THE EFFECTS OF AGE AND BILINGUALISM ON MEMORY RETRIEVAL

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A THESIS SUBMITTED TO
THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FUFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF ARTS

GRADUATE PROGRAM IN PSYCHOLOGY
YORK UNIVERSITY
TORONTO, ONTARIO

AUGUST 2024

Abstract

It is often argued that older adults show memory decline because they have fewer attentional resources which impedes the explicit retrieval of information. The present study aimed to assess the role of attentional control as a second factor that could influence memory in older adulthood. We recruited participants presumed to have different levels of attentional resources, younger and older adults, as well as participants presumed to have differences in attentional control, monolinguals and bilinguals. Testing consisted of verbal and non-verbal tasks that included both implicit and explicit retrieval conditions. We examined the influence of age (older, younger), language group (bilingual, monolingual) and condition (explicit, implicit) on memory performance and found different patterns of results for the verbal and non-verbal tasks. We also found correlations between bilingual experience (measured continuously) and explicit condition memory performance. Findings suggest that bilingual experience could be a potent factor in mitigating memory decline.

Acknowledgements

I first want to thank my wonderful supervisor Thanujeni (Jeni) Pathman whose consistent optimism and tutelage changed my perspective on research. Thank you Jeni for telling me that it was okay to change paths and for supporting me through my career realignments. If ever I match at least half of your conscientiousness and work ethic, I’ll know that I’ll have been successful. I want to extend my sincere gratitude to my advisor and committee member Ellen Bialystok, whose career long contributions to bilingualism research and unparallelled knowledge of the field played a central role in the development and direction of this thesis. My acknowledgements would not be complete were I not to mention and thank the illustrious Fergus Craik, whose insightful observations, exceptional knowledge of the field, and pleasant sense of humour facilitated the development of this project.

I next want to thank my colleague and friend Caitlin O’ Riordan for playing an important role in helping me wrap my head around the collected data, for openly discussing potential leads in my interpretations, and for always providing her insights and guidance when I felt overwhelmed with the present project. I want to additionally recognise the work and efforts of our laborious research assistants Disha Shukla and Diya Nijjar, whose contributions in administering tasks and data profiling strongly facilitated the completion of this thesis. A very special thanks to Rupkatha Basu, whose collaboration in this project from the very start played a pivotal role in participant recruitment.

I further want to acknowledge and recognise community member Clair Cafaro for her selfless contributions in facilitating older adult participant recruitment and by lending us space in her studio for data collection. I want to thank my amazing partner Emma for giving me hope and for consistently being by my side through the hardships and setbacks I encountered in the development of this project.

Last, but not least, I want to thank all my MDLaB and LCAD Lab peers for sharing their thoughts on the project, and for entertaining the absurd discussions we had during "Lunch Club" (whose rich range of conversation topics will stay in my memory for a long time). I am infinitely grateful to have met all of you.

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The Effects of Age and Bilingualism on Memory Retrieval

Memory competencies follow a systematic trajectory over one's lifespan; a steep increase in the first two decades of life, followed by substantial deterioration in older adulthood (Ofen & Shing, 2013). With many nations gradually inching towards an ever aging population (see Gu et al., 2021; Marois et al., 2020), there is growing urgency to better understand memory decline and to develop preventative measures. That being said, changes in memory capabilities in older adulthood, and lifestyle factors that could modulate these changes, are not well understood.

Although an aging population constitutes a modern phenomenon, the interest in understanding age-related memory decline is not recent. Experimental studies conducted as early as the 1930s attempted to measure the effects of senescence on memory capabilities (Gilbert, 1935). Initial explanations for memory decline remained sparse, however, as researchers seemed more interested in characterising memory decline rather than understanding its underlying reasons. Nonetheless, research tended to point towards an increased difficulty in forming new associations between novel concepts and information as being the main culprit for memory decline (Gilbert, 1941). Over the next three decades, a growing battery of research pointed towards both memory encoding and retrieval as the catalysts for declining memory capabilities in older adulthood (Schonfield & Robertson, 1966). However, much of the evidence brought forth in the earlier decades of age-related memory decline research did not always abide to any prominent theory or framework. This lack of widely accepted agreement only rendered the task of understanding memory changes more difficult as no semblance of consensus could be reached. This would change over the following decades.

