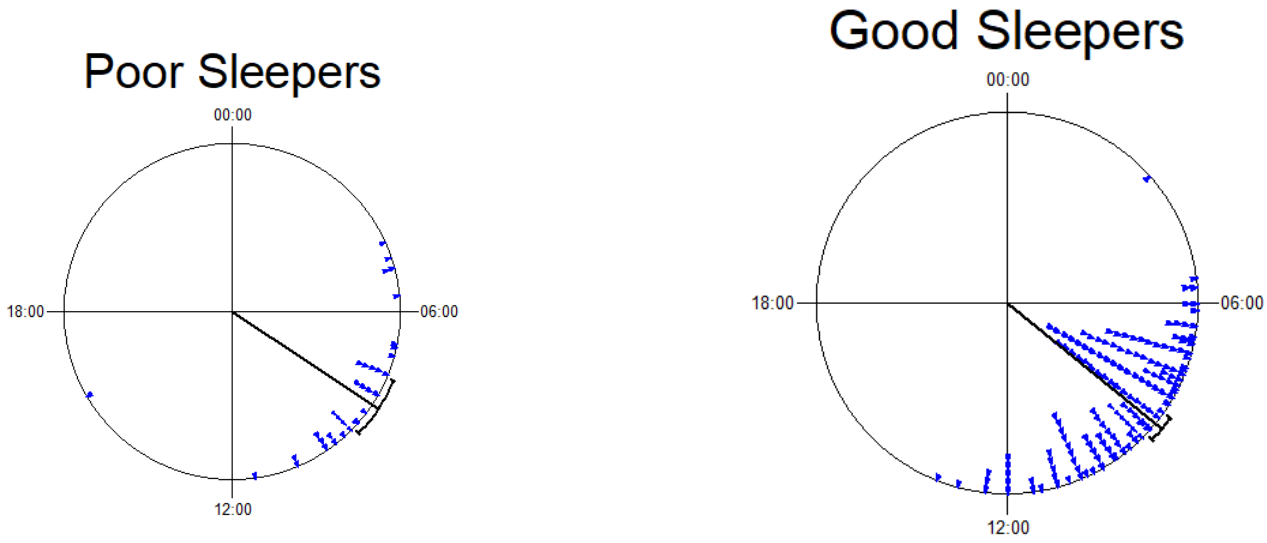


Figure 6.3: Mean wake up time for poor and good sleepers in the twenty-four hour group.

At one month, a Rayleigh test indicated that both poor sleepers (47 total, mean = 09.04, SD = 30.878; z = 35.153, $p < 0.001$) and good sleepers (123 total, mean = 08.35, SD = 28.405; z = 96.198, $p < 0.001$) were significantly clustered at wake up time. A Watson-Williams F-test indicated that there was no significant difference between the wake up times of poor and good sleepers (F (1, 168) = 2.037, $p < 0.155$) (see Figure 6.4).

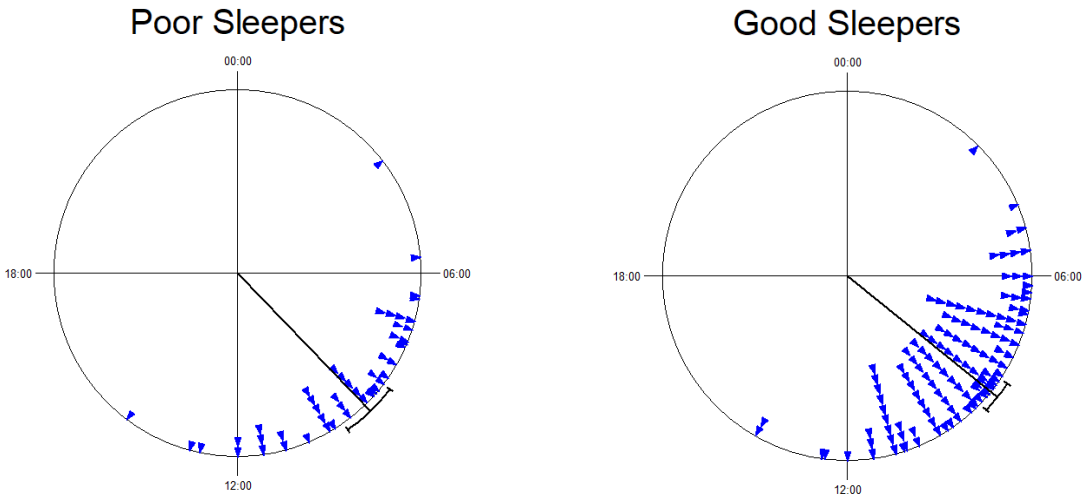


Figure 6.4: Mean wake up time for poor and good sleepers in the one month group.

An independent t-test was conducted to compare KSS scores for poor (mean = 4.92, SD = 1.935) and good sleepers (3.99, SD = 1.745). The results indicate that poor sleepers were significantly more sleepy than good sleepers on day one of the FNPT (t (355) = -4.322, $p < 0.001$, cohen's d = -0.014).

6.3.2 Correlations, gender, and age

6.3.2.1 Correlations

A number of correlation analyses were also conducted to further investigate the relationship between cognition, psychological factors, and sleep. Given the criticisms associated with categorisation of data based on a definitive cut-off score (Wong et al., 2015; Carson et al., 2017), for the purposes of this analysis sleep was not binarized. Instead, SCI score was correlated with other psychological and cognitive factors. SCI scores were significantly, negatively correlated with CFQ, DASS-21, GHQ-12, and AUDIT scores, suggesting that participants who score low on the SCI are also inclined to score high on psychological and subjective measures of cognition. As anticipated, DASS-21 scores were significantly, positively correlated with GHQ-12 ($r = 0.623$, $p < 0.001$) and AUDIT ($r = 0.307$, $p < 0.001$)

scores. Similarly, GHQ-12 scores were significantly, positively correlated with AUDIT (r = 0.153, $p < 0.001$) scores (see Table 6.1). This confirms that participants who score highly on the DASS-21 are also inclined to score highly on the GHQ-12, while participants who report feelings of depression and anxiety are also inclined to experience alcohol use disorders. Tower of Hanoi score and Face-Name Pairs task at both twenty-four hours and one month were not significantly correlated with DASS-21, GHQ-12, or AUDIT scores (see Table 6.1).

Interestingly, CFQ scores were significantly, positively correlated with DASS-21 (r = 0.467, $p < 0.001$), GHQ-12 ($r = 0.321$, $p < 0.001$), and AUDIT ($r = 0.253$, $p < 0.001$) scores, suggesting that participants who identify feelings of depression and anxiety, and who experience alcohol use disorders, are more likely to report cognitive failures (see Table 6.2). In order to further explore these results we conducted a multiple regression analysis to examine the relationship between CFQ scores and SCI, DASS-21, GHQ-12, and AUDIT scores as potential predictors. The model with all four predictors explained 24.2% of variance in CFQ scores ($F(4, 302) = 24.048$, $p < 0.001$. DASS-21 scores ($p < 0.001$) were most strongly associated with CFQ scores, suggesting that participants who report high levels of depression and anxiety are also more inclined to report experiencing cognitive failures. AUDIT scores ($p = 0.029$) were also associated with CFQ scores, suggesting that participants who report alcohol use disorders are also more likely to report cognitive failures. Interestingly, GHQ-12 scores ($p = 0.488$) and SCI scores ($p = 0.073$) did not contribute to the model (see Table 6.2). These results suggest that the effects of sleep on CFQ scores may be mediated by depression, anxiety, and alcohol use disorders.

Table 6.1: *Pearson correlations among age, cognition, and psychological factors.*

	SCI	CFQ	DASS	GHQ	AUDIT	FNPT-Day	FNPT-Month	TOH	
SCI	-								
p value									
CFQ	-0.374	-							
p value	<0.001								
DASS	-0.483	0.467	-						
p value	<0.001	<0.001							
GHQ	-0.386	0.321	0.623	-					
p value	<0.001	<0.001	<0.001						
AUDIT	-0.264	0.253	0.307	0.153	-				
p value	<0.001	<0.001	<0.001	0.007					
FNPT-Day	-0.123	0.057	0.075	0.105	0.095	-			
p value	0.092	0.434	0.338	0.181	0.228				
FNPT-Month	-0.004	0.062	0.085	0.135	0.087	0.164	-		
p value	0.962	0.425	0.305	0.105	0.296	0.032			
TOH	-0.078	0.102	0.037	0.047	-0.032	-0.172	0.004	-	
p value	0.171	0.074	0.542	0.444	0.602	0.019	0.958		
Age	0.041	-0.235	-0.306	-0.232	-0.269	-0.248	-0.234	2	-
p value	0.436	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	

Table 6.2: *Multiple regression model predicting CFQ scores.*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.242***	0.232***				
SCI Score			0.098	3.156	1.757	-0.3/6.61
DASS-21 Score			0.368***	0.243	0.045	-0.18/0.38
GHQ-12 Score			0.045	0.1	0.144	-0.18/0.38
AUDIT Score			0.116*	0.319	0.145	0.03/0.604

6.3.2.2 Gender

A number of independent t-tests were conducted to formally examine whether there was a gender difference across each of the psychological and cognitive measures. Results indicated that females outperformed males on the Face-Name Pairs task at twenty-four hours (t (186) = -2.261, p = 0.025), but not at one month (p = 0.117), and also on the Tower of Hanoi (t (305) = -2.528, p = 0.012). It is possible that this slight difference is due to the fact that there are more females than males in the sample. Females were also more inclined to score higher than males on the CFQ (t (355) = -5.507, p < 0.001), the DASS-21 (t (306) = -4.939, p < 0.001), and the GHQ-12 (t (305) = -2.279, p = 0.023). There was no gender difference for the SCI (p = 0.07) or the AUDIT (p = 0.383) (see Table 6.3).

Table 6.3: *Mean Face-Name Pairs task, Tower of Hanoi, CFQ, DASS-21, GHQ-12, AUDIT and SCI scores for both males and females.*

	FNPT 24 Hour	**FNPT Month**	**TOH**	**CFQ**	**DASS-21**	**GHQ-12**	**AUDIT**	**SCI**
Males	5.61	2.85	8.1061	37.18	31.48	12.45	6.45	22.1
(SEM)	(2.071)	(2.131)	(2.109)	(14.4)	(19.56)	(6.436)	(5.363)	(6.42)
Females	6.25	3.35	8.68	45.23	43.27	14.12	6.97	20.84
(SEM)	(1.813)	(2.030)	(1.86)	(13.09)	(21.49)	(6.255)	(5.030)	(6.59)
p values	**0.025**	0.117	**0.012**	**<0.001**	**<0.001**	**0.023**	0.388	0.070

6.3.2.3 Age

A number of correlation analyses were conducted to further investigate the relationship between age, cognition, psychological factors. Age was significantly, positively correlated with Tower of Hanoi score ($r = 0.2$, $p < 0.001$), suggesting that older adults performed better than younger adults on the task. Age was significantly, negatively correlated with Face-Name Pairs task score at twenty-four hours ($r = -0.248$, $p < 0.001$) and one month ($r = 0.234$, $p = 0.002$), with CFQ score ($r = -0.235$, $p < 0.001$), DASS-21 score ($r = -0.306$, $p < 0.001$), GHQ-12 score ($r = -0.232$, $p < 0.001$), and AUDIT score ($r = -0.269$, $p < 0.001$) (see Table 6.9). This suggests that older adults are inclined to perform worse than younger adults on the Face-Name Pairs task, complementing previous experiments (see Chapter 4). Interestingly, these results indicate that older adults are less likely to report cognitive failures, alcohol use

disorders, and feelings of anxiety and depression. Age was not significantly correlated with SCI score ($p = 0.436$).

6.3.3 Behavioural measures

6.3.3.1 Face-Name Pairs Task

When we compared those participants classified as either good or poor sleeper, we found no significant difference between the groups on the FNPT recall scores either twenty-four hours post-encoding (mean = 5.9, SD = 1.999, mean = 6.21, SD = 1.78, for good and poor sleepers, respectively; t (186) = - 0.869, $p = 0.386$, cohen's d = -0.156) or one month later (mean = 3.17, SD = 2.138, mean = 2.19, SD = 1.881, for good and poor sleepers, respectively; t (168) = 0.642, $p = 0.522$, cohen's d = 0.123; see Figures 6.5a & 6.5b).

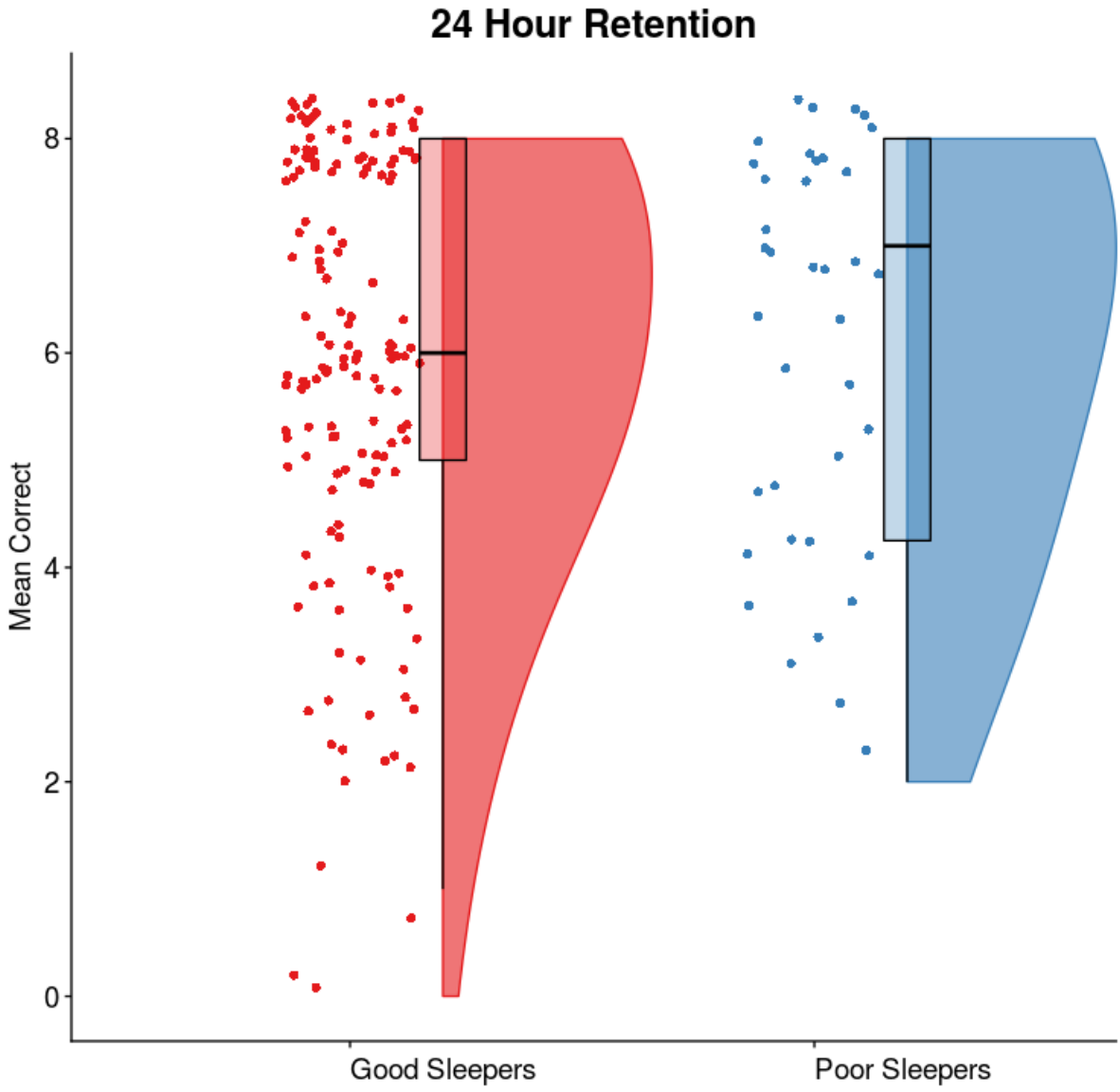


Figure 6.5a: Mean retrieval scores for both good and poor sleepers when retested at twenty-four hours post learning.

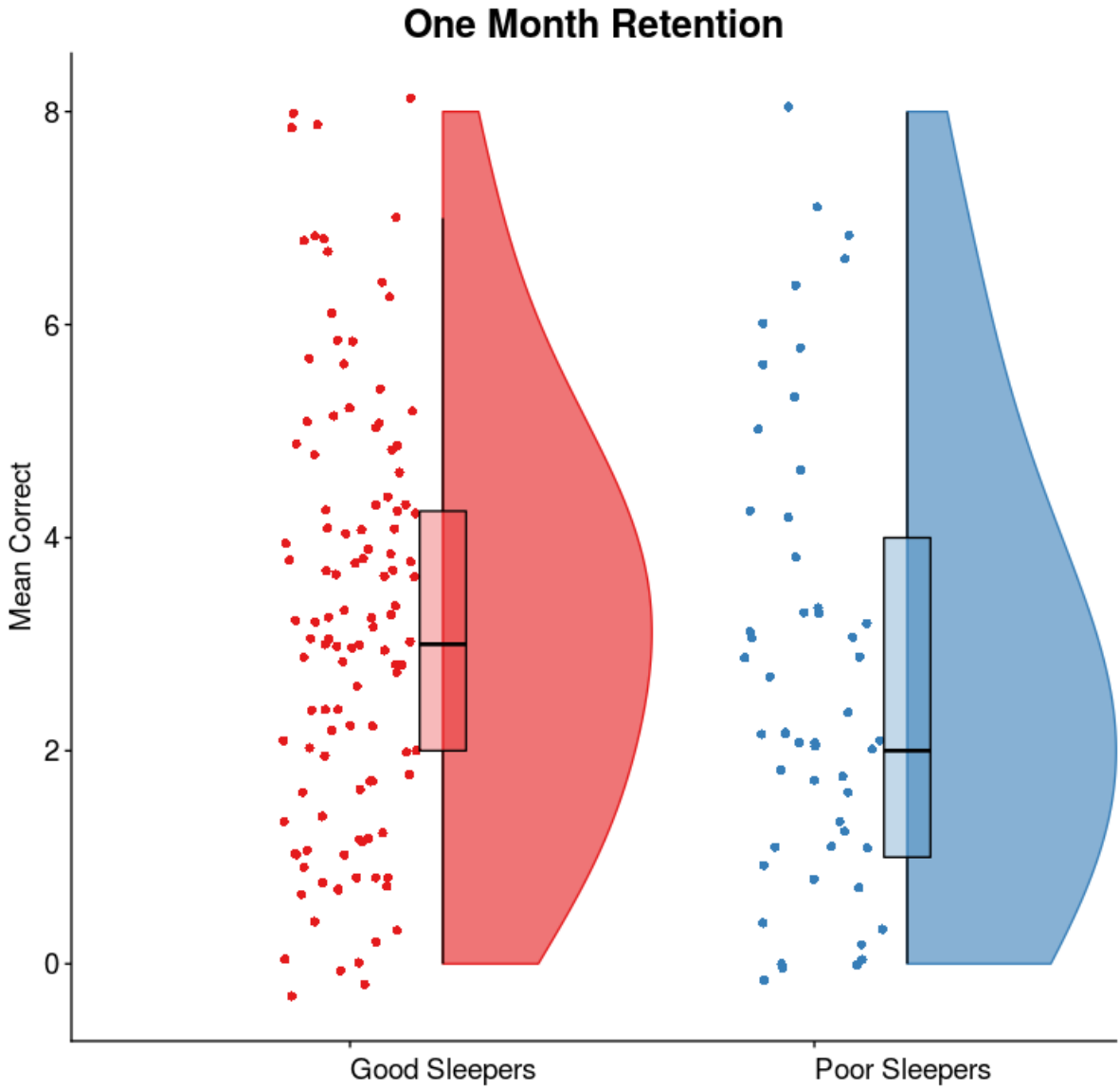


Figure 6.5b: Mean retrieval scores for both good and poor sleepers when retested at one month post learning.

Given the strong interaction between age, gender and sleep in the literature, we decided to conduct multiple regression analyses to examine the relationship between Face-Name Pairs task retrieval scores at both twenty-four hours and one month using SCI score, age, and gender as potential predictors. At twenty-four hours, the multiple regression model with all three predictors explained 8.2% of variance in Face-Name Pairs task scores ($F(3, 183) = 5.480$, $p =$

0.001). Only age (mean = 26.76, SD = 11.504) had a significant, negative regression weight (p = 0.001), indicating that older participants were expected to perform worse on the Face-Name Pairs Task. Gender (p = 0.085) and SCI scores (p = 0.314) did not contribute to the model (see Table 6.4). At one month, the multiple regression model with all three predictors explained 6.3% of variance in Face-Name Pairs Task scores (F(3, 165) = 3.726, p = 0.013). Again, only age had a significant, negative regression weight (p = 0.005), indicating that older participants were expected to perform worse on the Face-Name Pairs Task. Gender (p = 0.252) and sleep (p = 0.589) did not contribute to the model (see Table 6.5).

Table 6.4: *Multiple regression model predicting Face-Name Pairs Task scores at twenty-four hours (***p<0.001).*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.082***	0.067***				
Gender			0.124	0.490	0.283	-0.07/1.05
Age			-0.232***	-0.039	0.012	-0.06/-0.02
SCI Score			0.072	0.319	0.316	-0.3/0.94

Table 6.5: *Multiple regression model predicting Face-Name Pairs Task scores at one month (**p<0.01).*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.063**	0.046**				
Gender			0.088	0.369	0.322	-0.27/1.01
Age			-0.218**	-0.039	0.014	-0.07/-0.01
SCI Score			-0.041	-0.194	0.359	-0.9/0.51

6.3.3.2 Tower of Hanoi

When we compared good versus poor sleepers, we found no significant difference between the groups on ToH encoding (mean = 8.369, standard deviation = 1.939, mean = 8.635, standard deviation = 2.13, for good and poor sleepers, respectively; t (305) = - 1.004, p = 0.316). Further multiple regression analyses were conducted to examine the relationship between ToH scores and SCI score, age, and gender as potential predictors. The multiple regression model with all three predictors explained 7.3% of variance in Tower of Hanoi scores (F(3, 302) = 7.895, p < 0.001. Age (p < 0.001) was most strongly associated with Tower of Hanoi score, indicating that older adults were expected to perform slightly better on the task. Gender (p = 0.002) was also significantly associated with Tower of Hanoi scores, suggesting that women were expected to perform slightly better on the task. Sleep (p = 0.484) did not contribute to the model (see Table 6.6).

Table 6.6: *Multiple regression model predicting Tower of Hanoi scores.*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.073***	0.064***				
Gender			0.178**	0.712	0.225	0.27/1.12
Age			0.226***	0.039	0.010	0.02/0.06
SCI Score			0.039	0.176	0.251	-0.32/0.67

6.3.4 Psychological factors and sleep

6.3.4.1 Cognitive Failures Questionnaire

Multiple regression analyses were conducted to examine the relationship between CFQ scores (mean = 41.80, SD = 14.199) and SCI score, age, and gender as potential predictors. The

multiple regression model with all three predictors explained 18.9% of variance in CFQ scores ($F(3, 352) = 27.289$, $p < 0.001$. SCI score ($p < 0.001$) was mostly strongly associated with CFQ score, suggesting that good sleepers were expected to report less cognitive failures. Gender $p < 0.001$) was also significantly associated with CFQ scores, suggesting that men were expected to report less cognitive failures. Age ($p < 0.001$) was also significantly associated with lower CFQ scores (see Table 6.7).

Table 6.7: *Multiple regression model predicting CFQ scores.*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.189***	0.182***				
Gender			0.237***	6.805	1.395	4.06/9.55
Age			-0.212***	-0.261	0.060	-0.38/-0.14
SCI Score			0.270***	8.747	1.556	5.69/11.81

6.3.4.2 Depression and Anxiety Scale-21 and General Health Questionnaire-12

Multiple regression analyses were conducted to examine the relationship between DASS-21 scores (mean = 38.29, SD = 21.469) and SCI score, age, and gender as potential predictors. The multiple regression model with all three predictors explained 28.8% of variance in DASS-21 scores ($F(3, 303) = 40.847$, $p < 0.001$. Sleep ($p < 0.001$) was most strongly associated with DASS-21 score, indicating that good sleepers are expected to report less feelings of depression and anxiety. Age ($p < 0.001$) was also significantly associated with lower DASS-21 scores. Gender ($p < 0.001$) was also significantly associated with DASS-21 scores, indicating that men are expected to report less feelings of depression and anxiety (see Table 6.8).

Table 6.8: *Multiple regression model predicting DASS-21 scores.*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.288***	0.281***				
Gender			0.212***	9.184	2.130	4.99/13.38
Age			-0.293***	-0.547	0.092	-0.73/-0.37
SCI Score			0.379***	18.547	2.376	13.87/23.22

Multiple regression analyses were conducted to examine the relationship between GHQ-12 scores (mean = 13.42, SD = 6.375) and SCI score, age, and gender as potential predictors. The multiple regression model with all three predictors explained 15.8% of variance in GHQ-12 scores ($F(3, 302) = 18.873$, $p < 0.001$. SCI scores ($p < 0.001$) were mostly strongly associated with GHQ-12 scores, indicating that good sleepers are expected to report less feelings of depression and anxiety. Age ($p < 0.001$) was also significantly associated with lower GHQ-12 scores. Gender ($p = 0.131$) did not contribute to the model (see Table 6.9).

Table 6.9: *Multiple regression model predicting GHQ-12 scores.*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.158***	0.150***				
Gender			0.081	1.043	0.689	-0.31/2.4
Age			-0.236***	-0.131	0.030	-0.19/-0.07
SCI Score			0.309***	4.487	0.768	2.98/6.0

6.3.4.3 Alcohol Use Disorders Identification Test

Multiple regression analyses were conducted to examine the relationship between AUDIT scores (mean = 6.75, SD = 5.171) and SCI score, age, and gender as potential predictors. The multiple regression model with all three predictors explained 10.8% of variance in AUDIT scores ($F(3, 302) = 12.164$, $p < 0.001$. Age ($p < 0.001$) was most strongly associated with AUDIT scores, suggesting that older adults are less likely to report alcohol use disorders. SCI scores ($p < 0.001$) were also significantly associated with AUDIT scores, indicating that good sleepers are less likely to report alcohol use disorders. Gender ($p = 0.985$) did not contribute to the model (see Table 6.10).

Table 6.10: *Multiple regression model predicting AUDIT scores.*

	R^2	Adj R^2	β	B	SE	CI95%(B)
Model	0.108***	0.099***				
Gender			-0.001	-0.011	0.575	-1.14/1.12
Age			-0.280***	-0.126	0.025	-0.17/-0.08
SCI Score			0.188***	2.214	0.642	0.95/3.48

6.4 Discussion

There is no effect of sleep on ability to perform cognitive tasks such as the Face-Name Pairs task and the Tower of Hanoi. Both poor and good sleepers, as assessed using the SCI, performed equally well on each task, contradicting much of the literature. For example, Maurer et al. (2015) suggest that allowing participants to sleep between trials of a face-name association task leads to better performance. However, Whitmore et al. (2022) imply that sleep only leads to an improvement in face-name recognition when learning is reinforced during sleep, which was not the case here. Interestingly, participants performed significantly better overall on the FNPT in this experiment compared to others (see Chapter 5 for details). At twenty-four hours, in particular, a significant number of participants were able to accurately recall all eight face-name pairs. This is likely due to online administration which may have made the task easier (see Chapter 5). This has implications for the results of this experiment, suggesting that one possible explanation for the lack of difference between good versus poor sleepers is simply due to the task being too easy. However, this seems unlikely, given that there was no difference at one month or on the ToH. Similarly, there is significant research to support the positive effects of good sleep on tasks such as the Tower of Hanoi (Ashworth et al., 2013; Nielsen et al., 2014; Schiff & Vakil, 2015; Vermeulen et al., 2019). However, there are some studies which contradict this. Ozyigit et al. (2020) found no difference in performance of the task among medical students despite significantly different sleep duration, while Killgore et al. (2009) noted that stimulants such as caffeine and other medications eliminated the effects of sleep deprivation when attempting to complete the Tower of Hanoi. It has been acknowledged that the effects of sleep on memory and cognition depend on a number of factors, such as type of sleep (REM versus non-REM) and type of memory and task (declarative versus non-declarative memory; whether a task requires planning, working memory, self-control) (Plihal & Born, 1997; Smith & Rose, 2000; Siegel, 2001; Chambers,

2017). A more in-depth, objective analysis of participants' sleep quality and duration might yield different results. Alternatively, the effects of sleep may be over-exaggerated in the literature (Rieth et al., 2010).

It is worth noting that although it is reasonable to expect that the SCI gives a valid measure of insomnia, and can be used as a decent measure of poor sleep quality and duration, there is always the chance of exaggeration or misinformation with self-report measures of sleep. In particular, there is evidence to suggest that people are inclined to under-report the amount of sleep they get and over-report wake up times during the night (Bianchi, et al., 2013; Short et al., 2013; Dzierzewski et al., 2019). Furthermore, objective and subjective measures of sleep can be poorly correlated (Argyropoulos et al., 2003). However, this is not always the case (Boudebesse et al., 2014). Additionally, it is possible that binarizing SCI scores is problematic. Though Espie et al. (2014; 2018) recommend the use of a score of 16 as indicative of whether or not a patient has insomnia, some sources criticise the use of such definitive cut-off scores, suggesting that they can lead to false positives and misclassification (Wong et al., 2015; Carson et al., 2017). Though this approach allows for definitive classification of participants as good versus poor sleepers, it is possible that those who score in or around 16 have been incorrectly allocated. Perhaps a better system would be to use a less-definitive cut-off, whereby, for example, participants who score 13 or under are definite insomniacs, participants who score 19 or over are not, and those who score within a range of 14-18 should be considered more carefully. Alternatively, assessing sleep quality as a continuous variable instead may allow for a more all-encompassing analysis of the data. However, given that many studies have found the SCI to be a valid screening tool for insomnia, and given that correlational analyses of both the binarized SCI and continuous SCI scores produced similar results, it seems unreasonable to completely do away with the categorisation

approach (Espie et al., 2014; Wong et al., 2017; Espie et al., 2018; Hellstrom et al., 2019; Lin et al., 2020; Bayard et al., 2021).

In contrast, the results indicate a significant effect of sleep quality on self-report measures of cognition, in this case, the CFQ. Poor sleepers were more likely to report cognitive failures compared to good sleepers. This is in line with the literature, which suggests that poor sleep is particularly associated with greater failures on self-report measures of cognition (Simpson et al., 2005; Willert et al., 2005; Dalgaard et al., 2014; Xanidis & Brignell, 2016; Hong et al., 2020). Furthermore, the CFQ was significantly, positively correlated with DASS-21, GHQ-12, and AUDIT scores, suggesting that the effects of poor sleep may be mediated by other factors such as depression, anxiety, and alcohol use disorders. This is supported in the literature (Sullivan & Payne, 2007; Nair et al., 2017; Dzubur et al., 2020; Eskandari et al., 2021). Dzubur et al. (2020) suggest that factors such as alcohol consumption and anxiety, among others, could cause cognitive failures, while Sullivan & Payne (2007) observe that depressive symptoms are associated with higher CFQ scores. Of course, it is worth noting that the aforementioned results may be impacted by the fact that spaced- and massed-trained participants completed the SCI and CFQ on different days. Given the nature of sleep research, it is possible that completing these questionnaires on different days of the experiment may have caused an impact in the form of participants being more or less engaged, or indeed, more or less tired. Given that spaced-trained participants completed these questionnaires on day one, it seems likely that they were at peak motivation. Although massed participants completed these questionnaires on day two, it is likely that any drop in motivation would have occurred even if these questionnaires were administered on day one, given the crammed nature of the FNPT. In other words, massed-trained participants could either complete these questionnaires as part of a very long session, in which case motivation would likely drop as time passes, or they could be completed on day two in order to space out the

tasks and questionnaires to allow for optimum participant convenience. The latter option was chosen for this experiment (see procedures). Furthermore, it is unlikely that this element of the design impacted answers given on both the SCI and CFQ as questions are phrased in such a way as to make participants think about their behaviour over the last number of weeks, rather than on that very moment.

As expected, the results indicate that poor sleepers are more likely to report feelings of depression and anxiety (as measured by the DASS-21 and GHQ-12) and more likely to report alcohol use disorders (as measured by the AUDIT). This is in line with existing literature, which suggests that sleep disorders, such as insomnia, can often cause or be attributed to mood and alcohol use disorders (Harvey, 2011; Palmer & Alfano, 2017; Van Schrojenstein et al., 2017; Palmer et al., 2018; Koob & Colrain, 2020; Wan et al., 2020). Sleep and mood and alcohol use disorders tend to occur simultaneously, with one often causing another. For example, someone who is anxious or depressed may drink excessively in an attempt to feel better, which in turn causes problems with sleep (Colrain et al., 2014). Conversely, someone who is not sleeping well may attempt to self-medicate using alcohol, compounding the problem; prolonged sleep-deprivation and an increase in alcohol consumption may then cause feelings of depression and anxiety (Goodhines et al., 2019; Stanton et al., 2020).

The results also indicate a significant effect of age and gender across some variables. Women were inclined to perform better on the Face-Name Pairs task at twenty-four hours and also on the Tower of Hanoi. Similarly, women were significantly more likely to report cognitive failures and feelings of depression and anxiety. Younger participants were significantly better than older participants at the Face-Name Pairs task. This is somewhat in line with previous experiments (see Chapter 4), although the older participants in this experiment were middle-aged, making them significantly younger than the “older adults” discussed in previous chapters. Older participants significantly outperformed younger

participants on the Tower of Hanoi, and were also significantly less likely to report cognitive failures, alcohol use disorders, and feelings of anxiety and depression. There were no significant gender or age effects on SCI score.

These results are rather interesting. Literature regarding gender differences on the Tower of Hanoi (and a similar Tower of London task) tends to be rather conflicting, with some experiments finding no gender difference (Rhee et al., 1997; Demir & Oksuz, 2021), and others showing that men tend to outperform women (Leon-Carrion et al., 1991; Ronnlund et al., 2001; Safri et al., 2018). Neither of these suggestions are in line with the current results. However, there are significantly more female than male participants in the current study, which may account for the gender differences on cognitive tasks. There are mixed findings in the literature with regard to gender differences in CFQ score, with some observing that women are more likely to achieve a higher score (Bridger et al., 2013), others observing that men are more likely to achieve a higher score (Hadlington, 2015), and some observing no gender difference at all (Payne & Schnapp, 2014). Given the significant, positive correlation between CFQ and DASS-21 and GHQ-12 scores, and that women were more likely to score highly on the DASS-21 and GHQ-12, it is possible that the gender difference in the current sample is due to a significant number of female participants experiencing feelings of depression and anxiety, which in turn heightened their probability of experiencing and reporting cognitive failures.

Traditionally, women have always been more likely to report feelings of depression and anxiety than men (Angst et al., 2002; Tang et al., 2017; Stanton et al., 2020; Brace et al., 2021). For example, Hou et al. (2020) observed that Chinese females are at a greater risk of developing psychological conditions in the wake of the COVID-19 pandemic. Salk et al. (2017) noted that gender differences in depression can become apparent as early as the age of twelve, and that larger gender differences tend to occur in countries with greater gender

equality, while Gao et al. (2020) found that female students received significantly higher anxiety scores than males as measured by the DASS-21. A number of theories have been postulated to explain these prevalent gender differences. Prominent among them are the biomedical model, which explains gender differences in terms of differing genes and hormones, and the sociocultural and psychological models, which explain gender differences in terms of relevant social and cultural factors such as gender equality, gender roles, and economic background (Hammarstrom et al., 2009). Furthermore, depending on society, common gender roles often lead to differences in processing psychological distress; for example, men tend to respond externally (substance abuse, acting out), whereas women tend to respond internally (disorders such as depression and anxiety) (Gao et al., 2020). Given the focus on internal symptoms and the self-report nature of most depression and anxiety related questionnaires such as the DASS-21 and GHQ-12, it is more likely that women will indicate anxious or depressive tendencies than men. This is particularly true in the context of the DASS-21, as previous studies have observed that the DASS-21 does not include some physical indicators of depression, anxiety, and stress (such as sleep disturbances) which are acknowledged as being responsible for some sex and gender differences (Gomez et al., 2014). Conversely, it is interesting that there are no gender differences in AUDIT score as research indicates that men are more likely to suffer with alcohol use disorders than women (Park & Kim, 2019; Saal et al., 2020). However, these findings tend to be dependent on other variables, such as sleep quality, mental health, and socioeconomic factors (Goodhines, et al., 2019; Park & Kim, 2019; Stanton et al., 2020).

Typically, performance on tasks such as the Tower of Hanoi and questionnaires such as the CFQ declines with age (Ronnlund, et al., 2001; Rast et al., 2009; Philips et al., 2021). The opposite was true here, with older participants tending to outperform younger participants. Of course, most older participants in this study were not actually “old”, but rather, middle-

aged. Furthermore, the vast majority of participants were aged in their early twenties, therefore the sample of older participants cannot be considered representative. In the current experiment, older participants were also significantly less likely to report feelings of anxiety and depression or alcohol use disorders. This is supported to an extent in the literature (Wood et al., 2010; Lee et al., 2015; Nagasu et al., 2019; Kolakowsky-Hayner et al., 2021), although some research suggests that older adults are more likely to experience alcohol use disorders (Rosta & Aasland, 2010). The prevalence of alcohol use disorders across age groups appears to be dependent on socioeconomic factors, such as education, employment, and marital status, among others (Lee et al., 2015; Evans-Polce et al., 2020). It has been acknowledged that younger adults and adolescents may not distinguish between different unpleasant emotions the way that older adults do, which could account for age differences in depressive and anxious tendencies (Jovanovic et al., 2019). Moreover, given that our results imply a mediating effect of depression and anxiety on CFQ scores, it is possible that older participants received better scores as a result of improved mental health. It is also possible, given that self-report questionnaires are prone to distortions, that older participants in the current sample misreported certain behaviours on the CFQ (Gnambs & Kasper, 2014). Participants are more likely to misreport behaviours that go against social norms, or that they believe will portray them in a negative light, even when a questionnaire is anonymous (Chan, 2009). It is possible that older participants in the current study, aware of the stigma surrounding cognitive failures in ageing adults, underplayed or misreported certain behaviours, leading to better CFQ scores than younger participants.

In summary, quality of sleep as measured by the SCI does not affect cognitive tasks such as the Face-Name Pairs Task or the Tower of Hanoi, however poor sleepers are more likely to report cognitive failures. Furthermore, poor sleepers are more likely to report feelings of anxiety, depression, stress, and alcohol use disorders. It is possible that the effects of sleep

on memory and cognition are over-exaggerated in the literature, but a more in-depth, objective analysis of participants' sleep patterns is needed before any strong conclusions can be drawn. The effects of poor sleep on CFQ score appear to be mediated by experience of depression and anxiety. Gender and age analyses produce a number of interesting findings: Women were more likely to perform better on the Face-Name Pairs Task at twenty-four hours, and on the Tower of Hanoi task. Women were also more likely to report cognitive failures and depressive and anxious tendencies. Older participants received poorer scores on the Face-Name Pairs Task at both twenty-four hours and one month, however they performed better than younger participants on the Tower of Hanoi. Older participants were also less likely to report cognitive failures, feelings of depression and anxiety, and alcohol use disorders.

Chapter 7

The neural correlates of spacing

Abstract

Research regarding the neural basis underlying the spacing effect lends support to some of the theories posed to explain the effects of distributed practice. For example, literature indicates extra frontal activity in spaced-trained participants, which may be indicative of deficient processing, and differences in latency of ERP components, which may be indicative of study phase retrieval. In particular, there is limited research examining the electrophysiological correlates of spacing. This study attempted to investigate the neural basis of the spacing effect while learning face-name associations using EEG. The results suggest that there are significant differences between spaced- and massed-trained participants when correctly identifying previously learned face-name pairs. Most notably, spaced participants demonstrate neural activity indicative of greater processing, familiarity, and recognition of stimuli compared to massed participants. Results also provide support for theories of deficient processing and study phase retrieval. These findings may have implications with regard to explaining why spacing is so beneficial.

7.1 Introduction

There is a significant body of research surrounding the neural correlates of long-term memory consolidation (see Chapter 1). Perhaps the most well-known finding is in relation to the role of the hippocampus in long-term memory consolidation (Tompary & Davachi, 2017; Jeffrey, 2018; Sawangjit et al., 2018; Sekeres et al., 2018; Schapiro et al., 2019; Donato et al., 2021). Additionally, regions of the prefrontal cortex are known to be activated during learning and recall (Buckner & Koustal, 1998; Lee et al., 2000; Rugg et al., 2002; Blumenfeld & Ranganath, 2007; Dolcos & Denkova, 2008; Spalding et al., 2018; Tang et al., 2018; Finn et al., 2019). Furthermore, there is significant evidence to suggest that multiple cortical regions may be involved, depending on type of information to be encoded or recalled (Rugg et al., 2002; Kim, 2019).

Studies utilising fMRI have indicated that the hippocampus is active during the encoding and recall of associative information, such as face-name pairs (Sperling et al., 2003; Whalen, 2003; Kirwan & Stark, 2004; Chua et al., 2007; Bangen et al., 2012). Kirwan & Stark (2004) demonstrated significant activity in the right hippocampus, the right parahippocampal cortex, and the left amygdala during encoding of face-name associations, and significant right hippocampal, right parahippocampal, right entorhinal, and left perirhinal activation during successful retrieval of those face-name associations. Similarly, Whalen (2003) and Chua et al. (2007) also found activation of the medial temporal lobe, most notably the anterior hippocampal formation and the perirhinal cortex during encoding of subsequently correctly identified face-name associations. In addition to activation of the anterior hippocampal formation during successful face-name encoding, Sperling et al. (2003) noted significant activation of the left inferior prefrontal cortex during successful retrieval.

Event Related Potential (ERP) studies have expanded on these findings. Mitchell et al. (2016) found that successful retrieval of face-name associations elicited positive ERPs in both frontal and parietal regions. Similarly, Mangels et al. (2010) noted positive ERPs at later intervals of 700-900 milliseconds in central and parietal regions when confidently recognising face-name pairs. Furthermore, Mangels et al. (2010) observed negative posterior inferior temporal activity and negative fronto-central activity indicative of *separate* face and name encoding. These findings are similar to those of Guo et al. (2005), who noted differences in ERPs produced for face recognition, name recognition, and recognition of face-name associations, suggesting that encoding and retrieval of face-name association have a distinct neural signature. Furthermore, the authors suggest that different neural encoding and retrieval mechanisms may be engaged when learning individual names and faces versus face-name associations. In particular, they found that the correct retrieval of names alone elicited a negative P300 at parietal regions, compared to correct retrieval of both faces and face-name associations, each of which elicited a positive P300 across all scalp regions. This positive P300 was more pronounced in correct retrieval of associations. It is hypothesised that this similarity between ERPs of correctly retrieved faces and face-name associations is indicative of nonidentical encoding processes, though statistical analysis revealed no significant differences between the two (Guo et al., 2005).

In line with the above findings, many studies observe a prolonged P300 component associated with recognition of familiar stimuli (Munte et al., 1997; Henson et al., 2003; Hammer et al., 2013). Hammer et al. (2013) also observed an N250 and frontal N400 component during retrieval, both of which are thought to be associated with recognition of repeated, familiar faces. These components were greater for correctly remembered associations. The well-known N170 component was also observed. The N170 component is

arguably one of the most robust ERP findings to date, and can be indicative of face processing (Eimer, 2000; Itier & Taylor, 2004; Simon et al., 2007; Hammer et al., 2013; Stasch et al., 2018; Civile et al., 2020). Hammer et al. (2013) noted an increased N170 during retrieval for incorrectly remembered face-name associations. This finding contradicts the notion of the N170 component reflecting face processing without influence from memory processes. Given that the N170 can reflect attention, it is suggested that the enhanced component may be due to greater attention needed when retrieval is difficult.

Research regarding the neural correlates of distributed practice indicate that a number of brain regions are activated during spaced encoding. In initial sessions, the hippocampus tends to be fully active (Van Hoof et al., 2021). Over subsequent sessions, this hippocampal activity reduces. Instead, other neural regions are engaged, allowing for a greater chance of retrieval (Gerbier & Toppino, 2015; Van Hoof et al., 2021). Additionally, studies have found that spaced-trained participants tend to demonstrate greater neural activity compared to massed-trained participants during both encoding and retrieval (Zhao et al., 2015). For example, Callan & Schweighofer (2010) observed additional frontal activity during retrieval in spaced-trained participants that was not present in massed-trained participants. Similarly, ERP studies indicate comparable activity across subsequent distributed learning sessions when compared to massed-trained participants (Mollison & Curran, 2015). In contrast, massed-trained participants exhibited differing activity across subsequent learning sessions, possibly suggesting that less neural activity occurs due to a sense of familiarity with the to-be-learned material. Mangels et al. (2009) suggest that massed encoding of face-name associations elicits the strongest activity during the first learning session, but also found a correlation between neural activity during the third learning session and subsequent memory performance,

suggesting that utilisation of massed training schedules may be of some benefit when learning face-name associations.

Weston (2018) also noticed significant differences between ERPs elicited by spaced- versus massed-trained participants. Most notably, though both spaced- and massed-trained participants elicited later positive components in parietal regions during encoding, spaced-trained participants peaked significantly later than massed-trained participants and mean amplitude of this component was reduced compared to massed-trained participants. This later peak may be a representation of study-phase retrieval (that is, the idea that material presented following greater lags between presentations is harder to retrieve), while the lower amplitude may be indicative of massed-trained participants having to exert greater focus and attention when remembering compared to spaced-trained participants (Mollison & Curran, 2015; Weston, 2018).

In sum, there is significant research to date implicating various brain regions, such as the hippocampus and prefrontal cortex, among others, when engaging in encoding and retrieval of associative information such as face-name pairs (Buckner & Koustal, 1998; Lee et al., 2000; Rugg et al., 2002; Tompary & Davachi, 2017; Jeffrey, 2018; Sawangjit et al., 2018; Sekereset al., 2018; Tanget al., 2018; Finnet al., 2019; Schapiroet al., 2019; Donatoet al., 2021). Furthermore, analysis of ERP components support the concept of different neural networks which are involved in the encoding of faces, names, and face-name associations respectively (Guo et al., 2005). There are a number of specific ERP components associated with processing and retrieval of face-name associations, including the N170, N250, P300, and N400, to name but a few (Hammer et al., 2013). There is also significant research to indicate that different brain regions may be involved when encoding and retrieving spaced- versus massed-trained material (Mollison & Curran, 2015). This is supported by ERP studies, which

indicate differences in amplitude and latency between spaced- and massed-trained participants (Weston, 2018).

To date, there are few studies examining the specific electrophysiology underlying spaced versus massed learning of face-name associations. This chapter aims to further investigate this phenomenon by recording ERPs while retrieving novel face-name associations following utilisation of a spaced or massed training schedule. Retrieval occurred one month following initial learning. It is hypothesised that various components specific to face-name processing will be present (such as the N170 and N250, among others), and that there will be a significant difference in both latency and amplitude of ERPs elicited by spaced versus massed training schedules.

7.2 Methods

7.2.1 Participants

Power calculations were done to estimate the number of participants required. Using fixed effects ANOVAs and an effect size of 0.3 with power of 0.9, p = 0.05, and 2 groups estimates 119 participants. The sample consists of 43 participants, 4 males and 39 females, recruited from Maynooth University. All were students and recruited as part of a Research Participation module and as a result, there was a bias in gender. Participants were aged between 18 and 50 (mean = 21.21 years, standard deviation = 5.39). An exclusion and inclusion criteria were applied, so all participants were healthy, cognitively healthy, and had normal or corrected-to normal vision. No participant had a known history of drug or substance abuse, and no other relevant medical conditions.

7.2.2 Materials

Two control tasks were used to ensure that both training groups were similar in terms of IQ, executive functioning, and general memory ability: the National Adult Reading Test and the Trail Making Tasks (see Chapter 2 for details). Due to time constraints, the RAVLT (used in previous chapters) was not included. The Face-Name Pairs task was used to assess associative memory. Due to restrictions in place as a result of the COVID-19 pandemic, the Face-Name Pairs task was carried out both online and in-person: All encoding trials were administered via Qualtrics, while retrieval occurred one month later within the EEG lab at Maynooth University. This retrieval block was administered via Presentation version 23, using a Dell machine with a Windows 7 operating system. The task was presented through a series of short presentations. Encoding consisted of eight presentations in total - four study block presentations with each block immediately followed by a retrieval block. Each of the four study block presentations consisted of thirty different faces (equal male/female, presented on

a white background) paired with thirty different names, shown four times per block. The retrieval block presentations consisted of one-hundred and twenty face-name pairs, some previously viewed and some novel, which participants had to judge as correct or incorrect (see Chapter 2 for more details).