First coined by Miller and colleagues in the early 1960s (see Miller et al., 2017), and later expanded upon by Atkinson and Shiffrin (1968), "working memory" was widely popularised by

Baddeley and Hitch (1974). Working memory, defined as being a brain memory system that allowed for the short-term storage, retrieval, and processing of information, was argued to be necessary in complex cognitive tasks such as learning and reasoning (Baddeley, 1992). In some respects, age-related memory decline could be accounted for by early working memory models. Age was argued to affect two components of working memory: 1) information processing, which had consistently been demonstrated to decline with age (Babcock & Salthouse, 1990; Light & Anderson, 1985; Salthouse, 1990), and 2) short-term storage, which was also argued to decline with age (Stine & Wingfield, 1990), albeit to a lesser extent. It became clear that the effects of aging on working memory were not equally distributed among its components. A study by Morris and colleagues (1988) brought into question the role that short-term storage played on memory decline, and argued that aging had little effect on the ability to hold and rehearse information, but that, in contrast, aging had a significant impact on information processing capabilities. This suggested that age-related changes in memory could be better accounted for by other frameworks that focused primarily on processing capabilities instead of short-term storage.

Despite its relatively poor fit for age-related memory changes, the use of the term "working memory" persisted in subsequent aging research. While "working memory" is still prominently used in the field of psychology today, its meaning has gradually changed over the years – and is still the topic of much confusion as it often holds different definitions depending on the type of research being conducted (see Shah & Miyake, 1999). Originally, working memory frameworks incorporated both short-term storage and the "central executive" (an attention-controlling system) in a unitary system, though a growing proportion of studies now explicitly separated short-term storage from the concept of working memory, which was now more prominently used to denote the active allocation of attention to sensory and internal representations (D'Esposito & Postle, 2015). This popular reinterpretation of working memory from being a brain memory system to being an executive attention system, likely resulted from the explosion in executive control research around the turn of the millennium (Engle, 2002; Hasher et al., 2007). For these reasons, a renewed focus on memory decline research proceeded through the lens of working memory as a system of attentional resource allocation (which in this case is largely synonymous and interchangeable with “active executive functions”, “executive attention”, “executive control”, and “cognitive control”). This notion of “working memory” as a processing resource allocation system was substantiated by much neural evidence, which further cemented it as a disposition of the human frontal lobes (Kane & Engle, 2002).

While researchers have for a long time recognised the significant role that the human frontal cortex plays in higher cognitive operations and in the allocation of processing resources (Kane & Engle, 2002), its relations to memory were not always understood. Much debate on this matter came from mid-20th century research on the effects of medically induced frontal lobe lesioning, also known as lobotomies. While some argued that frontal lobe lesions severely affected memory capabilities and ensured that “torpor and stupidity” prevailed (Holzberg, 1949, p.11), others contended that no impacts to memory could be reasonably attributed to frontal lesioning (Holzberg, 1949). Even with subsequent (and more ethical) studies, our understanding of the extent to which frontal cortices were involved in memory was limited as much evidence originated from neuropathological case studies (Benton, 1968). Fortunately, in the advent of neuroimaging technique proliferation, concrete evidence would further our understanding of the interactions between cognitive control and memory.

Emerging evidence in healthy aging hinted that declines in cognitive control and memory were strongly associated with age-related decreases in brain grey matter volume (Fletcher et al., 2018; Ikram et al., 2010; Mungas et al., 2005). More specifically, cognitive control impairments were associated with smaller frontal lobe volumes, whereas memory decline was more strongly associated with smaller hippocampal regions (Cardenas et al., 2011). However, evidence from memory-updating paradigms, in which participants were tasked to update previously learned information, suggested that memory updating strongly relied on frontal cortical regions involved in cognitive control (Kluen et al., 2019). This suggested that while hippocampal regions played a central role in memory encoding and retrieval (Squire & Wixted, 2011), frontal region neural processes also played a crucial role when integrating new memories in existing structures (see Schlichting & Preston, 2016). Subsequent evidence reinforced these assertions by demonstrating that age-related hippocampal region atrophy was also associated with a substantial compensatory increase in frontal region activation (Maillet & Rajah, 2013; Sala-Llonch et al., 2015). In other words, frontal cortices compensated for declines in distal regions of the human cortex.

The abundance of evidence suggesting that cognitive control affects memory capabilities, notably in cases of age-related cortical atrophy, consolidated its importance in healthy aging research. That being said, while it is clearer that neural changes affect memory, it is unclear *what* it is about these age-related changes in frontal regions that resulted in memory decline. One theory that has proved itself promising in not only accounting for age-related memory declines, but also in integrating the emerging neural evidence discussed above, is that of the *inhibition theory of attention*.

Inhibition Theory and Memory Clutter

The inhibitory theory, first conceptualised by Hasher and Zacks (1988), frames age-related memory decline as resulting from a reduced ability to filter-out and suppress irrelevant or distracting information. More specifically, the Hasher-Zacks (1988) inhibition framework poised inhibition as a central mechanism that dictates the contents of working memory, in turn affecting a wide array of cognitive functions (Hasher et al., 1991). There are three major components at the core of inhibition frameworks: Access, Deletion, and Restraint (Campbell et al., 2020).