EEG was recorded using a Biosemi ActiveTwo system with a 32 electrode cap, using a 10-20 layout, and thirty-two active sintered Ag-AgCl electrodes (Laszlo et al., 2014). Four flat-type Active-electrodes were placed on the face to record electrooculogram signals in order to aid the detection of blinks. Electrodes made contact through an electrolyte gel link. Data were recorded continuously throughout the task in a room enclosed by a Faraday cage using a battery-powered amplifier and relayed to computers in an adjoining room (see Chapter 2 for details).

The EEG data were analysed off-line using Brainstorm software (version 3.210714) (see Chapter 2 for details). In brief, data were examined manually to determine and remove bad channels or segments. A band-pass filter using a High-pass filter of 0.1Hz and a Low-pass filter of 100Hz was applied, and an Independent Component Analysis (ICA) with thirty-one components was run on the raw data to remove obvious blink and facial movement artefacts. ERP epochs were imported and averaged in Brainstorm for "correct" triggers. Each epoch began 200ms before stimulus presentation and ended at 800ms post stimulus presentation. ERPs were averaged for each individual participant for each condition (spaced or massed) at each electrode site. Grand averages were then calculated across all participants in a group for each condition (spaced versus massed). Mean amplitudes and peak latencies were the dependent variables for all statistical comparisons.

7.2.3 Procedure

At the time of this experiment, COVID-19 restrictions were still in place and as a result, it was necessary to minimise contact with participants where possible. This resulted in adoption of a mixed-methods approach whereby encoding occurred online and retrieval occurred in person. This also afforded a unique opportunity to see if the results discussed in Chapters 5 and 6 could be conceptually replicated with a recognition based task. Furthermore, the decision was made to only record ERPs at retrieval. A stipulation of proceeding with this study was conducting the experiment in line with existing COVID-19 restrictions. This meant minimising contact with participants, which was not conducive to recording ERPs during encoding. Furthermore, we needed to allow adequate time between each participant in order for recording equipment to be properly sterilised. Therefore, it was necessary to minimise recording time in order to meet the number of participants required by the power analysis Furthermore, the experiment was more comfortable for and appealing to participants when ERPs were recorded at retrieval only. This is particularly true for spaced-trained participants, who participated across five days.

Upon reading an information sheet and agreeing to participate, participants were given a Qualtrics link via email. Participants were initially presented with a digital consent form (see Appendices P & Q). The consent form stressed that all results would be anonymised and kept completely confidential. Participants were initially randomly assigned to the spaced or massed conditions. There were twenty-one participants in the spaced group (two of these participants were later excluded as they did not learn the material, that is, they did not demonstrate any improvement during encoding) and a further twenty-two participants in the massed condition. Each condition included four study blocks. Participants in the spaced condition completed the four study blocks over four consecutive days. Participants in the massed condition completed the four study blocks on one day. Due to government restrictions, encoding was completed online, regardless of condition. Spaced participants were sent a

different Qualtrics link on each consecutive day in order to ensure that learning took place as intended. One month later, participants were invited to complete a single retrieval block in-person while EEG was recorded. Control tasks were administered during EEG setup.

7.2.4 Encoding

See Chapter 2 for details on encoding. In brief, participants were requested to watch a presentation of 30 face-name pairs via Qualtrics. A fixation cross was displayed on screen for 0.5 seconds. This was followed by a face-name pair presented for 2 seconds, then a blank screen presented for 1 second. The experiment repeated in this manner, cycling through all 30 face-name pairs (see Figure 7.1).

The 30 face-name pairs were presented four times per study block. Following each block, participants completed a single retrieval trial. They were presented with a number of face-name associations that they had seen before (60) and a number of new pairings (60) and had to indicate as quickly as possible if the face-name pair was correct (observed previously). This was done by clicking the correct/incorrect buttons on screen. Again, participants were presented with a fixation cross, lasting for 0.5 seconds, followed by a face-name pair. The face-name pair remained on screen for 15 seconds maximum, or until the participant responded. This was followed by a blank screen for 1 second (see Figure 7.1).

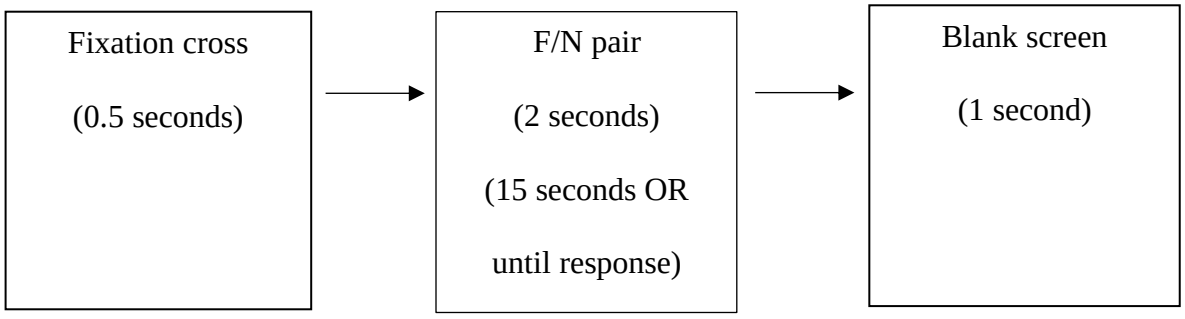


Figure 7.1 A visual representation of the encoding phase of the experiment

7.2.5 Retrieval

See Chapter 2 for details of retrieval. One month later, participants were invited to participate in a retrieval trial while EEG was recorded. The retrieval trial consisted of one presentation whereby participants were presented with 60 previously observed face-name pairs and 60 new face-name pairs (see Figure 7.1). Participants were required to recognise correct face-name pairs (previously observed) by responding with the mouse. This involved a single trial of 120 faces total.

7.2.6 Design

A mixed between-within factorial design was employed for both the encoding and retrieval phases. The independent variable was condition (spaced or massed learning). The dependent variable was mean correct score (how many face-name pairs participants could correctly recognise on a given trial). The between-subjects measure was difference (if any) between the ERPs of participants in each condition (spaced or massed) and the within-subjects measure was difference (if any) between trials during the encoding phase and difference (if any) between trial four and the retrieval trial. Between group comparisons were used to examine the massed and spaced groups on each of the control tasks (NART and TMTs).

7.2.7 Statistics

Brainstorm, Microsoft Excel and an IBM SPSS statistics software programme (version 28) were used to calculate the results. Means and standard errors of the mean were calculated through Microsoft Excel. A MANOVA was used to compare the means of the control tasks and demographics. An initial 2 X 4 mixed between factorial ANOVA was conducted to investigate whether learning had occurred and to show whether a difference existed between the massed and spaced conditions. Following this, a number of Bonferroni corrected

independent t-tests were used to compare mean score and mean reaction time during the retest. Further Bonferroni corrected independent t-tests were used to compare amplitude and latency of ERPs.

7.2.8 Ethics

The American Psychological Association and Psychological Society of Ireland codes of ethical conduct were observed throughout. Participants were provided with an information sheet in advance of the experiment, explaining the procedure in detail. All participants were over eighteen, consented to taking part, and were informed that they could pull out at any time. Data were anonymised for privacy. All experiments were approved by Maynooth University ethics committee (reference BSRESC-2021-2453422).

7.3 Results

To ensure that both massed- and spaced-trained groups were matched across age and control tasks, we used a MANOVA to compare participants from both groups with respect to age and scores on the NART and TMTs (see Table 7.1). The results indicate that there was no significant difference between the spaced and massed groups on the combined dependent variables ($F(5, 34) = 1.063$, $p = 0.398$). There was also no significant difference between groups when the results were considered separately: Age ($F(1, 38) = 0.008$, $p = 0.927$), NART score ($F(1, 38) = 0.483$, $p = 0.491$), TMTa score ($F(1, 38) = 3.008$, $p = 0.091$), TMTb score ($F(1, 38) = 0.012$, $p = 0.913$), TMTb-a score ($F(1, 38) = 0.509$, $p = 0.480$). This suggests that participants were cognitively-matched and that further results were not affected by these variables.

Table 7.1: *Mean age, NART, TMT, and RAVLT scores (standard error of the mean) for both spaced and massed conditions, and their p values.*

	N	M/F	Age	NART	TMTa	TMTb	TMTb-a
Spaced (SD)	21	2/19	21.11 (3.98)	16.00 (5.33)	21.93 (5.03)	38.57 (12.52)	16.72 (11.66)
Massed (SD)	22	2/20	21.27 (6.52)	14.91 (4.61)	19.41 (4.17)	39.03 (13.50)	19.59 (13.40)
p values			0.927	0.491	0.091	0.913	0.480

7.3.1 Behavioural Results

Encoding Phase

An initial 2 X 4 mixed between-within factorial ANOVA was conducted to compare learning across the four trials for both the spaced- and massed- trained conditions. There was a substantial main effect of Trial (F (3, 37) = 43.377, $p < 0.001$, partial eta squared = 0.779), but no effect of Group (F (1, 39) = 1.428, $p = 0.239$, partial eta squared = 0.035). There was no significant interaction between trial and group (F (3, 37) = 2.157, $p = 0.110$, partial eta squared = 0.149) (see Figure 7.2).

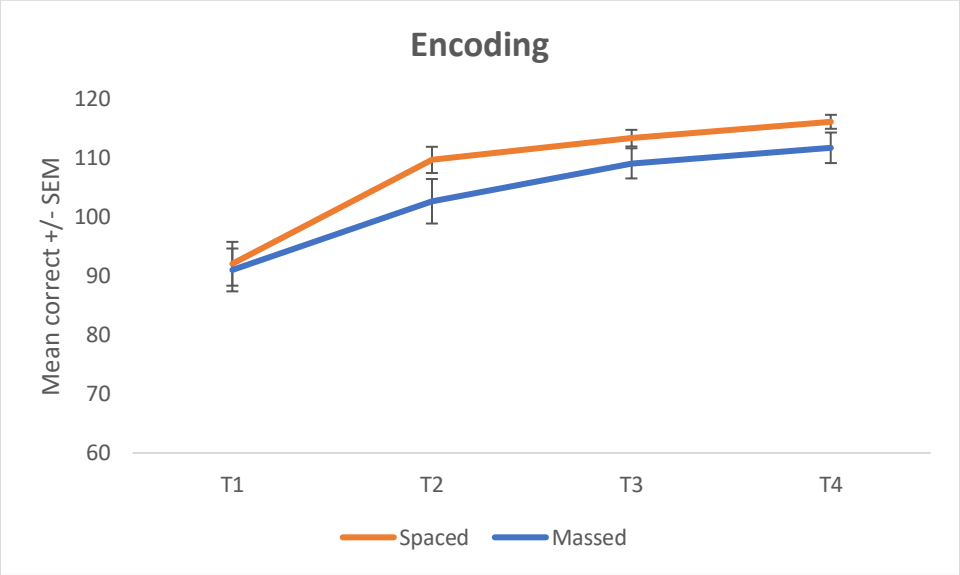


Figure 7.2: Mean encoding score and standard error of the mean for both spaced and massed groups.

Retrieval Phase

An independent t-test was conducted to explore the difference between the ability of those in the spaced and massed conditions to recall the face-name pairs following an interval of one month. Accuracy for both conditions was high, however the results indicate that there was a significant difference between the performance of the spaced and massed conditions (t (28.547) = 2.099, $p = 0.045$, cohen's d = 0.681) (see Figure 7.3a), with the spaced group

showing significantly better recall (M = 91.05, SD = 12.136) compared to the massed group (M = 84.36, SD = 7.274). A second independent t-test was conducted to investigate whether the spaced or massed conditions exhibited faster response times when correctly identifying previously seen face-name associations. The results indicate that there was no significant difference between conditions (t (40) = -1.310, p = 0.198, cohen's d = -0.406) (see Figure 7.3b) with the spaced group showing a mean reaction time of 181.16 and massed group of 204.43 .

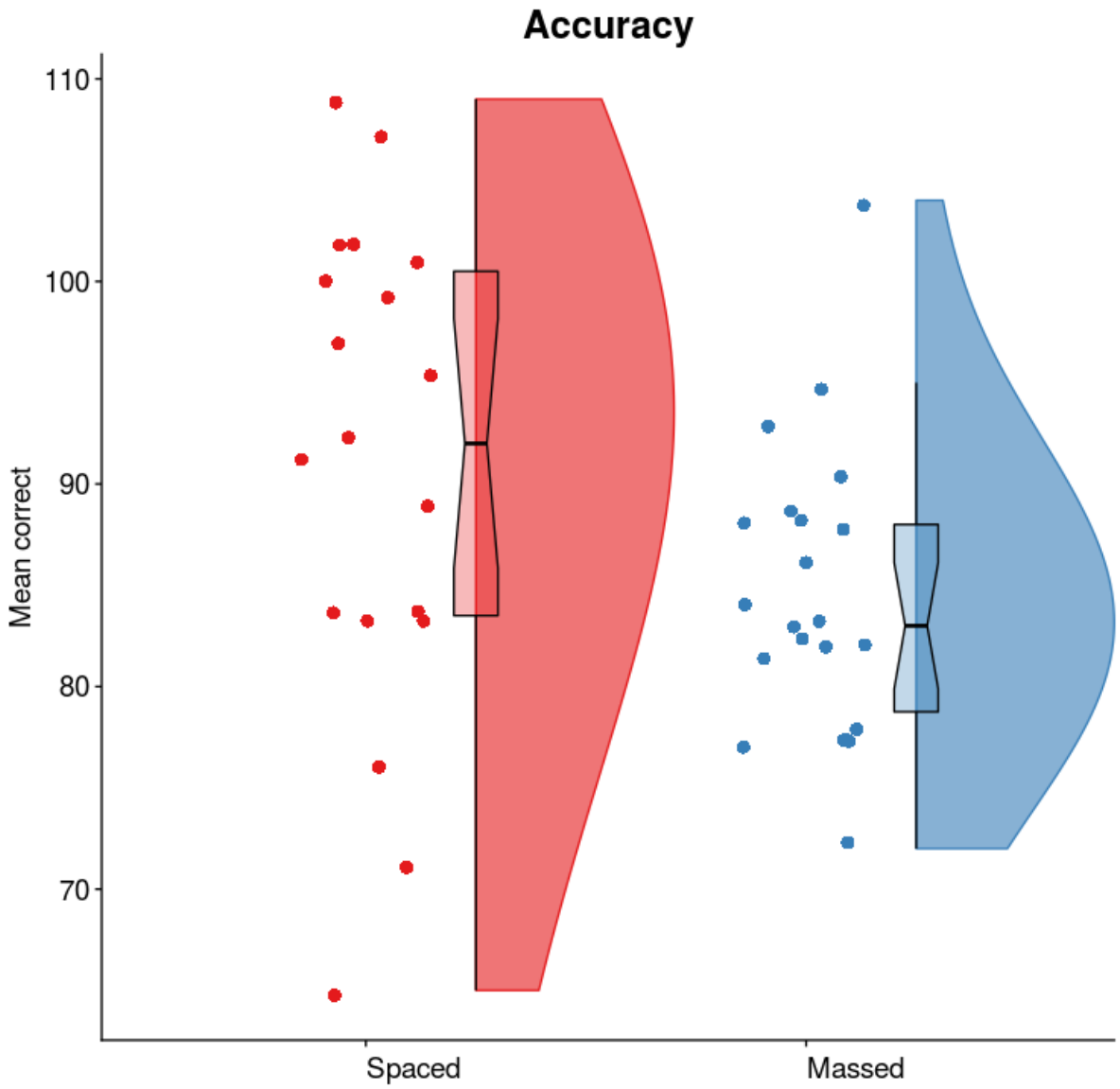


Figure 7.3a: Mean retrieval score for both the spaced and massed groups at one month.

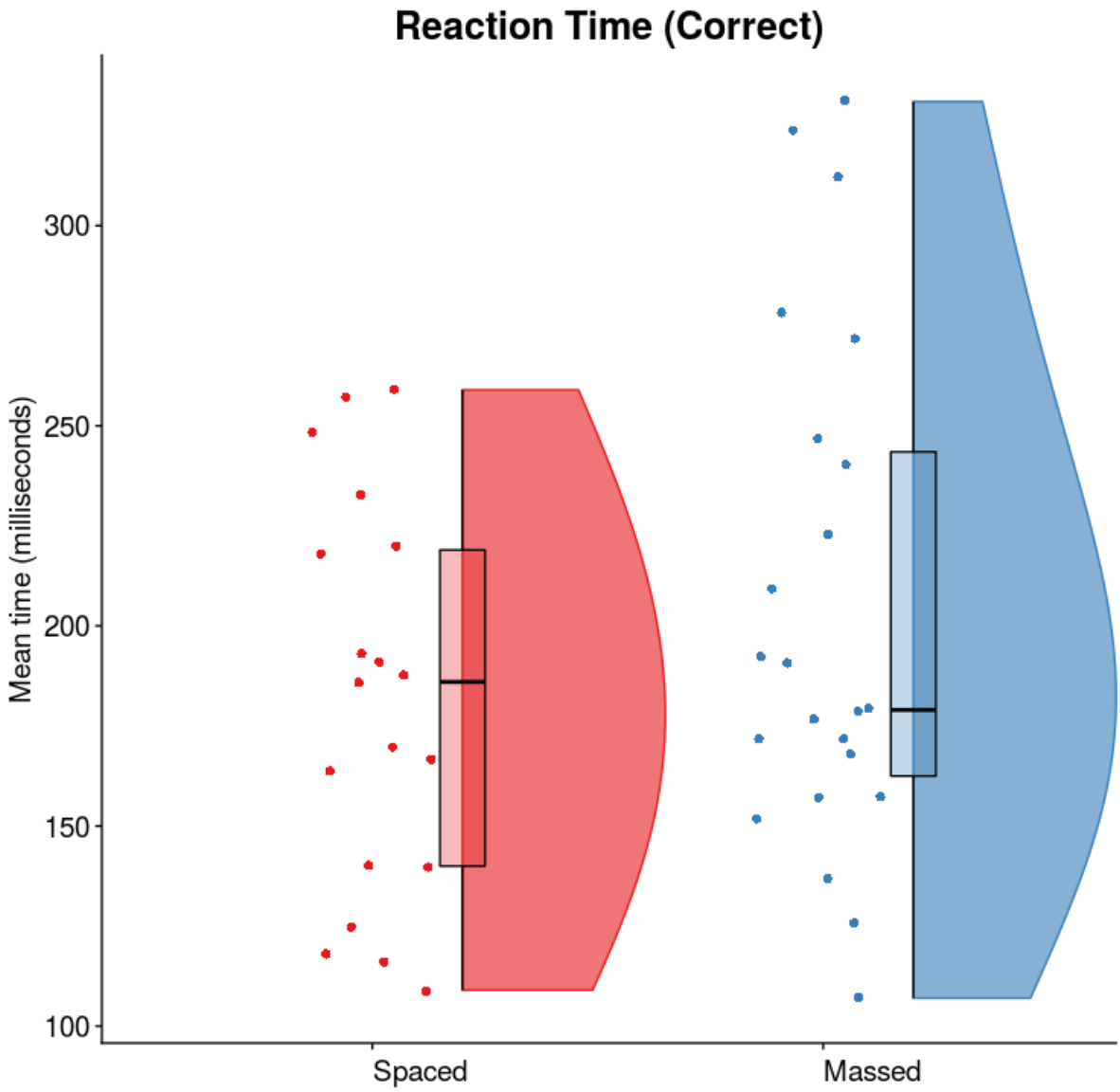


Figure 7.3b: Mean reaction times (correct) for both the spaced and massed groups.

7.3.2 EEG Results

Given the high recall rates by both groups (76% spaced and 70% massed), only ERPs for correct responses were analysed here. Trials where participants accurately recognised a previously seen face-name pair and trials where participants accurately dismissed an incorrect face-name pair were deemed "correct". This gave us a total of 1724 trials for the spaced condition and 1855 trials for the massed condition. Average ERPs were extracted for both

groups from four midline scalp locations (Oz, Pz, Cz, and Fz) and averaged across all subjects. These sites were chosen because close examination of ERP results obtained from all other scalp locations indicated that a midline analysis provided a good overview of all results. Furthermore, this procedure has been adopted by similar experiments (see Guo et al., 2005; Hammer et al., 2013).

7.3.2.1 Oz

Correct recall of face-name pairs elicited three major components at the Oz electrode, including a P100 component, followed by an N170 component, which in turn was followed by a P200 component (see Figure 7.4). Bonferroni corrected t-tests indicated that massed-trained participants (M = 9.15 uV, SD = 0.0000126) evoked an occipital P100 of significantly greater amplitude than spaced-trained participants (M = 6.55 uV, SD = 0.0000122) (t (3578) = -4.9023, $p \leq 0.01$). Massed-trained participants (M = 8.95 uV, SD = 0.0000125) also elicited a P200 of significantly greater amplitude than spaced-trained participants (M = 7.88 uV, SD = 0.0000135) (t (40) = -5.1012, $p \leq 0.01$). Conversely, spaced-trained participants (M = 2.41 uV, SD = 0.0000133) elicited an occipital N170 of significantly greater amplitude than massed-trained participants (M = 4.05 uV, SD = 0.0000121) (t (40) = -4.8984, $p \leq 0.01$) (see Figure 7.4).

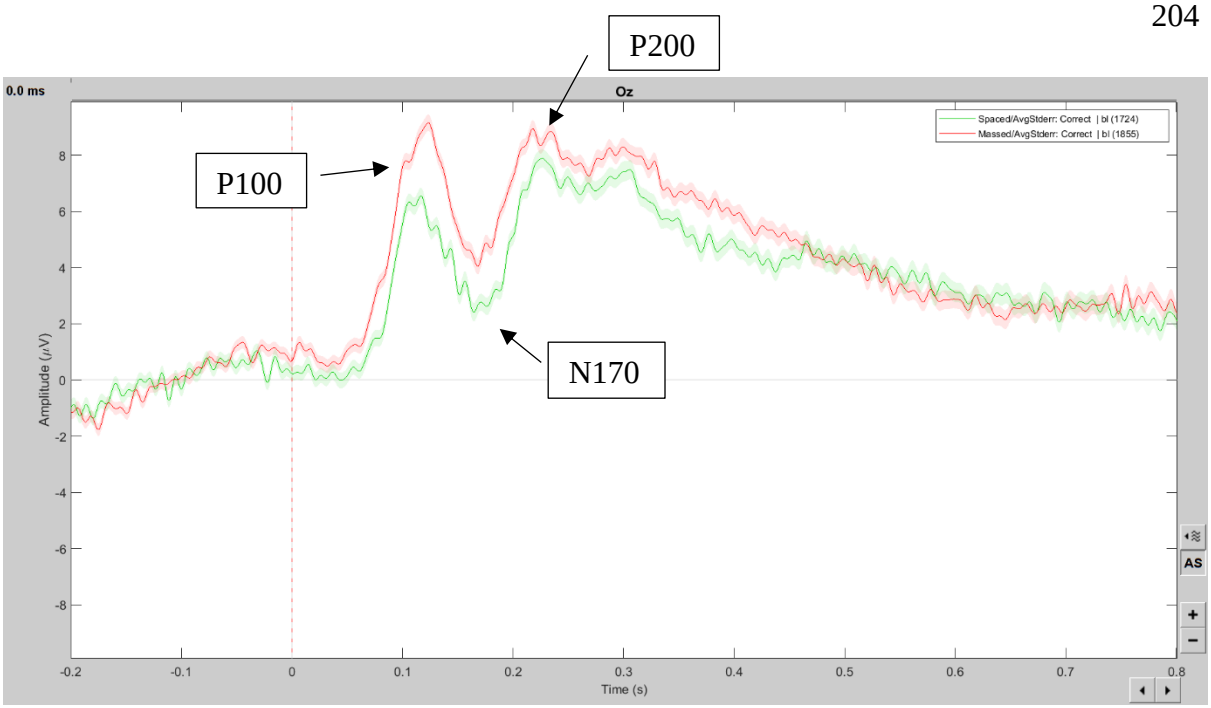
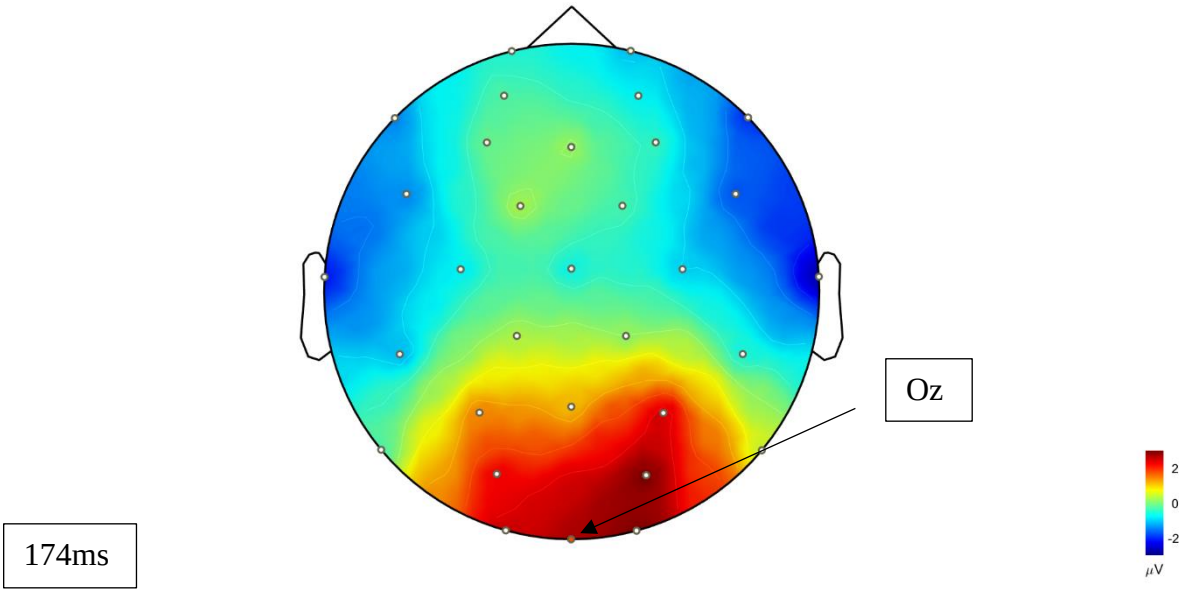


Figure 7.4a: Mean ERPs (+/- SEM) elicited at Oz for both the spaced (green) and massed (red) groups.



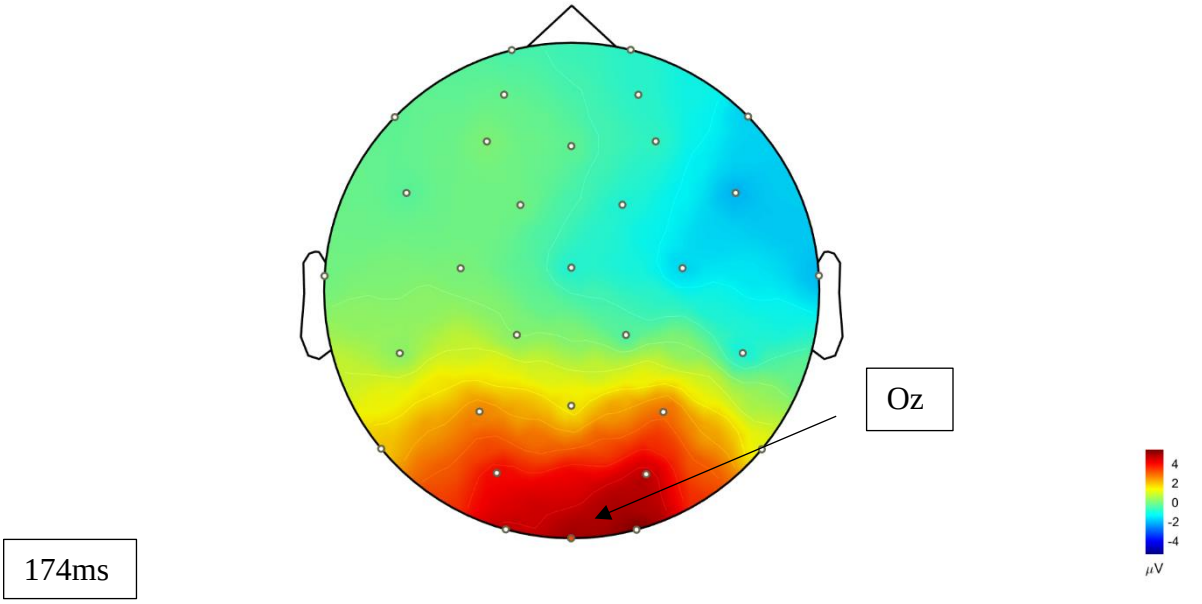


Figure 7.4b: Mean N170 topography for the spaced (top) and massed (bottom) participants.

7.3.2.2 Pz

Correct recall of face-name pairs elicited five major components at the Pz electrode, including a P100 component, followed by a negative deflection, a prominent P200, followed by another negative deflection, which in turn is followed by a P300 component (see Figure 7.5). In addition, spaced-trained participants exhibited an N400 component that is not present in massed-trained participants. Bonferroni corrected t-tests indicated that massed-trained participants (M = 3.9 uV, SD = 0.000008) elicited a parietal P100 component of significantly greater amplitude than spaced-trained participants (M = 2.37 uV, SD = 0.00000652) (t (40) = -6.0088, $p \leq 0.01$). Massed-trained participants (M = 3.54 uV, SD = 0.00000836) elicited a P200 component of significantly greater amplitude than spaced-trained participants (M = 1.78 uV, SD = 0.0000068) (t (40) = -4.8921, $p \leq 0.01$). Massed-trained participants (M = 5.6 uV, SD = 0.00000911) also evoked a P300 component of significantly greater amplitude than spaced-trained participants (M = 4.19 uV, SD = 0.00000792) (t (40) = -4.8776, $p \leq 0.01$). Spaced-trained participants (M = 2.85 uV, SD = 0.00000777) produced a parietal N400 that is

not present in massed-trained participants (t (40) = -4.9223, $p \leq 0.01$). A Bonferroni corrected independent t-test was conducted to examine whether there were significant differences in the latency of the P300 component for both the spaced and massed conditions at Pz. The results indicate that the LPC peaked earlier and was significantly longer for massed participants (t (40) = 22.9995, $p \leq 0.01$) (see Figure 7.5).

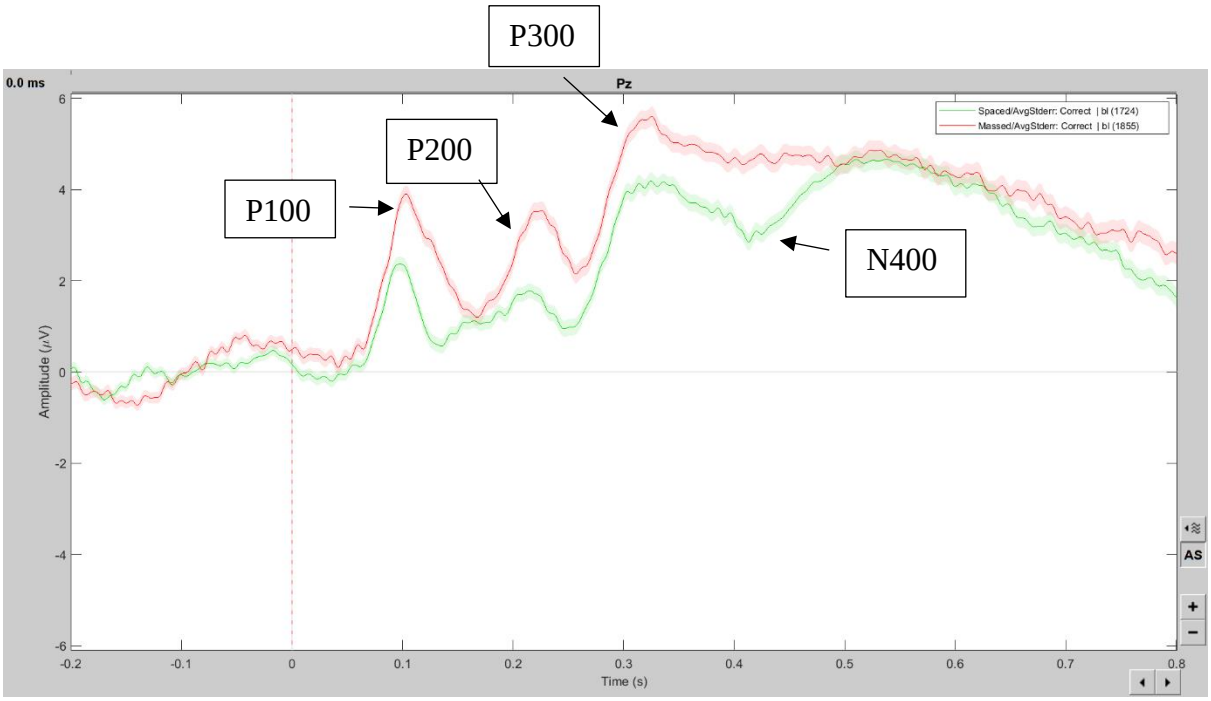
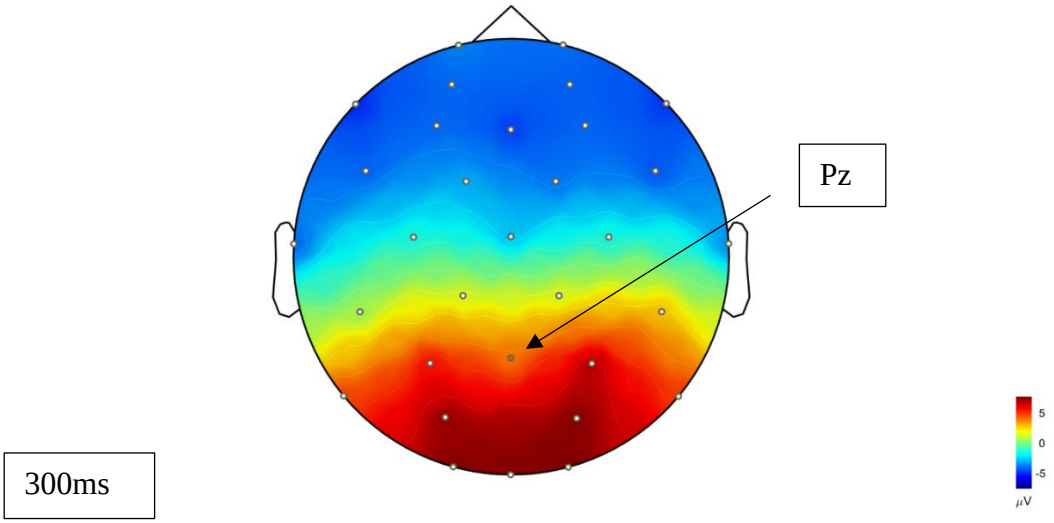


Figure 7.5a: Mean ERPs (+/- SEM) elicited at Pz for both the spaced (green) and massed (red) groups.



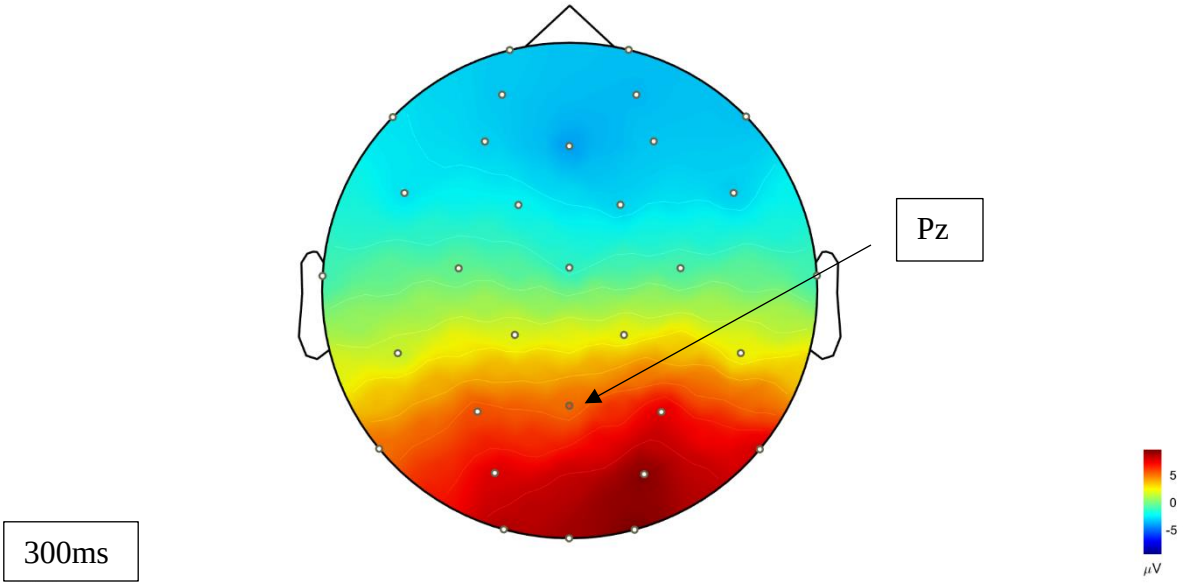


Figure 7.5b: Mean P300 topography for the spaced (top) and massed (bottom) participants.

7.3.2.3 Cz

Correct recall of face-name pairs elicited three major components at the Cz electrode, including an N100 component, followed by a positive deflection, which in turn was followed by a prominent N200 (see Figure 7.6). In addition, spaced-trained participants exhibited an N400 component that is not present in massed-trained participants. Bonferroni corrected t-tests showed that spaced-trained participants (M = -3.34 uV, SD = 0.00000716) elicited a significantly greater N100 component than massed-trained participants (M = -1.81 uV, SD = 0.00000549) (t (40) = -6.0413, $p < 0.01$). Spaced participants (M = -4.4 uV, SD = 0.00000843) also evoked a significantly greater N200 than massed participants (M = -2.18 uV, SD = 0.00000593) (t (40) = -5.008, $p < 0.01$). The N400 component evident in spaced participants (M = -3.08 uV, SD = 0.0000093) is not present in massed-trained participants (t (40) = -6.6064, $p < 0.01$) (see Figure 7.6).

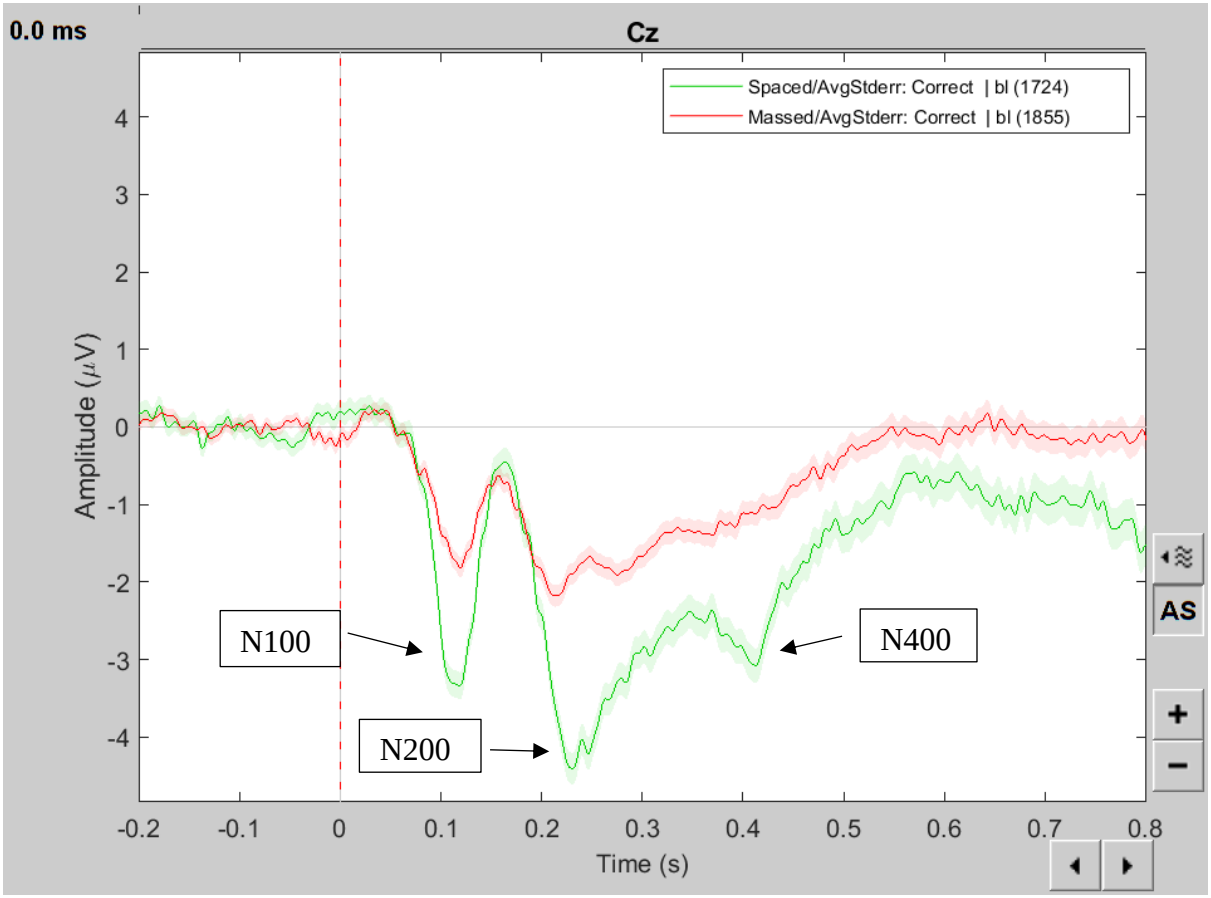
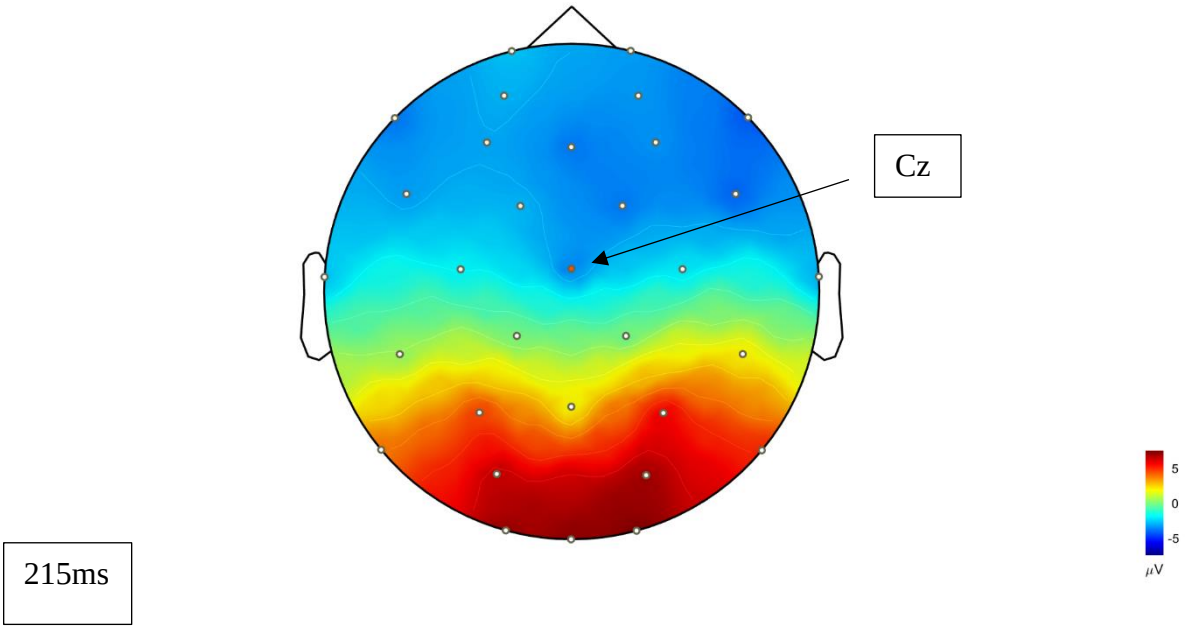


Figure 7.6a: Mean ERPs (+/- SEM) elicited at Cz for both the spaced (green) and massed (red) groups.



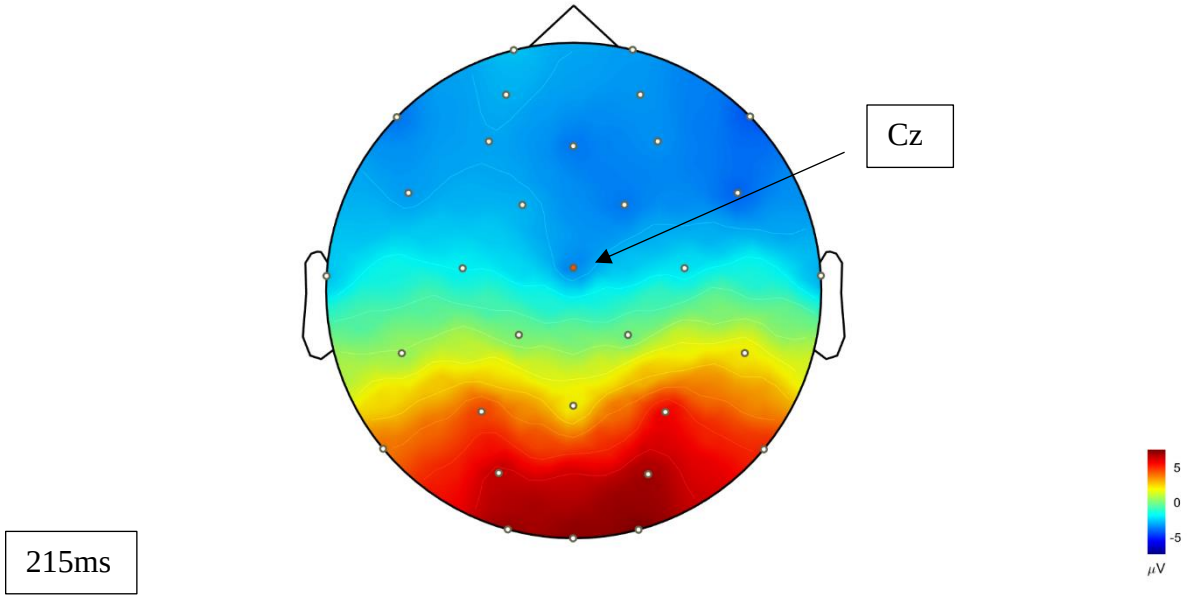
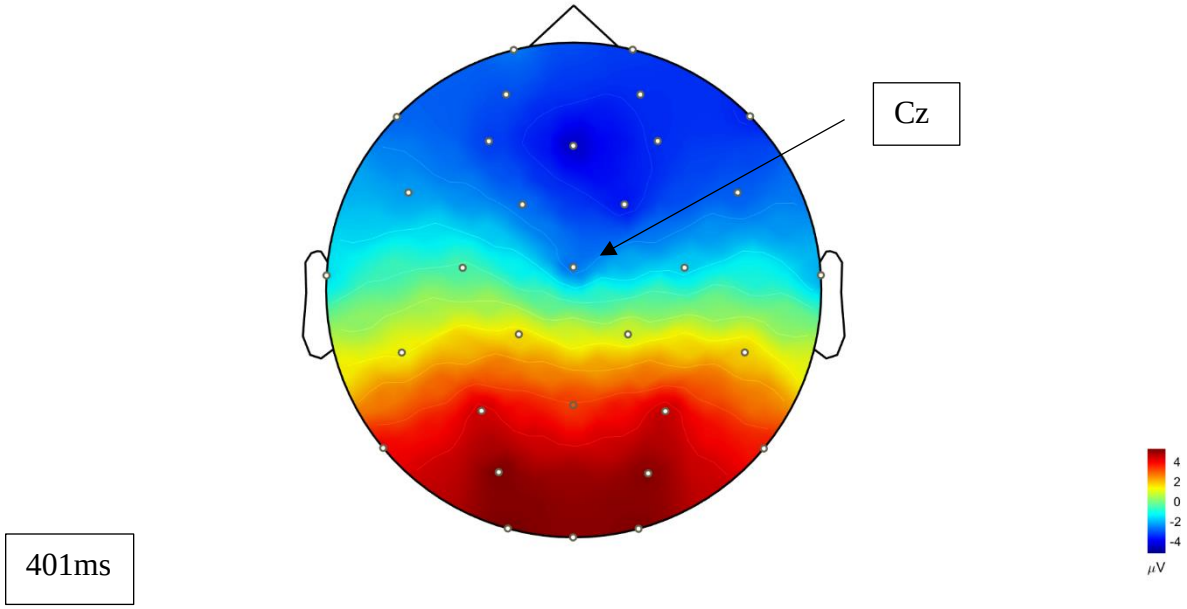


Figure 7.6b: Mean N200 topography for the spaced (top) and massed (bottom) participants.