Access refers to the ability to ignore, or inhibit, task irrelevant information by driving attention away from distractions. This is also known as access control. As access fails, distractions can influence the processing of target stimuli (Lustig et al., 2007). Depending on the type of distractors, this influence on target stimuli processing can either result in significant costs or in substantial benefits to processing speed. For instance, processing speeds of older adults can be reduced when distractors interfere with the processing of target stimuli, such as randomly placed words (distractors) in reading materials (target stimuli) (see Carlson et al., 1995). Processing speeds, however, can also be enhanced if distracting materials facilitate the processing of target stimuli. Such enhanced processing times can surface in Remote Association Tasks, a task in which participants are required to identify a target word that connects three presented cue words; if cue words are associated with leading prompts, target word retrieval can be facilitated (May, 1999).

Deletion, the second component, refers to one's ability to discard both irrelevant information that bypassed the initial attentional filter and information that became irrelevant as a result of a change in goal or context (Campbell et al., 2020). The inability to discard irrelevant information, also known as proactive interference, can have significant benefits or costs on task performance depending on their relation to the target stimuli at the time of retrieval. Information considered no longer relevant but remaining in memory can be utilised in subsequent creativity tasks, boosting creative response in both younger and older adults (Carpenter et al., 2020; Kim et al., 2007). However, a sustained failure to suppress and discard irrelevant information is believed to result in greater memory impairments (Gazzaley et al., 2005; Ikier et al., 2008).

Finally, Restraint refers to one's ability to inhibit competing responses in order to select a goal-relevant response (Campbell et al., 2020). For instance, Restraint is required to inhibit automatic word reading in the Stroop task in goal of correctly naming the font colour of the word. While evidence suggests that there are reliable means of eliciting observable age-related performance differences in tasks requiring Restraint, such as the go/no-go task (see Rey-Mermet & Gade, 2018), other studies report that response inhibition may only be reliably observed at the neural level (see Kardos et al., 2020).

The inhibition theory has been expanded since its conception. A recent review by Amer and colleagues (2022) propelled the concept of *cluttered memory representations* in goal of better describing and interpreting the differences in memory capacities between younger and older adults. Memory representations denote stored interconnected mnemonic information, which can be cluttered by the unintentional interference of irrelevant or previously relevant information. The inability to inhibit interfering information is argued to draw processing resources away from relevant information, leading to memory cluttering, and ultimately memory decline. The notion of cluttered memories has its roots in inhibition theory, and thus shares many similarities with concepts discussed above (Amer et al., 2022). For instance, older adults' memories are cluttered with excessive information as a result of their reduced ability to inhibit the intake of non-target information (failure in access control). This cluttering, in turn, poses a challenge as it interferes with the retrieval of relevant information (failure in deletion). Older adults' reduced ability to delete irrelevant information results in a reduced ability to regulate competing responses in action and thought (failure in restraint). However, the continuous inability to prevent/inhibit the integration of irrelevant information from interfering with efficient functioning is what is argued to result in saturated and cluttered memory representations. That older adults struggle with active suppression of irrelevant information (whether from the environment or from memory representations) does not mean that young adults filter-out *all* irrelevant information from their surroundings. While younger adults are argued to be better at filtering out irrelevant information before they can be integrated in memory representations, Amer and colleagues (2022) suggest that younger adults are also better at suppressing interference from information they unintentionally picked-up. In addition to this, Amer and colleagues (2022) further emphasise that the ability to suppress irrelevant or distracting information from memory representations is subject to much variation, not only between age groups, but also between individuals. By virtue of this, inhibition proficiency can be seen as a spectrum ranging from poorer inhibition to proficient inhibition (see Campbell et al., 2020).

An Incomplete Account of Age-related Memory Decline

The inhibition theory is based on the fundamental notion that younger adults are better than older adults at filtering out and suppressing irrelevant information, thus preventing the excessive cluttering of memory representations. It follows from this that older adults, as a result of their cluttered memory representations, should perform better than younger adults in tasks where previously irrelevant information is made relevant. To test this hypothesis, Gopie and colleagues (2011) utilised an incidental encoding task to assess younger and older participants' implicit and explicit memory retrieval capabilities for irrelevant information. Participants were asked to press keyboard keys of four different colours to match the font colour of words that appeared on a computer monitor. In a subsequent task, participants were placed in one of two conditions (implicit or explicit) in which they were asked to verbally complete word fragments, some of which were based on the previously irrelevant words from the colour identification task.