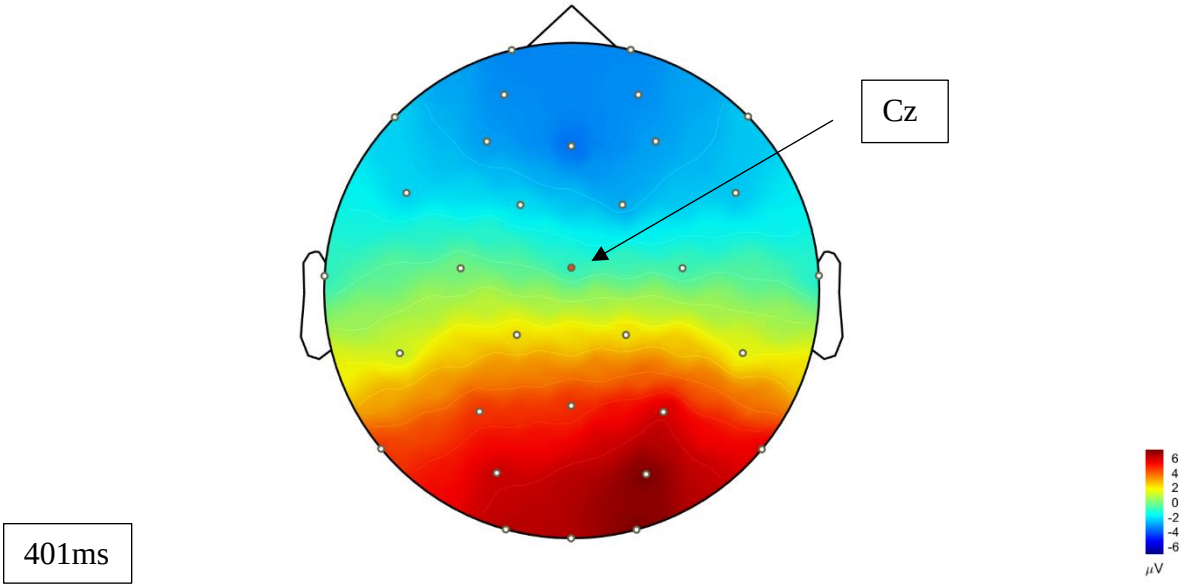


Figure 7.6c: Mean N400 topography for the spaced (top) and massed (bottom) participants.

7.3.2.4 Fz

Correct recall of face-name pairs elicited three major components at the Fz electrode, including an N100 component, followed by a positive deflection, which in turn was followed by a prominent N200 (see Figure 7.7). Bonferroni-corrected t-tests indicated that spaced-trained participants (M = -3.85 uV, SD = 0.0000076) elicited significantly more negative frontal ERPs at about 100 milliseconds than massed-trained participants (M = -2.64 uV, SD = 0.00000725) (t (40) = -4.8933 , $p < 0.01$). In addition, there was a significant difference between the two conditions at the N200, with the spaced group (M = -4.6 uV, SD = 0.00000829) eliciting a significantly more negative response compared to the massed group (M = -3.23 uV, SD = 0.00000794) (t (40) = -4.9844 , $p < 0.01$) post stimulus (see Figure 7.7).

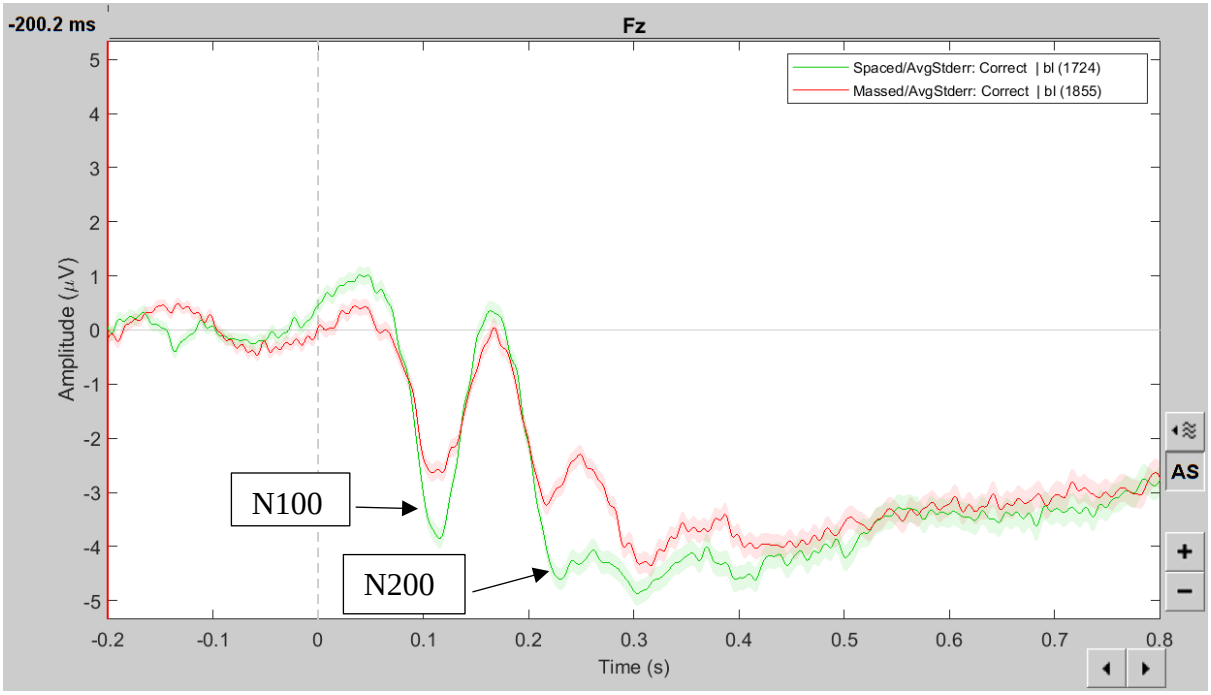
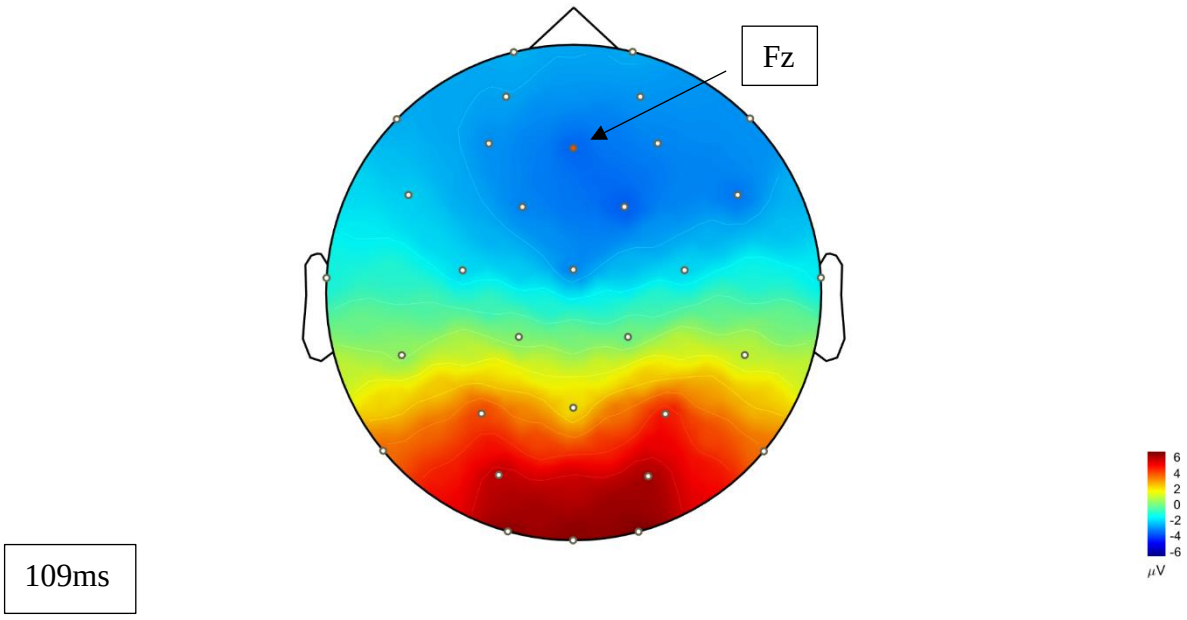


Figure 7.7a: Mean ERPs (+/- SEM) elicited at Fz for both the spaced (green) and massed (red) groups.



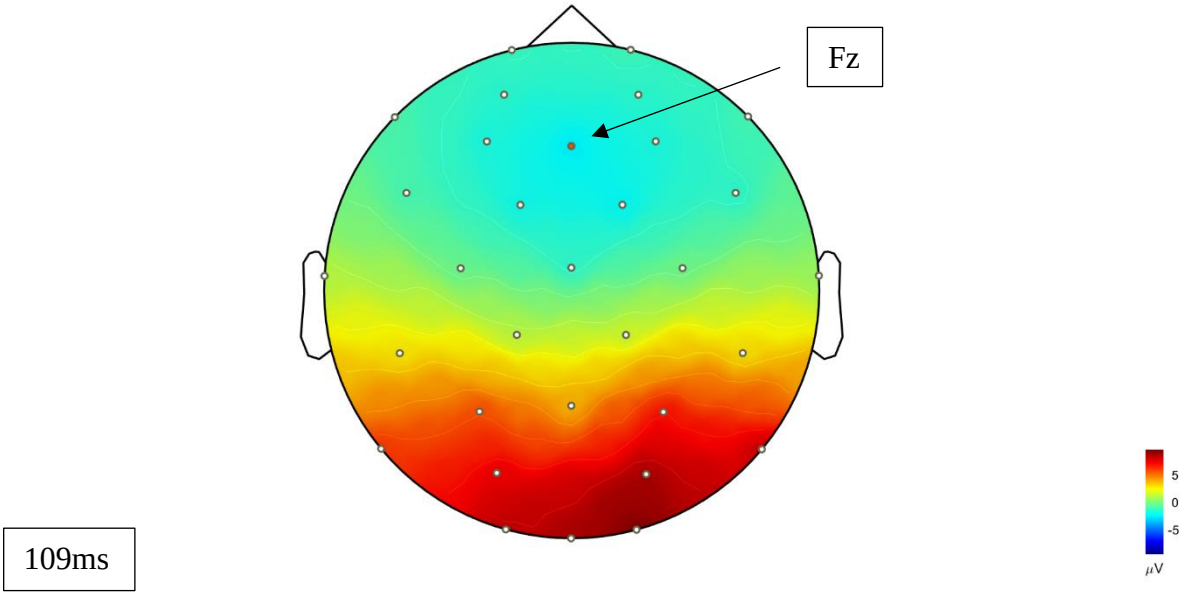


Figure 7.7b: Mean N100 topography for the spaced (top) and massed (bottom) participants.

In sum, participants from the spaced group show greater negativity at Oz and Pz around 100-200 milliseconds post-stimulus. Similarly, spaced-trained participants demonstrate more negativity at Cz and Fz around 100-200 milliseconds post-stimulus. Furthermore, spaced participants exhibit an N400 component at both Cz and Pz that is not present for massed participants.

7.4 Discussion

The results from the encoding phase suggest that all participants learned over the course of the four trials, and that both spaced- and massed-trained participants learned equally well. This is in line with other research which has found no significant difference between spaced- and massed-trained participants during encoding (Simone et al., 2013; Spruit et al., 2014). Previous experiments outlined in this thesis found that massed-trained participants tended to significantly outperform spaced-trained participants during encoding (see Chapters 3 & 4). However, given that the current experiment uses a different version of the Face-Name Pairs Task that requires recognition rather than free recall, it is possible that both groups found this version of the task a little easier and therefore performed equally. Furthermore, it is worth noting that recognition based FNPTs, though relevant to an extent, tend to be less ecologically valid than free recall, given that in most instances of real-world face-name memory, people need to actively retrieve, rather than check, a name (Weinstein et al., 2011). That being said, a number of studies which use the FNPT involve use of prompts to encourage successful retrieval, which is arguably less ecologically valid than recognition (Pfeifer et al., 2017; Whitmore et al., 2022).

Behaviourally, the results from the retrieval phase indicated that spaced participants were able to recall significantly more correct pairs than massed participants. This is in line with our previous experiments, which also found a significant difference between spaced and massed groups when retested at intervals of one month (see Chapters 3 and 4), and existing literature (Vlach, et al., 2008; Goverover, et al., 2009; Benjamin et al., 2010; Kapler, et al., 2015; Breckwoldt, et al., 2016; Wang, et al., 2017; Delaney, et al., 2018). Interestingly, these results are slightly different to those reported in Chapters 5 and 6, despite use of online administration techniques during encoding. This suggests a possible difference between the influence of a spacing effect on recognition and free recall of face-name pairs learned online.

Given that recognition-based tasks are easier (requiring less information in storage compared to recall; Haist et al., 1992), it is possible that spacing is particularly effective here due to previously discussed factors, such as the influence of study-phase retrieval and deficient processing. In particular, massed-trained participants may be especially susceptible to over-confidence when responding, which may in turn affect performance. Tulving (1983) suggested that encoding specificity and, by extension, encoding variability may also play a role, in that successful retrieval is dependent on correctly pairing information available during both encoding and retrieval. Again, because recognition requires less information, this is automatically easier, and therefore successful implementation of encoding variability strategies may allow for more significant spacing. Alternatively, the results here may be attributable to factors such as mixed methods (retrieval occurred in-person, as in Chapters 3 and 4), power (there are significantly less participants in this experiment), and motivation (participants in this experiment received credits in exchange for participation and were therefore more likely to pay attention). Spaced-trained participants exhibited slightly quicker reaction times when correctly responding, implying that they may have been more confident in their responses than massed-trained participants, however this finding was not significant.

A number of expected ERP components were visible for both spaced- and massed-trained participants. For example, both conditions exhibited frontal and central N100 components and parietal and occipital P100 components, which are associated with visual attention processes (Vogel & Luck, 2000; Martinez et al., 2007; Woodman, 2010; Bauer et al., 2020). Spaced participants elicited both frontal and central N100 components of significantly greater negative amplitude than massed participants, which may be indicative of greater visual processing depending on attention paid to particular features of the stimulus (in this case, possibly select facial features) (Martinez et al., 2007; Saavedra & Bougrain, 2012). This may be in line with theories of deficient processing, which suggest that spaced participants tend to

pay more attention to material on subsequent presentations. In contrast, massed participants tend to experience high levels of confidence in their knowledge of the to-be-learned material due to presentations happening in such quick succession, and thus are less likely to engage with the material (see Chapter 1) (Benjamin & Tullis, 2010). This also complements the findings of Callan & Schweighofer (2010) who observed increased frontal activity in spaced-trained participants.

Spaced- and massed-trained participants both exhibited a parietal and occipital P100 component, however this was significantly enhanced in massed participants. The occipital P100 component is associated with visual processing, and in the case of faces, is usually followed by an N170 component (Keufner et al., 2009). Both conditions exhibited the well-known occipital N170 component, followed by the VPP. There was a significant difference between amplitude of this component, with spaced-trained participants eliciting a greater N170 (that is, more negative component), which is interesting as most research suggests that the N170 is indicative of face processing irrespective of memory process (Hammer et al., 2013). Hammer et al. (2013) also noted differences in the N170; they found an increase in amplitude for incorrectly remembered face-name associations and suggested that the enhanced component may be due to greater attention needed when retrieval is difficult. We did not look at ERPs for incorrectly remembered stimuli, but our findings may lend support to this hypothesis, as well as study phase retrieval. Study phase retrieval suggests that material is more difficult to retrieve following longer lags between study sessions, however, when retrieval is successful the memory trace tends be stronger due to the difficulty involved. This theory suggests that spaced-trained participants should perform better than massed-trained participants, but should also find retrieval more difficult due to the gap between study sessions, which appears to be reflected in these results. This finding is interesting as it implies that the

N170 component may indeed be affected by memory processes. Furthermore, massed participants evoked an occipital P200 component of significantly greater amplitude than spaced participants. Posterior P200 components tend to be elicited by distinctive facial characteristics, such as age and race. Of particular relevance to this experiment, occipital P200s tend to be elicited when processing younger faces (Wiese et al., 2008; Ebner et al., 2011). The faces used in this experiment all belonged to young men and women. The increased amplitude for massed-trained participants may be indicative of greater visual attention due to a lack of familiarity compared to spaced-trained participants.

Both conditions also exhibited frontal and central N200 components, which are also thought to be associated with perception and attention processes (Patel & Azzam, 2005). Patel & Azzam (2005) suggest that the N200 component may be elicited prior to motor responses and thus may be associated with identification (or in this case, recognition) of a stimulus. Karanasiou et al. (2010) suggest that the N200 component may be representative of a reorientation of attention following initial stimulus presentation and that larger amplitudes may be indicative of participant's knowledge of correct versus incorrect responding. Spaced participants exhibited a significantly stronger N200 component compared to massed participants, which may be indicative of superior recognition. Conversely, massed-trained participants exhibited an enhanced parietal P200 component compared to spaced-trained participants. The P200 component is also related to attention, and there is some research to indicate that it may be indicative of familiarity, particularly in relation to face processing (Caharel et al., 2002). Caharel et al. (2002) observed that posterior P200 components tended to be larger in amplitude when faces were less or unfamiliar. Given that the massed-trained participants performed more poorly overall, it is possible that this P200 component was evoked by lack of familiarity with the stimuli.

Both spaced and massed participants exhibited parietal P300 components. The P300 component is generally associated with recognition, attention, speed of processing, and memory processes, and may be indicative of implementation of working memory (Patel & Azzam, 2005; Zhong et al., 2019). In the context of the current experiment, it is likely that both spaced- and massed-trained participants were engaged in recognising the stimulus. Massed-trained participants elicited a P300 component of significantly greater amplitude which may be indicative of working memory (Patel & Azam, 2005). When processing faces, it has been shown that P300 amplitude is correlated with working memory load. In particular, a decrease in amplitude is indicative of increased working memory (Morgan et al., 2008). Again, this may be evidence of spaced-trained participants engaging in a deeper level of processing. Interestingly, there was also a significant difference in onset and duration of a subsequent LPC. Weston (2018) found an LPC that peaked significantly later for spaced-trained participants during encoding. It was suggested that this is evidence of study phase retrieval, the idea that material presented following greater lags between presentations is harder to retrieve (see Chapter 1). It is possible that the delayed LPC evident for spaced-trained participants in the current experiment is also indicative of study phase retrieval, while the increased latency elicited by massed-trained participants may be due to longer engagement and maintenance of working memory due to less familiarity and less in-depth processing (Kim et al., 2001).

A central and parietal N400 component was also elicited. The N400 component is thought to be linked with comprehension of action events and linguistic processing (Amoruso et al., 2013). It is also associated with face processing (Caldara et al., 2004). The N400 elicited at central and parietal regions is thought to be stronger for familiar versus unfamiliar stimuli, and is only evoked by known stimuli (Schweinberger et al., 1995; Guillem et al., 2001). Given that both N400 components appear only for spaced-trained participants, it might be reasonable

to conclude that spaced-trained participants were more familiar with and confident in their identification of correct face-name pairs, thus evoking the N400.

In sum, this experiment has demonstrated that there are significant differences between ERP components elicited by spaced- versus massed-trained individuals when recognising face-name associations. In particular, there is evidence to support deficient processing and study phase retrieval as explanations for the superiority of spacing. Spaced-trained participants elicit a number of enhanced ERP components indicative of better recognition and processing compared to massed-trained participants. Conversely, massed participants demonstrate enhanced posterior P100, P200, and P300 components, as well as a longer and earlier onset parietal LPC, which may be indicative of a lack of familiarity with the presented stimuli and a shallower level of processing. Furthermore, spaced-trained participants elicited central and parietal N400 components that were not present in massed data. These components suggest that spaced-trained participants were generally more familiar with the face-name associations than massed-trained stimuli.

Chapter 8

General discussion

The main goal of this thesis was to examine the impact of distributed practice on associative memory, and determine how various factors (including time, age, context, and sleep) might play a role. In addition, we examined the neural correlates of spacing during recall to help determine the underlying mechanism of spacing. The experiments outlined within this thesis established the existence of a strong spacing effect when consolidating face-name associations at longer time intervals, and explored the factors that may influence this effect, such as age, medium, and neural underpinnings. Furthermore, this thesis explored the effect of sleep on associative memory and general cognition, aiming to further elaborate on the exact role of sleep with regard to cognitive processes. This thesis has contributed to existing literature in a number of ways. These are outlined in more detail in the next section.

8.1 Overview of findings

In the first experimental chapter (**Chapter 3**) we aimed to (i) establish whether a spacing effect could be observed using an associative learning Face-Name Pairs task, and (ii) determine whether the spacing effect could be observed across multiple retrieval periods. While the literature has shown that the spacing effect is a robust phenomenon, it is not widely used in practice (Dempster, 1988; Murphy & Pavlik Jr, 2018; Walsh et al., 2018; Kim et al., 2019). The Face-Name Pairs task, in particular, has been seldom used as a means of testing spacing, despite it being more ecologically valid (Zeineh et al., 2003; Hampstead et al., 2008; Irish et al., 2011), hippocampal-dependent (Zeineh et al., 2003; Dickerson & Sperling, 2008; Nestor et al., 2008; Smith et al., 2014) and a well-established associative learning task (Zeineh et al., 2003). Furthermore, it is not clear whether the spacing effect is observed at both short and long term recall intervals when learning more abstract concepts. There are ample studies demonstrating the benefits of spacing at shorter intervals of up to one week or ten days (Vlach et al., 2008; Kapler et al., 2015; Delaney et al., 2018). There are less studies which

demonstrate the benefits of spacing at longer retrieval intervals, however those that do examine long-term retention, (Price Kerfoot et al., 2010; Simanton & Hansen, 2012) tend to focus on learning of nonverbal sequences, names of objects, and/or word pairs, and medical knowledge. In our experiment we found that distributed practice was more advantageous than massed learning when attempting to retain face-name associations, but only at longer intervals of one month. There was no difference between the performance of spaced- and massed-trained participants at shorter intervals of twenty-four hours or one week. Furthermore, we showed a particular pattern of forgetting, whereby those in the massed group tended to forget quickly after one week, and exhibited low levels of recall at one month, whereas memory of those in the spaced group tended to be preserved over time in comparison. This was interesting, given that massed participants learned significantly more during encoding. Overall, these findings are important and add to the literature as they show the benefits of spacing when learning abstract concepts such as face-name associations, particularly at longer intervals of one month. Furthermore, though there was no significant difference in performance of the spaced and massed participants at shorter intervals of twenty-four hours and one week, these results demonstrate that distributed practice encourages better overall retention, and less forgetting.

Having established a strong spacing effect, particularly at longer retrieval intervals, we then wanted to examine whether the effects held true for older as well as younger adults. This was the primary aim of **Chapter 4**. Most of the literature has examined the spacing effect in children and young adults (students, mostly), with other populations being overlooked. The literature on this does suggest that older adults should benefit from spacing, but not to the extent that younger adults do (Benjamin & Craik, 2001; Hawley, Cherry, Boudreaux, & Jackson, 2008; Logan & Balota, 2008; Kornell et al., 2010; Maddox, Balota et al., 2011; Wahlheim et al., 2011; Jackson et al., 2012; Simoneet al., 2013; Bercovitz et al., 2017). In our

experiment, we first replicated the spacing effect of the previous chapter with younger adults but importantly we also observed the effects in older adults too. In general, older adults were much poorer at the task but recall in the spaced group was significantly better than recall in the massed group at the one-month retrieval interval. Again, no difference was found at shorter retrieval intervals of twenty-four hours. Interestingly, spaced-trained participants exhibited similar patterns of forgetting at twenty-four hours and one month, regardless of age, suggesting that memory failures experienced by cognitively healthy older adults may lie in the encoding rather than the retrieval of information. These results have important implications, demonstrating that (i) spacing is a more general phenomenon that can be observed across the age spectrum, at least in older and younger adults and (ii) older adults exhibit patterns of forgetting very similar to younger adults, suggesting that poorer performance may be due to lapses during encoding rather than retrieval of information. As older adults tend to have poorer recall (as observed here), with some going on to develop age-related diseases, being able to enhance long-term memory is critical. These results may have implications for improving general memory in cognitively healthy older adults.

COVID-19 brought about a lot of disruption, particularly with experimental research and we were unable to further explore the spacing effect in a laboratory setting. However, it did allow us the opportunity to examine the robustness of the effect and determine whether we could replicate the laboratory findings via an online medium. This is important, given the widespread implications of the pandemic for both research and interventions. In **Chapter 5** we compared the effects of spacing when the Face-Name Pairs task was administered online versus in-person. While the laboratory provides much experimental control, the online medium allowed us to collect many more participants. Unfortunately we were unable to fully replicate our previous findings. While we found that the spaced group did recall more than the massed group overall, it wasn't specific to the long-term retrieval interval that we observed

previously. We did note a number of factors that could have led to this result and have discussed these in detail in the chapter. We further noted that both encoding and recall generally seemed to be better when learning occurred online rather than in-person. The findings from this chapter are important as they (i) serve as a bit of a caution to online experimentation, implying that significant consideration is needed when adapting experiments for online use and (ii) question the strength of the spacing phenomenon when learning abstract concepts, given that this experiment was significantly more powered than previous versions, and many of the previously cited studies.

We initially hoped to examine whether sleep was the an important factor in the spacing effect and to examine the idea that distributed learning may attenuate the poor recall often observed in those classified as poor sleepers (as determined by the well-established Sleep Condition Indicator). However, as we did not find a strong spacing effect using the online methods, **Chapter 6** instead aimed to examine how sleep (i) generally impacts on cognition (using different types of tasks) and (ii) impacts on general psychological measures. Given that consolidation involves the hippocampus (McClelland & Goddard, 1996; Dudai & Morris, 2013; Squire et al, 2015), with the hippocamps and sleep largely intertwined (Vecsey et al., 2009; Murata et al., 2018), we had hypothesised that those classified as poor sleepers would perform much worse in the Face-Name Pairs task, especially at longer recall intervals, as the Face-Name Pairs task is generally considered a hippocampal-dependent task. Similarly, we hypothesised that poor sleep would also affect performance on the Tower of Hanoi task, though not to the same extent as this is a more pre-frontally driven planning task. However, we did not find this to be the case as participants performed equally well on both tasks regardless of sleep quality. However, poor sleepers were significantly more likely to report subjective cognitive failures, as well as experiencing feelings of depression, anxiety, stress, and alcohol use disorders. Gender and age also played a critical role in this. These results are

important as they suggest that (i) the effects of sleep on objective cognitive tasks may be overexaggerated in the literature, however (ii) sleep quality does impact subjective measures of cognition and other psychological measures too. Furthermore, (iii) we observed a number of gender and age effects that contribute to the current literature.

Having explored some of the factors that may influence spacing, we then wanted to investigate the neural correlates of spacing. This was the main goal of **Chapter 7**. Most of the studies examining the neural underpinnings of spacing use fMRI and PET, and implicate the involvement of a number of cortical regions across subsequent study sessions, as well as providing support for theories of deficient processing (Callan & Schweighofer, 2010; Gerbier & Toppino, 2015; Van Hoof et al., 2021). The use of temporal techniques such as EEG are less common, however the literature that does exist provides evidence of both deficient processing and study-phase retrieval (Mollison & Curran, 2015; Weston, 2018). In this experiment, we further replicated the findings of Chapters 3 and 4 but this time using a recognition version of the Face-Name Pairs task rather than the recall version - spaced-trained participants significantly outperformed massed-trained participants at intervals of one month. Furthermore, there were marked differences between ERP components produced by spaced versus massed participants. Spaced-trained participants elicited a number of enhanced ERP components, including N400 components that were not present in their massed-trained peers, indicative of increased recognition and visual processing and attention. Furthermore, massed-trained participants evoked an earlier onset LPC of greater latency than spaced-trained participants, which may be indicative of a lack of familiarity with the face-name associations and a shallower level of processing. These differences contribute to existing literature in that they demonstrate (i) separate neural networks when recognising associative stimuli following different training schedules and (ii) may provide evidence for theories such as study-phase retrieval and deficient processing.

8.2 How our results inform the various theories of spacing

There are three particularly prevalent theories posed in the literature to explain the spacing effect. These theories include encoding variability, deficient processing, and study phase retrieval (see Chapter 1) (Benjamin & Tullis, 2010; Delaney et al., 2010). The results of the experiments detailed within this thesis provide evidence for all three theories, to varying degrees, and will be discussed in detail.

As outlined in Chapters 3 and 4, massed-trained participants performed significantly better than spaced-trained participants during encoding. This apparently enhanced encoding ability did not translate to long-term retrieval, however. The **encoding specificity principle** suggests that individuals remember better when contextual cues available during recall match those available during encoding (Tulving & Thompson, 1973). During implementation of massed training schedules, participants are privy to less contextual cues, however due to the short lag between study sessions, the contextual cues that are available will be more strongly associated with to-be-learned material due to repeated exposure over a short timeframe. Conversely, during implementation of spaced training schedules, participants are exposed to a greater array of contextual cues. However, these cues tend to be more weakly associated with to-be-learned material due to less exposure in general, and greater lags between exposure. As a result, it is reasonable to expect that, in the short-term (such as, on subsequent encoding trials) massed participants would perform better due to stronger memory traces prompted by contextual cues. As time passes, however, it becomes increasingly less likely that the test environment will exactly mimic the study environment, both in terms of physical features and general context (such as, time of day, mood of participant, etcetera). Therefore, spaced participants are inclined to perform better on a retest, particularly following longer time intervals, due to ability to access a greater number of retrieval routes prompted by contextual cues, that is, *encoding variability*. Encoding variability also aligns nicely with theories of

long-term memory such as multiple trace theory, which suggests that each time a memory is reactivated, a new memory trace is created an consolidated (Nadel & Moscovitch, 1997; Sekeres et al., 2018). Therefore, with subsequent successful reactivations of a given memory trace, a number of new memory traces are formed, thus creating a number of possible retrieval routes. The more retrieval routes a person has access to, the more likely they are to correctly retrieve information, regardless of circumstances. Furthermore, encoding variability could explain, to an extent, why younger adults significantly outperform older adults in the experiment disclosed in Chapter 4. Older adults have been shown to struggle when faced with context-specific cues, and thus are unlikely to benefit from encoding variability when compared to younger adults (Rabinowitz et al. 1982; Smith et al. 1998).

However, encoding variability theory is arguably the most difficult of the three to test formally, and this thesis did not include specific questions or controls in relation to this theory. Though some of the findings reported could potentially be explained in terms of encoding variability, if it is taken as the only explanation of the spacing effect, this would imply that older adults should not benefit from spacing at all, which is clearly not the case. When taken in tandem with deficient processing and study-phase retrieval, however, this idea becomes more plausible. **Deficient processing** refers to the likelihood that spaced-trained participants will engage in deeper processing and encoding than massed-trained individuals, thus allowing for a greater long-term memory trace (Hintzman, 1974; Limons & Shea, 1988; Benjamin & Tullis, 2010; Delaney et al., 2010; Maddox, 2016). For example, Callan and Schweighofer (2010) found activation in the left frontal operculum of spaced-trained participants that was not present in massed-trained participants, while Li & Yang (2020) noted significantly greater hippocampal activity in spaced-trained participants compared to massed-trained participants. Though most studies in the literature investigate the neural underpinnings of deficient processing in younger adults, it is possible that the same thing occurs in older adults.

Additionally, it is likely that massed-trained older adults also engage in controlled deficient processing, that is, an intentional decrease in processing and time devoted to study compared to spaced-trained participants. This may be due to a heightened sense of familiarity with to-be-studied material. Due to the short lags between study sessions, massed-trained participants tend to feel more confident about the to-be-learned material, and as a result may intentionally engage in lower levels of processing.

Moreover, it is likely that older adults perform significantly poorer than younger adults due to over-activation or compensation-related brain activity (Davis et al., 2007). In other words, older adults may benefit from spacing due to implementation of a combination of **deficient processing** and **study-phase retrieval** (the likelihood of subsequent study sessions separated by time prompting the retrieval of initial study sessions, thus strengthening a memory through constant retrieval that is not present in massed training schedules) (Thios & D'Agostino, 1976; Benjamin & Tullis, 2010; Maddox, 2016). Study-phase retrieval has been demonstrated to be an involuntary process which occurs in older adults too (McCormack, 1982; Taylor, 2018). Similarly, both automatic and controlled deficient processing may occur in older adults, though further research examining the neural correlates of spacing in older adults is needed to confirm this, thus explaining why spacing perseveres with old age This effect is, however, reduced when compared to younger adults due to a number of possible factors. Younger adults are more likely to be able to engage with and form stronger memory traces prompted by contextual cues; in contrast, older adults are more likely to experience over-activation due to natural neural atrophy with age, and are also more susceptible to interference and hyper-binding as a result of this atrophy (Campbell et al., 2010; Powell et al., 2018). Subsequently, older adults cannot distinguish between relevant and irrelevant context cues the way younger adults can, and may form associations between target information and distractors leading to more errors. Furthermore, automatic deficient processing may be

inhibited to an extent in older adults by phenomena such as the Posterior-Anterior Shift in Ageing (PASA) (Davis et al., 2007). It is possible, for example, that increased frontal activation such as that found by Callan & Schweighofer (2010) is present in older adults, as compensatory frontal activity often occurs as a result of ageing. Conversely, increased temporal activity, such as that noted by Li & Yang (2020), may be reduced or not present at all in older adults due to potential atrophy. This atrophy may also explain why older participants learn less in general than younger adults. If neural networks specific to recognition and recall of face-name associations have declined in older adults, it is reasonable to expect poorer learning and subsequent recall.

There is significant evidence from Chapter 7 to support both deficient processing and study phase retrieval in younger participants at a neural level. ERP components taken from both spaced- and massed-trained participants were significantly different in amplitude. Spaced-trained participants evoked a number of enhanced components, including frontal and central N100 and N200s and an occipital N170 and P200. Additionally, spaced participants elicited central and parietal N400s that were not present in massed participants. All of these components are indicative of enhanced recognition and familiarity with the stimuli as well as enhanced processing, and may, in turn, be representative of automatic deficient processing on the part of massed-trained participants. Massed-trained participants exhibited enhanced parietal P200 and P300 components, as well as enhanced occipital P100 and P200 components. These components may be indicative of a lack of familiarity with the presented stimuli and a shallower level of processing. In particular, the enhanced P300 component is associated with a decrease in working memory load when processing faces, suggesting that massed participants did not engage in the same level of processing as spaced participants (Morgan et al., 2008). Furthermore, massed-trained participants evoked a parietal LPC of greater latency which peaked earlier than in spaced-trained participants. This may be indicative of longer

engagement and maintenance of working memory in massed-trained participants, as they were less familiar with the presented stimuli. The later peak in LPC exhibited by spaced-trained participants immediately following the central and parietal N400s (thought to be indicative of recognition of facial stimuli) may be representative of study-phase retrieval. That is, due to longer lags between study sessions, material is harder to retrieve (Kim et al., 2001; Weston, 2018). This could also align nicely with multiple trace theory or reconsolidation, which aims to address some of the failings of multiple trace theory. According to reconsolidation, memories become unstable upon retrieval and need to be correctly reconsolidated in order for successful long-term retention. Naturally, successful retrieval is more difficult when there are long gaps between study sessions, but successful retrieval and reconsolidation under difficult circumstances allow for stronger memory traces (Smith & Scarf, 2017). Furthermore, this should also allow for enhanced systems consolidation (greater generalisation of memories throughout the cortex) which provides a greater array of memory traces, in line with multiple trace theory (Lehmann et al., 2009). The initial P300 may represent recognition and engagement of working memory, followed by the N400 component, indicative of spaced-trained participants recognising familiar facial stimuli, and finally the later peak in the LPC. Conversely, massed-trained participants do not demonstrate posterior N400 components, suggesting that the stimuli are less familiar to them. As a result, the earlier peak in LPC may be indicative of active working memory without the same level of recognition, processing, or certainty of the presented stimuli.

Reaping the benefits of spacing appears to be dependent on a number of factors, however. Experiments detailed in Chapter 5 failed to replicate the findings of previous chapters, that is, though there was evidence of a slight, overall spacing effect, spaced-trained participants did not perform significantly better than massed-trained participants at longer intervals of one month. There were some key differences in methodology between the

experiments outlined in Chapter 5 versus previous chapters, which may explain the change in results. Due to the COVID-19 pandemic, experiments could no longer be carried out face-to-face. As a result, the Face-Name Pairs task was administered online via Qualtrics. Though efforts were made to keep the online version as similar as possible to the in-person version of the task, there were a few key differences, namely the lack of experimenter presence, the ability of participants to complete each study session in any environment they desired, no cap on response time, and use of the "force response" function. Though these differences would lend themselves to massed participants performing better overall, the same is also true of spaced participants. Furthermore, research indicates that a spacing effect should be visible even when study sessions occur online, and may actually be enhanced (Fulton et al., 2013; Marzouk et al., 2016; Carvalho et al., 2020; Jost et al., 2021). So given that both groups experienced the same advantages, why was the spacing effect diminished? Of course, due to the online platform, the experiment outlined in Chapter 5 had a significantly higher sample size than those reported in Chapters 3, 4, and 7, and as a result was significantly more powered. It is possible that the spacing effect is not as robust or as generalisable as literature would suggest, occurring as a result of small sample sizes and other potential p-hacking measures. Given it's prevalence, however, this is probably unlikely. It is difficult to say with certainty, but it seems possible that a combination of the advantages presented in the online experiment and a more relaxed test environment (familiar, at home, no experimenter presence) may have contributed to a reduction in behaviours associated with spacing, while benefiting massed participants in such a way as to close the gap between the two. For example, encoding variability may have been diminished if spaced-trained participants completed study sessions in vastly different environments across the four days, thus making it too difficult to form meaningful associations with context cues. Similarly, deficient processing and study-phase retrieval may also have been diminished if spaced participants were not paying sufficient

attention to the task at hand, thus reducing the spacing effect significantly. In other words, it seems that consistency and attention may be key factors in determining the success of distributed practice (Versteijlen et al., 2017).

In sum, the results of experiments detailed within this thesis seem to support the existence of a **hybrid model** which encompasses all three theories proposed to explain spacing. In particular, a combination of deficient processing and study-phase retrieval may explain the occurrence of the spacing effect. Spaced-trained participants are inclined to feel less familiar with to-be-studied material than massed-trained participants and therefore, may intentionally or automatically devote more attention to study on subsequent sessions. Additionally, due to the longer lags between study sessions, spaced-trained participants have greater difficulty retrieving information and therefore successful retrieval encourages the development of stronger memory traces. Depending on context, encoding variability and specificity may also play a role. In the short term, massed-trained participants may perform better due to forming stronger memory traces dependent on contextual cues, particularly if the test environment mimics the study environment. In the long-term, however, or in cases where the test environment differs from the study environment, spaced-trained participants may be further buoyed by having access to a greater number of retrieval routes dependent on contextual cues. Successful spacing is, however, dependent on consistency and attention; an individual needs to be actively engaged with material across the distributed study sessions in order to reap the benefits.

8.3 The role of sleep

There is significant research to suggest that quality and duration of sleep may correlate directly with memory performance and overall cognitive ability (Ellenbogen et al., 2007; Gillen-O'Neel et al., 2013; Rieth et al., 2010; Maurer et al., 2015; Huang et al., 2016; Chambers,

2017; Wilckens et al., 2018; Kapsi et al., 2020). The results reported in Chapter 7 do not support this. Good sleepers, as judged by the SCI, did not perform any better than poor sleepers on either the Face-Name Pairs task or the Tower of Hanoi task. These results are interesting in light of existing literature, and provide much food for thought. The SCI is considered a reliable and valid measure of insomnia, included on the DSM-5 as a diagnostic measure, and contains a number of questions pertaining to sleep duration and quality (Espie et al., 2014; Wong et al., 2017; Ballesio et al., 2018; Espie et al., 2018). As such, it is reasonable to expect that the SCI gives a valid measure of insomnia, and can be used as a decent measure of poor sleep quality and duration. However, with self-report measures, there is always the chance of exaggeration or misinformation on the part of participants. Furthermore, good sleepers significantly outnumbered poor sleepers in this study. It is possible that with a more representative sample size, the results might have been different. That being said, a number of studies suggest that the effects of sleep on memory and cognition are non-existent, greatly exaggerated, or in some cases eliminated by stimulants such as caffeine or particular medications (Killgore et al., 2009; Rieth et al., 2010; Ozyigit et al., 2020). Though certain medications were included as part of the exclusion criteria, caffeine was not controlled for in this study. Much of the literature acknowledges that the effects of sleep may be dependent on particular factors, such as type of sleep, type of memory, and type of task (Plihal & Born, 1997; Smith & Rose, 2000; Siegel, 2001; Chambers, 2017). It is possible, in this instance, that sleep quality and duration as assessed by the SCI did not actually effect performance on the Face-Name Pairs or Tower of Hanoi tasks.

8.3.1 The effect of sleep and psychological factors on consolidation

These findings go against the literature, which suggests that both the Face-Name Pairs task and the Tower of Hanoi tasks should be affected by poor sleep (Ashworth et al., 2013; Nielsen

et al., 2014; Maurer et al., 2015; Schiff & Vakil, 2015; Vermeulen et al., 2019; Whitmore et al., 2022). In particular, Walker (2009) suggested that sleep may be of importance when forming associations between concepts and integrating memories. This, in conjunction with the knowledge that poor sleep can negatively impact the hippocampus (Vecsey et al., 2009; Murata et al., 2018), implies that sleep should be important for systems consolidation, and other hippocampal dependent functions, including those necessary for successful recall of face-name associations in particular. Furthermore, sleep ties in with many of the aforementioned theories posed to explain spacing. At the very least, a poor night's sleep could result in low mood and heightened anxiety (as evidenced by our own study), which could contribute to encoding variability theory. Similarly, poor mood as a result of a bad night's sleep may contribute to both automatic and controlled deficient processing. Other research suggests that memories are reactivated during sleep and, as a result, a type of reconsolidation occurs during sleep which is similar to, but not exactly the same as, wakeful consolidation (Smith & Scarf, 2017). This memory reactivation during sleep may mimic, and even contribute to, study-phase retrieval in that reactivation and retrieval of memory tends to strengthen that memory trace, particularly under circumstances where retrieval is difficult. If this hypothesis is correct, it implies that our results do not give a true reflection of what is happening, either because poor sleepers are somewhat underrepresented in this sample, because the SCI does not in fact give an adequate indication of sleep quality, or perhaps because the type of sleep necessary for enhanced consolidation of face-name associations did not occur. This last suggestion seems unlikely, however, given that there is significant evidence to suggest that our learning experiences influence type of sleep (Smith & Scarf, 2017).

Most interestingly, although there was no difference between the performance of good versus poor sleepers on objective measures of cognition, good sleepers significantly

outperformed poor sleepers on the CFQ. Poor sleepers also received higher depression, anxiety, and stress scores, and were more likely to report alcohol use disorders, which is in line with existing literature (Simpson et al., 2005; Willert et al., 2005; Sullivan & Payne, 2007; Dalgaard et al., 2014; Xanidis & Brignell, 2016; Nair et al., 2017; Dzubur et al., 2020; Hong et al., 2020). In this context, experience of cognitive failures appears to be mediated by depressive and anxious tendencies, as well as alcohol abuse. Although sleep quality and duration had no effect on objective measures of cognition, it severely impacted self-report measures of cognition and psychological measures. Sleep is considered a mediating variable that may explain the relationship between other variables. For example, poor sleep, depressive and anxious symptoms, and substance abuse disorders often go hand-in-hand, with one variable impacting another (Palmer & Alfano, 2017; Vandekerckhove & Wang, 2018; Goodhines et al., 2019; Koob & Colrain, 2020). A stressed individual may self-medicate with alcohol in an attempt to cope with anxiety; this over-reliance on alcohol may cause insomnia, which in turn heightens feelings of anxiety. In other words, any negative effects attributed to sleep are unlikely to be caused by sleep quality and duration alone, but rather a combination of factors. In this instance, it is likely that poor sleepers (as indicated by SCI scores) are more inclined to exhibit depressive and anxious symptoms, and to experience alcohol use disorders. Many of the items on the CFQ are significantly correlated with symptoms of both depressive disorders and insomnia (Merckelbach et al., 1996; Wilkerson et al., 2012). This, in conjunction with the self-report nature of the CFQ and battery of psychological measures, supports a correlation between scores. Recent research suggests that depressive and anxious symptoms do not themselves affect working memory and executive function in young adults, however, they can affect elements of autobiographical memory and memory for affective images (Fishman & Ashbaugh, 2021). These findings imply that mild-to-moderate symptoms do not directly cause deficits in cognition, depending on task. Rather, deficits in cognition

that coincide with these symptoms may be attributable to other, mediating variables such as sleep. In the context of the experiment outlined in Chapter 6, this may lend support to the notion that the effect of sleep on cognition is dependent on specific factors, or possibly even overexaggerated in the literature.

8.3.2 Effects of gender and age

Some of the variables included in Chapter 6 also exhibited gender and age differences. Literature regarding gender differences on objective measures of cognition, such as the Face-Name Pairs task and the Tower of Hanoi tend to be conflicting (Leon-Carrion et al., 1991; Rhee et al., 1997; Ronnlund et al., 2001; Safri et al., 2018; Demir & Oksuz, 2021). Given that there are significantly more female than male participants in the current study, it is probably not unreasonable to expect to see females performing better on cognitive tasks. There are also mixed findings in the literature with regard to gender differences in CFQ score, (Bridger et al., 2013; Payne & Schnapp, 2014; Hadlington, 2015). Given the significant, positive correlation between CFQ and DASS-21 and GHQ-12 scores, and that women were more likely to score highly on the DASS-21 and GHQ-12, it is possible that the gender difference in the current sample is due to a significant number of female participants experiencing feelings of depression and anxiety, which in turn heightened their probability of experiencing and reporting cognitive failures.

Performance on tasks such as the Tower of Hanoi and questionnaires such as the CFQ declines with age (Ronnlund, et al., 2001; Rast et al., 2009; Philips et al., 2021), however, older participants received better scores in this experiment. Older participants were also significantly less likely to report feelings of anxiety and depression or alcohol use disorders. It should be noted that most older participants in this study were actually middle-aged, and significantly outnumbered by younger adults in their mid-twenties. These findings are

interesting, nonetheless. Literature suggests that older adults are indeed less likely to report feelings of anxiety and depression (Wood et al., 2010; Lee et al., 2015; Nagasu et al., 2019; Kolakowsky-Hayner et al., 2021). Given that our results imply a mediating effect of depression and anxiety on CFQ scores, it is possible that older participants received better scores as a result of improved mental health. It is also possible that older participants in the current study, aware of the stigma surrounding cognitive failures in ageing adults, underplayed or misreported certain behaviours, leading to better CFQ scores than younger participants.

In this context, gender and age differences might further explain the unexpected cognitive results of these experiments. According to literature, young women tend to exhibit significantly better sleep quality and duration compared to young men (Lindberg et al., 1997; Krishnan & Collop, 2006; Markovic et al., 2020). Though there was no significant difference between male and female SCI scores in this study, again, this may be due to the increased number of female participants. Additionally, given that there are significantly more females than males in this study, perhaps sleep-related effects on cognition were simply not visible in the current sample. Similarly, sleep quality and duration tend to decrease with age (Rediehs et al., 1990; Li et al., 2021), however, as previously mentioned, the older adults in this sample are not elderly, rather they are middle-aged, and also underrepresented. In other words, it is probable that most participants fit gender and age criteria that allow for better sleep quality. This is reflected in our SCI results, which indicate that poor sleepers were underrepresented in this sample. With regard to spacing specifically, the gender and age differences observed here would support a diminished effect. Given that the sample consisted mainly of young women, and in this case, young women were significantly more likely to report feelings of anxiety, depression, and stress, as well as subjective experiences of cognitive failures (which may indicate a lack of confidence in their own abilities), it is not necessarily surprising that the spacing effect was greatly reduced compared to other experiments. Fluctuating or low

mood in this instance may contribute to theories of encoding variability. As previously discussed, encoding variability can be a hindrance or a help to learning, depending on circumstance. In this instance, it is possible that low mood made processing of face-name associations difficult, given that the faces all wore happy, smiling expressions (research shows that individuals are better able to process images that fit their own emotional state (Fishman & Ashbaugh, 2021)). Furthermore, fluctuating mood could have led to very weak contextual memory traces on the part of spaced-trained participants, thus making recall more difficult. Additionally, such experiences may contribute to both controlled and automatic deficient processing. Controlled (or intentional) deficient processing may occur due to a lack of motivation, while automatic deficient processing may occur due to structural changes in the brain caused by depressive and anxious symptoms (Sheline et al., 2002; Liu et al., 2017). Of particular relevance to the processing of face-name pairs, depressive symptoms are known to negatively affect the hippocampus (Liu et al., 2017).

8.4 Consideration of limitations

One of the greatest limitations of the current thesis is a result of the impact of the COVID-19 pandemic. COVID-19 had a significant effect on all research, causing particular disruption to laboratories where research is ordinarily conducted in-person but not deemed essential (Weiner et al., 2020; Alam et al., 2021). As a result of this interruption, the intended outline of the current thesis underwent a number of revisions. The main outcome of these revisions were significant changes in methodology, primarily converting the Face-Name Pairs task to an online format and halting administration of EEG until such a time as it was deemed safe to run in-person experiments again. Every attempt was made to keep online versions of the Face-Name Pairs task consistent with existing versions, but there were some inevitable differences which may bring into question the reliability of some of our findings. Furthermore, the

disruption caused by the pandemic made certain measures difficult to implement. In this instance, we had to rely on self-report measures of sleep in Chapter 6, and were under enormous time pressure to conduct EEG experiments in Chapter 7.

As a result, it is difficult to draw definitive conclusions based on the findings described in Chapter 6. It would be preferable to have an objective measure of sleep in addition to the SCI. For example, use of smart-watch or even phone applications would allow for a more all-encompassing examination of sleep effects on cognition. Though there were some interesting and significant findings, under the circumstances, these lend themselves more to speculation and further hypothesising than reliable conclusions. Similarly, the time constraints placed on the EEG experiment detailed in Chapter 7, coupled with attempts to keep in-person contact to a minimum, meant that data collection was somewhat hindered. Though the results produced some interesting findings, it would have been preferable to record ERP data throughout encoding as well as during retrieval. Furthermore, for the sake of consistency, a twenty-four hour condition would have been desirable.

Another limitation related to the pandemic is the gender imbalance that exists in some experiments, most notably those detailed in Chapters 5, 6, and 7. The population samples recruited for these experiments were predominantly female, particularly in Chapter 7. When recruiting participants online, it is difficult to control for gender. Furthermore, due to time constraints and the various restrictions in place at the time of data collection, we could not afford to be picky about the participants recruited for Chapter 7. This gender bias limits interpretation and generalisability of the results discussed. Gender bias, as well as lack of diversity, are common issues in psychology, brought to light by the recent replication crisis, though gender bias tends to favour men rather than women, which is not the case here (Garb, 2021). The generalisability of these studies may be further hindered by a lack of diversity among participants. Most fall into the category of young, white, and educated.

Additionally, it should be noted that we did not originally set out to test the theories of spacing. Rather, as we began to research the phenomenon and test the factors under which it can occur, we found ourselves referring to the theories underlying spacing to explain our results. This raised a number of further questions and hypotheses, particularly with regard to Chapter 7 and the potential for different neural networks which might be indicative of the different theories, which we did not have the time to answer. Though we did find some evidence in support of theories such as study-phase retrieval and deficient processing, these theories were not adequately tested and any conclusions drawn regarding these hypotheses are speculative at best.

8.5 Future directions

In addressing the aforementioned limitations, any future experiments should aim for more numbers to ensure that the studies are powered and attempt to have gender balance. In addressing the limitations of Chapter 6, it would be valuable to conduct a follow-on study that includes more objective measures, such as wrist-worn sleep trackers. Potentially, a greater quality analysis could be conducted using EEG or similar sleep-tracking devices (Liang & Ploderer, 2020). In addition to using these objective sleep measures as a way of tracking stages of sleep throughout the night, we could also compare objective sleep data to self-report sleep data as measured by the SCI, thus comparing the reliability and validity of the two sleep measures.

Moreover, it would be worth further investigating the neural mechanisms of spacing during encoding, particularly using ERP analyses. Literature surrounding this phenomenon is limited (Kim et al., 2001; Weston, 2018). EEG allows a superior analysis of temporal information, which could be useful in identifying patterns consistent with study phase retrieval, in particular. One might expect to see later parietal peaks on subsequent study

sessions in spaced-trained participants compared to massed-trained participants (Weston, 2018). One might also expect to see similar activity in spaced-trained participants across subsequent study sessions, but differences in massed-trained participants, indicative of deficient processing (Mangels et al., 2009; Mollison & Curran, 2015). This might allow for further support of the theories underlying spacing, and the extent to which each one plays a role. Recordings taken during encoding might also allow for support or contradiction of the new theory of disuse (see Chapter 3) proposed to further explain the results obtained in this thesis, particularly those of massed participants significantly outperforming spaced participants during encoding. Furthermore, it would be prudent to include cognitively healthy older adults in any neuroimaging studies regarding distributed practice. Such an addition would allow for a greater generalisability of results, as well as an exploration of what happens at a neural level when older adults are spaced-trained in comparison to younger adults. For example, such neuroimaging studies might provide evidence in support of or contradicting the implementation of encoding variability, study phase retrieval, or deficient processing in an older population. Moreover, results might further explain why older spaced-trained adults are less likely to learn new information, yet are still able to retain what they learn just as well as younger adults. Future ERP studies might also address the question of whether the famous N170 component associated with face processing is affected by memory process. This could be done by comparing the N170 component elicited by correct versus incorrect responses, to see if the results of Hammer et al. (2013) can be replicated.

Furthermore, it would be prudent to attempt to replicate the studies outlined in this thesis with a mind to specifically testing the theories that underly spacing. These conceptual replications could seek to test theories such as encoding variability, which is more difficult to examine neurally. For example, one might compare two spaced-trained groups where, for one group, the context is changed dramatically on subsequent study sessions while for the other,

the study environment is kept as similar as possible. In addition, it would be interesting to see what happens when the environment is changed at retrieval, but not during subsequent study sessions. This could test encoding specificity. Furthermore, one might go beyond modifying the physical environment by introducing other contextual cues, for example, cranking up the heat to make the room uncomfortable, or playing upbeat music prior to encoding to attempt to put the participant in a good mood. Further ERP analyses could attempt to test theories such as study-phase retrieval and deficient processing. ERPs could be extracted across encoding to demonstrate whether there is greater activity in spaced-trained participants (evidence of deficient processing theory) or indeed, whether spaced-trained participants exhibit later components compared to massed-trained participants (evidence of study-phase retrieval).

8.6 Wider implications and applications

Despite how well-known spacing is as a phenomenon, there is still no one underlying theory posed to explain it (Delaney et al., 2010). Furthermore, though spacing is acknowledged as an optimal learning strategy that could, and perhaps should, be employed in educational settings, this tends not to be a reality (Dempster, 1988; Murphy & Pavlik Jr, 2018; Walsh et al., 2018; Kim et al., 2019). Concurrently, some researchers argue that laboratory based research into the effects of spacing is not transferable to real-world or classroom settings, mainly due to discrepancies in findings (though spacing is generally a robust finding, it is not always replicable) and the assertion that simple, laboratory tasks are not representative of the more complex cognitive abilities required in day-to-day life (Dempster, 1986; Dempster, 1988; Rohrer & Pashler, 2010; Kapler et al., 2015). Given the significant research that lends support to use of spacing as an optimum tool when acquiring new information, further research to pinpoint the underlying mechanisms of spacing (and thus, potentially explain any

discrepancies in findings) and to make results as generalisable and applicable as possible when utilising distributed practice outside the laboratory, is needed.

In particular, it is beneficial to further examine the conditions under which spacing may occur (for example, in older adults, on-line versus in-person learning, recognition versus free recall of information), the types of material that spacing may be used with (does spacing occur when learning more abstract and ecologically valid concepts, such as face-name associations?), and the neural underpinnings of spacing, particularly with regard to temporal information, which is less prevalent in the literature. There are a number of studies which examine the neural mechanisms of spacing using techniques such as fMRI and PET (Callan & Schweighofer, 2010; Gerbier & Toppino, 2015; Bredart, 2019; Van Hoof et al., 2021). However, there are fewer studies which use EEG to investigate the neural correlates of spacing (Kim et al., 2001; Mollison & Curran, 2015; Weston, 2018). Such research could lend support to or contradict existing findings, particularly with regard to more temporal theories such as study-phase retrieval.

Given the discrepancies that do occasionally occur in spacing literature, and the ongoing replication crisis in the field of psychology as a whole, further replication and reproduction of established results, particularly with greater sample sizes, could lead to more robust and generalisable findings. Such research could lend itself to further clarifying the conditions under which spacing is most likely to occur, as well as lending support to or contradicting well-known findings that may rely only on a small sample-size (Anderson et al., 2017). Moreover, conceptual replications are particularly valuable in the current climate, where the ways in which research are conducted have changed dramatically as a result of the COVID-19 pandemic (Goldsack et al., 2020; Ranganathan et al., 2020; Sohrabi et al., 2021). With regard to spacing specifically, it is prudent to examine whether this effect is still present when learning occurs via online mediums, or indeed, across different types of learning, such

as recognition versus free recall. Such findings could potentially have wider implications for other areas too. If effects such as spacing are brought into question by a change in medium, then it is worth exploring whether the same is true of other fields. For example, many classrooms and college courses moved online during the height of the pandemic, and even now with eased restrictions, continue to use a hybrid model based on ease of administration; can we be certain that students are engaging in the same quality of learning? Additionally, a range of other psychological and healthcare services that would ordinarily be held in-person have now been moved online as a result of the pandemic; do patients and consumers get the same impact when services are administered online? It is important that research addresses these questions to ensure the best experience for students, patients, and anyone effected by the dramatic change in circumstances.

Research regarding the effects of sleep on cognition are somewhat contradictory. Though there seems to be an argument for a significant effect of sleep quality and duration on aspects of memory and cognition (Ellenbogen et al., 2007; Gillen-O'Neel et al., 2013; Rieth et al., 2010; Maurer et al., 2015; Huang et al., 2016; Chambers, 2017; Wilckens et al., 2018; Kapsi et al., 2020), some researchers insist that the effects of sleep are overexaggerated in the literature, or may even be more hindrance than help, for example, encouraging the consolidation of false memories (Wood et al., 1992; Mednick et al., 2009; Geyer et al., 2013; Casey et al., 2016; Day & Fenn, 2020). Literature suggests that sleep is impactful, however the extent to which it effects cognition may be dependent on a number of factors such as type of sleep, type of task, and other mediating variables, such as emotional regulation and substance abuse disorders (Sullivan, & Erkstrand, 1973; Stickgold, 2005; Dickelmann et al., 2009, Dickelmann & Born, 2010; Boyce et al., 2017; Palmer & Alfano, 2017; Vandekerckhove & Wang, 2018; Goodhines et al., 2019; Manoach & Stickgold, 2019; Koob & Colrain, 2020). Further studies examining the effects of sleep on different elements of

cognition contribute to existing literature, allowing for a deeper understanding of the conditions under which sleep may have a significant impact, and further probing the complex relationship between mediating variables that may affect or be affected by sleep. Overall, the hope is that memory and cognition can be improved by implementing certain techniques and habits, such as spacing, or simply getting a good night's sleep following consolidation. With increased research to better understand these phenomena, it becomes increasingly likely that results yielded will be more generalisable to, relevant to, and comprehensible by members of the general public, thus leading to improved strategies of encoding and consolidation, which may in turn improve general memory.

8.7 Conclusions

In conclusion, this thesis presents five experiments which examine the spacing effect under different conditions (at recent and remote intervals, in older adults, on-line versus in-person, the neural correlates of spacing) and the effects of sleep on memory and cognition. Results suggest that spacing is beneficial at longer intervals of one month when learning novel face-name pairs, occurs in cognitively healthy older populations, and may be underpinned by a hybrid model encompassing theories of encoding variability, study phase retrieval, and deficient processing, but only when participants are attentive to material during encoding. Results also suggest that sleep does not affect objective measures of cognition, such as performance on the Face-Name Pairs or Tower of Hanoi tasks, however it may act as a mediating variable in conjunction with symptoms of anxiety, depression, stress, and alcohol use disorders. These findings contribute to existing literature, with implications for improving associative memory in the general population.

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Appendices

Appendix A: The National Adult Reading Test

Appendix B: The Trail Making Task A

Appendix C: The Trail Making Task B

Appendix D: The Rey Auditory Verbal Learning Test

Appendix E: The Montreal Cognitive Assessment

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Appendix I: The Depression, Anxiety, Stress Scale-21

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Appendix M: Consent Form (Chapter 3)

Appendix N: Consent Form (Chapter 4)

Appendix O: Consent Form (Chapters 5 and 6)

Appendix P: Consent Form Online (Chapter 7)

Appendix Q: Consent Form In-person (Chapter 7)

Appendix A

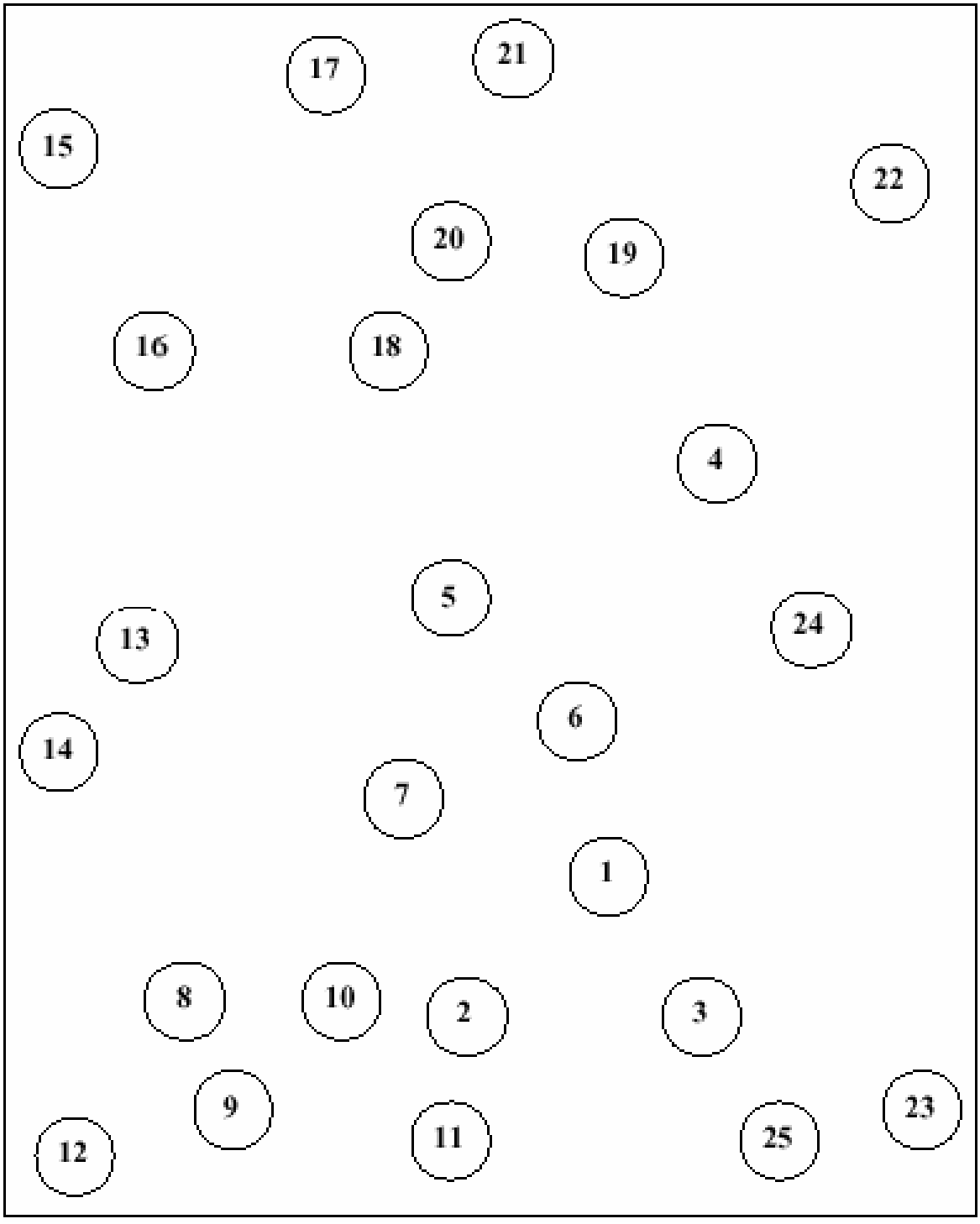
National Adult Reading Test

Ache	Simile
Debt	Aeon
Psalm	Cellist
Depot	Zealot
Chord	Abstemious
Bouquet	Gouge
Deny	Placebo
Capon	Façade
Heir	Aver
Aisle	Leviathan
Subtle	Chagrin
Nausea	Détente
Equivocal	Gauche
Naïve	Drachm
Thyme	Idyll
Courteous	Beatify
Gaoled	Banal
Procreate	Sidereal
Quadruped	Puerperal
Catacomb	Topiary
Superfluous	Desmesne
Radix	Labile
Assignate	Phlegm
Gist	Syncope
Hiatus	Prelate

Appendix B

Trail Making Test Part A

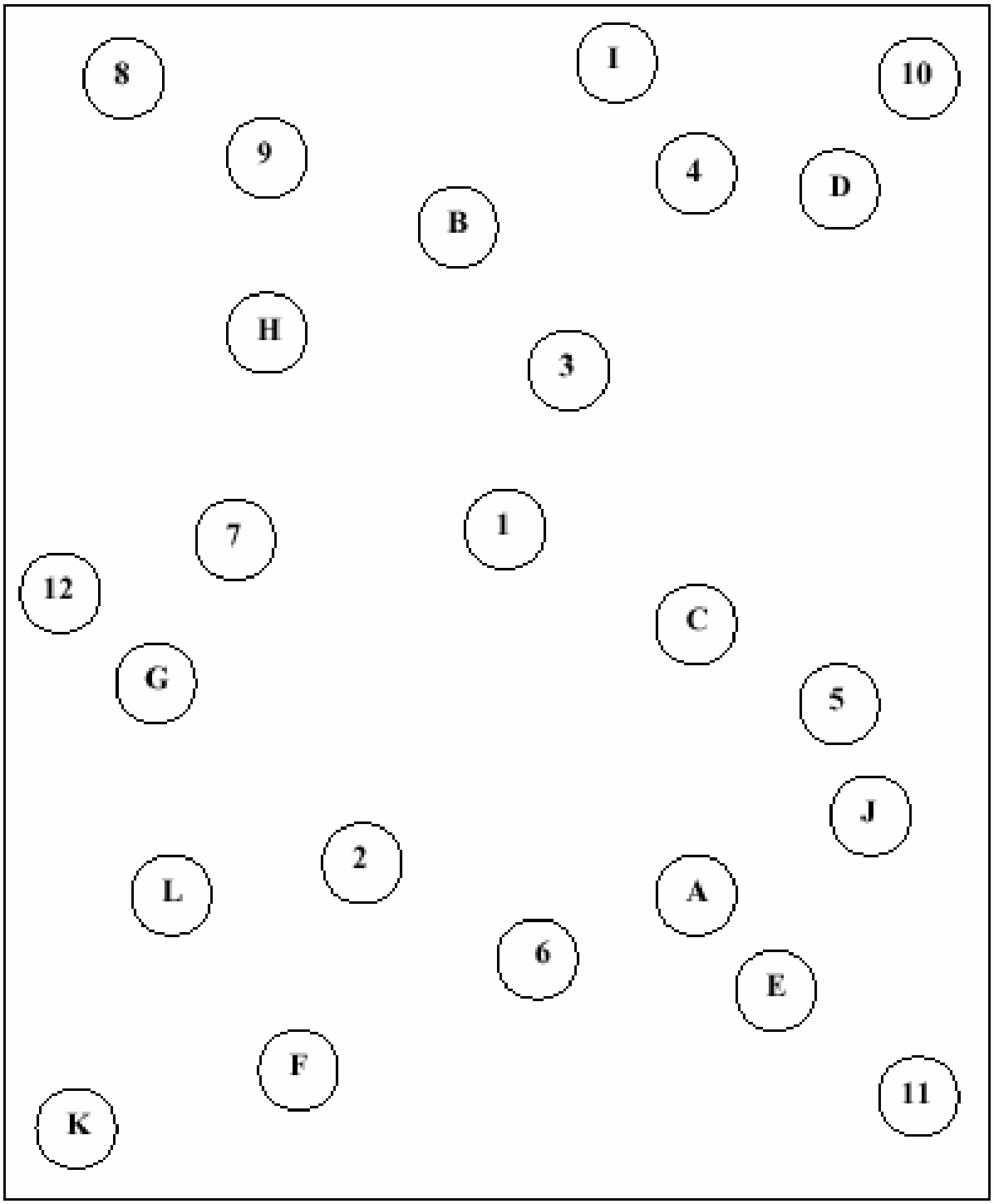
Patient's Name: Date:



Appendix C

Trail Making Test Part B

Patient's Name: Date:



Appendix D

RAVLT Sample Scoring Sheet

Name & Age: _____
Date: _____
Examiner: _____

(Note: do not re-read List A for Recall A6)

Do Not Re-read List A

List A	A1	A2	A3	A4	A5	List B	B	A6	List A
Drum						Desk			Drum
Curtain						Ranger			Curtain
River						Fish			River
Bell						Bird			Bell
Coffee						Shoe			Coffee
School						Stove			School
Parent						Mountain			Parent
Moon						Glasses			Moon
Garden						Towel			Garden
Hat						Cloud			Hat
Farmer						Boat			Farmer
Nose						Lamb			Nose
Turkey						Gun			Turkey
Colour						Pencil			Colour
House						Church			House
# Correct									

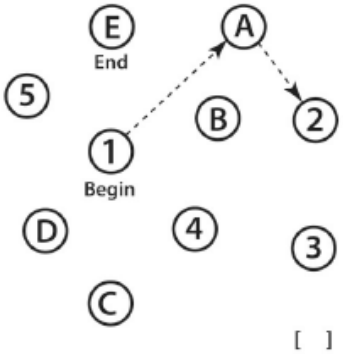
Total A1 to A5 = _____
Trial A6 - A5 = _____

Appendix E

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

Name :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



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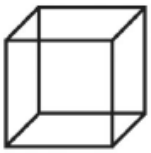


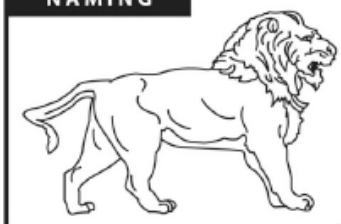
[ ] [ ]

Draw CLOCK (Ten past eleven) (3 points)

[ ] Contour [ ] Numbers [ ] Hands

__/5

NAMING



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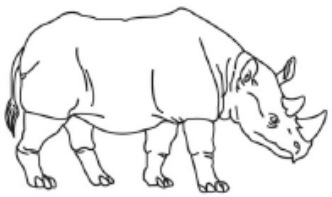

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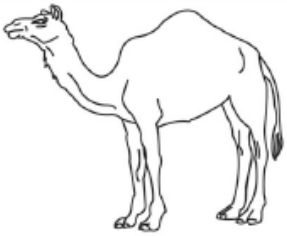

[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 2 1 8 5 4

Subject has to repeat them in the backward order [ ] 7 4 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]

The cat always hid under the couch when dogs were in the room. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words)

__/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler

__/2

DELAYED RECALL

	Has to recall words WITH NO CUE	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

© Z.Nasreddine MD **www.mocatest.org** Normal ≥ 26 / 30

TOTAL __/30

Add 1 point if ≤ 12 yr edu

Administered by: _____

Appendix F

Participant ID:_____

Thinking about a typical night in the last month, what time do you go to sleep?

Thinking about a typical morning in the last month, what time do you wake up?

Do you use an alarm?

What time did you wake up at this morning?

On average, does your bedtime/wake-up time differ on days where you go to work/school versus a day off?

Appendix G

The Sleep Condition Indicator

	Score				
Item	4	3	2	1	0
Thinking about a typical night in the last month … 1. … how long does it take you to fall asleep?	0 – 15 min	16 – 30 min	31 – 45 min	46 – 60 min	≥ 61 min
2. … if you then wake up duringthe night … how long are you awakefor in total? (add all the wakenings up)	0 – 15 min	16 – 30 min	31 – 45 min	46 – 60 min	≥ 61 min
3. … how many nights a week do you have a problem with your sleep?	0 - 1	2	3	4	5 - 7
4. … how would you rate your sleep quality?	Very good	Good	Average	Poor	Very poor
Thinking about the past month, to what extent has poor sleep … 5. … affected your mood, energy, or relationships?	Not at all	A little	Somewhat	Much	Very much
6. … affected your concentration, productivity, or ability to stay awake	Not at all	A little	Somewhat	Much	Very much
7. … troubled you in general	Not at all	A little	Somewhat	Much	Very much
Finally … 8. … how long have you had a problem with your sleep?	I don't have a problem / < 1 mo	1 – 2 mo	3 – 6 mo	7 – 12 mo	> 1 yr

Scoring instructions:

a. Add the item scores to obtain the SCI total (minimum 0, maximum 32)
b. A higher score means better sleep
c. Scores can be converted to 0 – 10 format (minimum 0, maximum 10) by dividing total by 3.2
d. Item scores in grey area represent threshold criteria for Insomnia Disorder

Appendix H

KAROLINSKA SLEEPINESS SCALE

Please, indicate your sleepiness during the 5 minutes before this rating through circling the appropriate description

1=extremely alert
2=very alert
3=alert
4=rather alert
5=neither alert nor sleepy
6=some signs of sleepiness
7=sleepy, but no effort to keep awake
8=sleepy, some effort to keep awake
9=very sleepy, great effort to keep awake, fighting sleep

If used electronically, please make sure that the wording of the scale is presented at each rating for easy reference

References

Original study: Åkerstedt, T. and Gillberg, M. Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience*, 1990, 52: 29-37.

Recent review: Akerstedt, T., Anund, A., Axelsson, J. and Kecklund, G. Subjective sleepiness is a sensitive indicator of insufficient sleep and impaired waking function. *Journal of Sleep Research*, 2014, 23: 240-52.

Appendix I

Scoring the DASS

The scale to which each item belongs is indicated by the letters D (Depression), A (Anxiety) and S (Stress). For each scale (D, A & S) sum the scores for identified items. Because the DASS 21 is a short form version of the DASS (the Long Form has 42 items), the final score of each item groups (Depression, Anxiety and Stress) needs to be multiplied by two (x2).

Interpreting the DASS

Once multiplied by 2, each score can now be transferred to the DASS profile sheet, enabling comparisons to be made between the three scales and also giving percentile rankings and severity labels.

DASS Severity Ratings

(Don't forget to multiply summed scores by x 2)

Severity	Depression	Anxiety	Stress
Normal	0-9	0-7	0-14
Mild	10-13	8-9	15-18
Moderate	14-20	10-14	19-25
Severe	21-27	15-19	26-33
Extremely Severe	28+	20+	34+

As previously mentioned, the DASS should not be used on its own to assess the presence or absence of Depression or Anxiety. High scores on the DASS would certainly alert the clinician to a high level of distress in the patient and this would need to be explored further within the interview process. Similarly, low scores on the DASS should not be a substitute for a comprehensive clinical interview.

High DASS scores which are not changing, may prompt the clinician to look for explanations and perhaps augment dosages or change medication. Here again, the DASS should be interpreted along side the clinical interview.

Changes in scores in one scale (EG: Depression), with consistently high and unchanging scores in another scale (Anxiety) may alert the clinician to pay particular attention to the presence of a co-existing anxiety disorder which may need specific treatment in its own right. Similarly, decreasing Depression scores alongside unchanging Stress scores may alert the clinician to the presence of some life event or problem, which may need to be addressed directly.

DASS 21 NAME_____ DATE _____

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you over the past week. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all - NEVER

1 Applied to me to some degree, or some of the time - SOMETIMES

2 Applied to me to a considerable degree, or a good part of time - OFTEN

3 Applied to me very much, or most of the time - ALMOST ALWAYS

FOR OFFICE USE

						D	A	S
		N	S	0	AA			
1	I found it hard to wind down	0	1	2	3			
2	I was aware of dryness of my mouth	0	1	2	3			
3	I couldn't seem to experience any positive feeling at all	0	1	2	3			
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3			
5	I found it difficult to work up the initiative to do things	0	1	2	3			
6	I tended to over-react to situations	0	1	2	3			
7	I experienced trembling (eg, in the hands)	0	1	2	3			
8	I felt that I was using a lot of nervous energy	0	1	2	3			
9	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3			
10	I felt that I had nothing to look forward to	0	1	2	3			
11	I found myself getting agitated	0	1	2	131			
12	I found it difficult to relax	0	1	2				
13	I felt down-hearted and blue	0	1	2				
14	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3			
15	I felt I was close to panic	0	1	2	131			
16	I was unable to become enthusiastic about anything	0	1	2				
17	I felt I wasn't worth much as a person	0	1	2				
18	I felt that I was rather touchy	0	1	2	3			
19	I was aware of the action of my heart in the absence of physicalexertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	131			
20	I felt scared without any good reason	0	1	2	3			
21	I felt that life was meaningless	0	1	2	131			

Appendix J

General Health Questionnaire

We want to know how your health has been in general over the last few weeks. Please read the questions below and each of the four possible answers. Circle the response that best applies to you. Thank you for answering all the questions.

Have you recently:

1. been able to concentrate on what you're doing?

better than usual	same as usual	less than usual	much less than usual
(0)	(1)	(2)	(3)

2. lost much sleep over worry?

Not at all	no more than usual	rather more than usual	much more than usual
(0)	(1)	(2)	(3)

3. felt that you are playing a useful part in things?

more so than usual	same as usual	less so than usual	much less than usual
(0)	(1)	(2)	(3)

4. felt capable of making decisions about things?

more so than usual	same as usual	less than usual	much less than usual
(0)	(1)	(2)	(3)

5. felt constantly under strain?

Not at all	no more than usual	rather more than usual	much more than usual
(0)	(1)	(2)	(3)

6. felt you couldn't overcome your difficulties?

Not at all	no more than usual	rather more than usual	much more than usual
(0)	(1)	(2)	(3)

7. been able to enjoy your normal day to day activities?

more so than usual	same as usual	less so than usual	much less than usual
(0)	(1)	(2)	(3)

8. been able to face up to your problems?

more so than usual	same as usual	less than usual	much less than usual
(0)	(1)	(2)	(3)

9. been feeling unhappy or depressed?

not at all (0) | no more than usual (1) | rather more than usual (2) | much more than usual (3)

10. been losing confidence in yourself?

not at all (0) | no more than usual (1) | rather more than usual (2) | much more than usual (3)

11. been thinking of yourself as a worthless person?

not at all (0) | no more than usual (1) | rather more than usual (2) | much more than usual (3)

12. been feeling reasonably happy, all things considered?

more so than usual (0) | same as usual (1) | less so than usual (2) | much less than usual (3)

General Health Questionnaire Scoring

Scoring – Likert Scale 0, 1, 2, 3 from left to right.
12 items, 0 to 3 each item
Score range 0 to 36.

Scores vary by study population. Scores about 11-12

typical.Score >15 evidence of distress
Score >20 suggests severe problems and psychological distress

Appendix K

The Alcohol Use Disorders Identification Test Interview Version

Read questions as written. Record answers carefully. Begin the AUDIT by saying " Now I am going to ask you some questions about your use of alcoholic beverages during this past year." Explain what is meant by " alcoholic beverages" by using local examples of beer, wine, vodka, etc. Code answers in terms of " standard drinks". Place the correct answer number in the box at the right.

1. How often do you have a drink containing alcohol? (0) Never [Skip to Qs 9-10] (1) Monthly or less (2) 2 to 4 times a month (3) 2 to 3 times a week (4) 4 or more times a week	6. How often during the last year have you needed a first drink in the morning to get yourself going after a heavy drinking session? (0) Never (1) Less than monthly (2) Monthly (3) Weekly (4) Daily or almost daily
2. How many drinks containing alcohol do you have on a typical day when you are drinking? (0) 1 or 2 (1) 3 or 4 (2) 5 or 6 (3) 7, 8, or 9 (4) 10 or more	7. How often during the last year have you had a feeling of guilt or remorse after drinking? (0) Never (1) Less than monthly (2) Monthly (3) Weekly (4) Daily or almost daily
3. How often do you have six or more drinks on one occasion? (0) Never (1) Less than monthly (2) Monthly (3) Weekly (4) Daily or almost daily *Skip to Questions 9 and 10 if Total Score for Questions 2 and 3 = 0*	8. How often during the last year have you been unable to remember what happened the night before because you had been drinking? (0) Never (1) Less than monthly (2) Monthly (3) Weekly (4) Daily or almost daily
4. How often during the last year have you found that you were not able to stop drinking once you had started? (0) Never (1) Less than monthly (2) Monthly (3) Weekly (4) Daily or almost daily	9. Have you or someone else been injured as a result of your drinking? (0) No (2) Yes, but not in the last year (4) Yes, during the last year
5. How often during the last year have you failed to do what was normally expected from you because of drinking? (0) Never (1) Less than monthly (2) Monthly (3) Weekly (4) Daily or almost daily	10. Has a relative or friend or a doctor or another health worker been concerned about your drinking or suggested you cut down? (0) No (2) Yes, but not in the last year (4) Yes, during the last year

Record total of specific items here
If total is greater than recommended cut-off, consult User's Manual.

The Alcohol Use Disorders Identification Test: Self-Report Version

PATIENT: Because alcohol use can affect your health and can interfere with certain medications and treatments, it is important that we ask some questions about your use of alcohol. Your answers will remain confidential so please be honest. Place an X in one box that best describes your answer to each question.

Questions	0	1	2	3	4	
1. How often do you have a drink containing alcohol?	Never	Monthly or less	2-4 times a month	2-3 times a week	4 or more times a week	
2. How many drinks containing alcohol do you have on a typical day when you are drinking?	1 or 2	3 or 4	5 or 6	7 to 9	10 or more	
3. How often do you have six or more drinks on one occasion?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
4. How often during the last year have you found that you were not able to stop drinking once you had started?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
5. How often during the last year have you failed to do what was normally expected of you because of drinking?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
6. How often during the last year have you needed a first drink in the morning to get yourself going after a heavy drinking session?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
7. How often during the last year have you had a feeling of guilt or remorse after drinking?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
8. How often during the last year have you been unable to remember what happened the night before because of your drinking?	Never	Less than monthly	Monthly	Weekly	Daily or almost daily	
9. Have you or someone else been injured because of your drinking?	No		Yes, but not in the last year		Yes, during the last year	
10. Has a relative, friend, doctor, or other health care worker been concerned about your drinking or suggested you cut down?	No		Yes, but not in the last year		Yes, during the last year	
					Total	

Appendix L

The Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald & Parkes, 1982)

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to you in the past 6 months. Please circle the appropriate number.

	Very often	Quite often	Occasion-ally	Very rarely	Never
1. Do you read something and find you haven't been thinking aboutit and must read it again?	4	3	2	1	0
2. Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
3. Do you fail to notice signposts on the road?	4	3	2	1	0
4. Do you find you confuse right and left when giving directions?	4	3	2	1	0
5. Do you bump into people?	4	3	2	1	0
6. Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
7. Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0
8. Do you say something and realize afterwards that it might be taken as insulting?	4	3	2	1	0
9. Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
10. Do you lose your temper and regret it?	4	3	2	1	0
11. Do you leave important letters unanswered for days?	4	3	2	1	0
12. Do you find you forget which way to turn on a road you know well but rarely use?	4	3	2	1	0
13. Do you fail to see what you want in a supermarket (although it's there)?	4	3	2	1	0
14. Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0

	Very often	Quite often	Occasion-ally	Very rarely	Never
15. Do you have trouble making up your mind?	4	3	2	1	0
16. Do you find you forget appointments?	4	3	2	1	0
17. Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
18. Do you find you accidentally throw away the thing you want and keep what you meant to throw away – as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
19. Do you daydream when you ought to be listening to something?	4	3	2	1	0
20. Do you find you forget people's names?	4	3	2	1	0
21. Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
22. Do you find you can't quite remember something although it's "on the tip of your tongue"?	4	3	2	1	0
23. Do you find you forget what you came to the shops to buy?	4	3	2	1	0
24. Do you drop things?	4	3	2	1	0
25. Do you find you can't think of anything to say?	4	3	2	1	0

References

Broadbent, D.E., Cooper, P.F., FitzGerald, P., & Parkes, K.R. (1982). The Cognitive Failures Questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology*, *21*, 1-16.

Appendix M

Consent Form

I . . . . . agree to participate in Michelle Caffrey's research study titled "The effects of distributed practice on short- and long-term memory in healthy younger adults".

Please tick each statement below:

The purpose and nature of the study has been explained to me verbally & in writing. I've been able to ask questions, which were answered satisfactorily. ☐
I am participating voluntarily. ☐
I understand that I can withdraw from the study, without repercussions, at any time, whether that is before it starts or while I am participating. ☐
I understand that I can withdraw permission to use the data right up to publication. ☐
I understand how my data will be managed and that I may access it on request. ☐
I understand the limits of confidentiality as described in the information sheet. ☐

I the undersigned have taken the time to fully explain to the above participant the nature and purpose of this study in a manner that they could understand. I have explained the risks involved as well as the possible benefits. I have invited them to ask questions on any aspect of the study that concerned them.

Signed……. Date…….

Researcher Name in block capitals ……...
If during your participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the Maynooth University Ethics Committee at research.ethics@mu.ie or +353 (0)1 708 6019. Please be assured that your concerns will be dealt with in a sensitive manner.

For your information the Data Controller for this research project is Maynooth University, Maynooth, Co. Kildare. Maynooth University Data Protection officer is Ann McKeon in Humanity house, room 17, who can be contacted at ann.mckeon@mu.ie. Maynooth University Data Privacy policies can be found at https://www.maynoothuniversity.ie/data-protection.

Appendix N

Consent Form

I . . . . . agree to participate in Michelle Caffrey's research study titled "The effects of distributed practice on short- and long-term memory in healthy younger and older adults".

Please tick each statement below:

The purpose and nature of the study has been explained to me verbally & in writing. I've been able to ask questions, which were answered satisfactorily. ☐

I am participating voluntarily. ☐

I understand that I can withdraw from the study, without repercussions, at any time, whether that is before it starts or while I am participating. ☐

I understand that I can withdraw permission to use the data right up to publication. ☐

I understand how my data will be managed and that I may access it on request. ☐

I understand the limits of confidentiality as described in the information sheet. ☐

I the undersigned have taken the time to fully explain to the above participant the nature and purpose of this study in a manner that they could understand. I have explained the risks involved as well as the possible benefits. I have invited them to ask questions on any aspect of the study that concerned them.

Signed……. Date…….

Researcher Name in block capitals ……..

If during your participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the Maynooth University Ethics Committee at research.ethics@mu.ie or +353 (0)1 708 6019. Please be assured that your concerns will be dealt with in a sensitive manner.

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Appendix O

Study Title:

An examination of the interaction between sleep and distributed practice on short- and long-term memory.

What are the risks?

There are no known risks associated with participation in this study, as there are no invasive procedures and no stress to be applied.

Research Standards and Rights of Participation:

Participation in this study is completely voluntary and you may decide not to participate. You may cease participation at any time. However, if you do cease participation, or if you do not complete each element of the experiment satisfactorily, the researcher reserves the right to abstain from signing your participation form. Participation in this study does not lead to any form of psychological or medical diagnosis, or treatment. Information collected from this study is for research purposes only and will not be of any direct clinical use to you.

Data Usage and Confidentiality:

Data collected from this study may be used for academic publication. Anonymised research data will be stored for at least 10 years, as per National University of Ireland Maynooth Research Integrity guidelines. Treatment of data will be in accordance with all relevant legislation.

All data collected will be treated as confidential, in compliance with both University regulations and current statutory provisions, or as required by law. All data will be held in a fully anonymised format and all analysis will be at the group level. You will not be personally identified with the data obtained.

Data will be electronically stored on encrypted PCs and backed up to University secure cloud-based services, accessible only to the researchers and supervisor. It must be recognized that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.

Researcher Contact Information:

If you have any questions before you participate, please contact the researcher directly (**michelle.caffrey.2015@mumail.ie**). If you have any concerns during or following participation, please contact the research supervisor, Dr. Sean Commins (**sean.commins@mu.ie**).

Appendix P

Study Title:

An examination of the neural correlates of spacing

What are the risks?

There are no known risks associated with participation in this study, as there are no invasive procedures and no stress to be applied.

Research Standards and Rights of Participation:

Participation in this study is completely voluntary and you may decide not to participate. You may cease participation at any time. However, if you do cease participation, or if you do not complete each element of the experiment satisfactorily, the researcher reserves the right to abstain from signing your participation form. Participation in this study does not lead to any form of psychological or medical diagnosis, or treatment. Information collected from this study is for research purposes only and will not be of any direct clinical use to you.

Data Usage and Confidentiality:

Data collected from this study may be used for academic publication. Anonymised research data will be stored for at least 10 years, as per National University of Ireland Maynooth Research Integrity guidelines. Treatment of data will be in accordance with all relevant legislation.

All data collected will be treated as confidential, in compliance with both University regulations and current statutory provisions, or as required by law. All data will be held in a fully anonymised format and all analysis will be at the group level. You will not be personally identified with the data obtained.

Data will be electronically stored on encrypted PCs and backed up to University secure cloud-based services, accessible only to the researchers and supervisor. It must be recognized that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.

Researcher Contact Information:

If you have any questions before you participate, please contact the researcher directly (**michelle.caffrey.2015@mumail.ie**). If you have any concerns during or following participation, please contact the research supervisor, Dr. Sean Commins (**sean.commins@mu.ie**).

Appendix Q

Roinn Síceolaíochta Ollscoil Mhá Nuad
Maynooth University Department of Psychology

Information Sheet:

An Examination of the Brains Electrical Activity Underlying Human Learning and Recall

Postgraduate Researcher:
Conor Thornberry
Michelle Caffrey

conor.thornberry@mu.ie
michelle.caffrey@mu.ie

Supervisor:
Dr. Sean Commins
Department of Psychology
Maynooth University,
Co. Kildare,
Ireland.

Sean.Commins@mu.ie

Ph 017086182

Your participation is requested in an experimental study taking place with the Department of Psychology at Maynooth University examining the brains electrical activity underlying learning and recall in humans with tasks that depend on the association between objects.

What is the study about?

The brains electrical activity during our daily learning and recall has been relatively unexplored. Most daily tasks involve understanding relationships between objects and being able to recall them, known as associations. Therefore, using two tasks that involve this type of associative learning and recall, we wish to examine brain activity as humans learn and remember using non-invasive Electroencephalography (EEG). EEG is a safe, harmless method of recording the electrical activity of the brain.

What does it involve? What would I have to do?

There would be two parts to your involvement, all of which will take place in a quiet location free from distraction.

1. You will be set-up with the EEG cap and connected to our monitoring software. This will take about 15 minutes.

2. You will then be asked to perform two computerized tasks. The first will be a computer-based task - NavWell – which will involve learning the spatial position of a goal in relation to the environment. The second task will be the Face-Name Pairs Task – in which you will attempt to learn several faces and their associated names. The researcher will then organize a time that suits you to return to see if you can recall both the spatial location and the list of face-name pairs. This will be greater than 24 hours but no longer than 1 month.

3. In your follow-up session, you will be set-up with our EEG system again. Your ability to recall the goal location will be examined using NavWell. Your ability to recall the face-name pairs will also be examined using the Face-Name Pairs task. This should take up to 20 minutes. You will then be asked to complete 3 brief cognitive tasks. These consist of the National Adult Reading Test (NART) for general intelligence, the Trail Making Task (TMT) for executive functioning, and the Rey Auditory Verbal Learning Task (RAVLT) for memory. These tasks will take about 10 minutes and are only carried out to ensure participants are cognitively matched. The specific aims of the study will be explained as soon as you have completed the experiment.

Are there any risks to me?

There are no risks associated with this study. The procedure involves very little discomfort and should be an enjoyable experience for most participants. This procedure is safe, painless and non-invasive; it does not involve radiation, x-rays, magnetic fields or any other dangerous elements, so you should consider it similar to having your heart rate or blood-pressure measured. The procedure involves applying a conductive gel to your scalp to help us get a clear signal from the brain, so you will need to wash your hair afterwards – washing and drying facilities will be provided for you.

The questionnaires will involve either verbally answering questions or filling in answers with pen and paper. The NavWell software involves the simple mouse and keyboard controlled first-person navigation of a virtual environment, very similar to playing a computer game. The Face-Name Pairs task involves simple responding via a keyboard.

In the unlikely event that you experience any distress, discomfort or if you have any concerns about any aspect of your performance on these tasks, you should feel free to contact Dr. Sean Commins or contact your own GP with these concerns. Should you be a student of the University you may also avail of the Student Counseling Service (01 708 3554) or Student Health Service (01 708 3878); both are on campus and located very close to the Psychology Department.

We hope to provide a baseline of healthy neural activity during every day association-based learning tasks, which could be used for comparison with at-risk older adults suffering from memory-related disorders such as dementia.

What happens to my test scores?

The printed data from your participation (i.e. test scores) will be strictly confidential and will be kept in a locked cabinet in the Psychology Department. Your results will be kept confidential by assigning a random number to each participant instead of your name. Aside from your age, no other personal data will be recorded. Except for the researcher(s) involved in running this study, nobody will be allowed to see or discuss any of your data. Your data will be combined with many others and reported in group form – averages etc. – in a scientific paper, but your own data will be available to you at your discretion.

Can I withdraw from the study?

Yes, you may withdraw your data and involvement in the study at any time up until the completion of your participation.

If you are willing to help us by participating in this study, we will ask you to sign a **Letter of Consent**, which accompanies this information sheet. We are very grateful for your participation.

I have some health issues – am I still eligible to take part?

Finally, if you suffer from **any** of the following, you may not be eligible to take part:

- severe visual impairments;
- history of psychological/neurological impairment;
- history of motion or simulator sickness;
- history of epilepsy or memory issues;
- history of drug or alcohol abuse;
- currently taking psychoactive medication;
- other relevant medical conditions; such as **vertigo** or **claustrophobia**

Do you suffer from/have suffered from any of the above?

Yes ☐ No ☐

You are welcome to discuss this decision with us but you are under no obligation to do so. Please feel free to study these criteria during a cooling off period of up to one week. Should you choose not to participate, no further action is required. If you have any doubts as to whether or not you are eligible to take place in this study, please inform us so we may determine your eligibility.

In agreeing to participate in this research I understand the following:

This research is being conducted by Conor Thornberry and Michelle Caffrey, postgraduate students at the Department of Psychology, Maynooth University. The method proposed for this research project adheres in principle to the Psychological Society of Ireland (PSI) code of professional ethics. It is, however, the above-named student's responsibility to adhere to ethical guidelines in their dealings with participants and the collection and handling of data. If I have any concerns about participation, I understand that I may refuse to participateor withdraw at any stage.

I have been informed as to the general nature of the study and agree voluntarily to participate.

The total time for your participation will be approximately 2 hours in total across two sessions. The follow up session is carried out no less than 24 hours later. There are no known expected discomforts or risks associated with participation.

The results of my participation will be documented by participant number only. No names or individual identifying information will be recorded. With the exception of the researcher(s) involved in running this study, nobody will be allowed to see or discuss any of the individual responses. My responses will be combined with many others and reported in group form in a scientific paper and/or a report submitted to the Department of Psychology. My own data will be available to me at my discretion. I may withdraw my data and involvement in the study at any time, up until the completion of your participation.

Please Note: students participating in this research as part of the Year 2 Research Credit Participation Scheme (connected to the modules PS256 and PS260) should be aware that, while you may withdraw your participation at any stage, this may mean you will have to complete a short written assignment in lieu of participation. You may also withdraw and choose to not receive credit. The credit system is managed independently of the researchers. Should you have any concerns please refer to the module description in your Year 2 Handbook (https://www.maynoothuniversity.ie/psychology/resources).

At the conclusion of my participation, any questions or concerns I have will be fully addressed.
I may withdraw from this study at any time and may withdraw my data at the conclusion of my participation if I still have concerns.

Signed:

_____Participant

_____Researcher

_____Date