In the implicit condition, participants were told to complete the word fragments as best they could within the allocated time frame. In the explicit condition, however, participants were informed that some of the word fragments were based on the words previously displayed in the colour identification task. Gopie and colleagues (2011) demonstrated that older adults had better implicit memory capabilities for irrelevant information than younger adults. This evidence in turn supports the assertion by Amer and colleagues (2022) that older adults do not suppress irrelevant information as efficiently as their younger peers. In contrast, younger adults had better memory than older adults for information considered irrelevant once the task was made explicit. The fact that younger adults outperformed older adults in the explicit condition does not contradict the notion of memory clutter, as it clearly states that younger adults can still pick-up irrelevant information at encoding, and that they are better at suppressing irrelevant information until made relevant once again (Amer et al., 2022). As a result, younger adult performance could be accounted for by Amer and colleagues' (2022) stance.

What is unclear, however, is why older adult performance significantly dropped between condition types. That is, it is unclear why older adults had significantly lower performance scores in the explicit condition than in the implicit condition; in essence, the complete opposite performance to that of young adults. In accordance with the memory clutter framework discussed in Amer and colleagues (2022), older adults should have benefited from memory clutter in both the implicit and explicit trials, as their memory representations would have been similarly cluttered in both conditions – that is, unless another process actively prevented them from explicitly retrieving this information. Although Amer and colleagues (2022) account for the superior performance of older adults over their younger peers in implicit conditions, they provide no explanation as to why this pattern is reversed in explicit conditions. Thus, Gopie and colleagues' (2011) findings suggest that there could be a supplementary factor, in addition to inhibition competencies, that affect implicit and explicit memory retrieval.

Differential-Encoding Hypothesis

To explain these results, Gopie and colleagues (2011) posited that information could be encoded differently as a function of available *attentional resources*, which in turn dictated whether this information would be retrieved implicitly or explicitly; they referred to this as the *differential-encoding hypothesis*. Here, attentional resources refer to the "mental energy" required to complete cognitive tasks (see Craik & Byrd, 1982); the concept of attentional resources is described as a concept similar to that of *brain reserve*, in which attentional resources refer to the total processing capacity of a given individual as a function of neural structures (Stern, 2002). According to Craik and Byrd (1982), if a task exceeds one's processing abilities, performance is expected to decrease as a result of a diminished ability to process information.

Gopie and colleagues (2011) argued that, in older adults, information was encoded with less demanding, shallower perceptual processing as a result of reduced attentional resources. More specifically, it was suggested that older adults primarily encoded perceptual information as a result of a lessened ability to add depth to memorial processes because of age-related declines in frontal lobe volumes (attentional resources). This shallow perceptual encoding has been argued to be largely automatic and unconscious (Craik et al., 1994), thus facilitating implicit retrieval and preventing explicit recall. In contrast, Gopie and colleagues (2011) argued that younger adults primarily encoded conceptual information as a result of an increased propensity to incorporate rich depth to memorial processes thanks to greater attentional resources. This elaborative, conceptual encoding has been argued to mostly rely on conscious control (Craik et al., 1994), thus facilitating explicit recall, and preventing implicit retrieval.

It follows from this logic that exerting additional pressures on young adults’ attentional resources at the time of encoding could result in shallow processing as opposed to the more demanding processing typical of increased attentional resources. An additional experiment conducted by Gopie and colleagues (2011) demonstrated that younger adults, when undergoing a task dividing their attention at the time of encoding, performed identically to older adults at retrieval. In other words, younger adults displayed poor explicit memory and better implicit memory when their attention was divided at encoding. This suggests that attentional resources available at encoding, rather than exclusively inhibition of irrelevant information, could be a mediating factor in how well individuals perform in implicit and explicit tasks.

It must be noted that there has been pushback in regard to the findings brought forth by Gopie and colleagues (2011). For instance, a study by Amer and colleagues (2018) failed to replicate Gopie and colleagues’ (2011) young adult findings; however their study did not include older adults, which makes thorough comparisons to Gopie and colleagues’ (2011) study difficult. Another study by Amer and Hasher (2014) demonstrated that there are instances in which older adults, but not younger adults, can implicitly encode conceptual information of distractors, which would denote a more thorough processing of irrelevant information according to the differential-encoding hypothesis. However, Greene and Naveh-Benjamin (2022) demonstrated that, while strained attentional resources at encoding did not necessarily affect conceptual encoding in older adults, worse memory recall was likely in part attributable to less effective memory encoding and retrieval resulting from fewer available attentional resources. Greene and Naveh-Benjamin’s (2022) findings, according to Craik (2023), suggest that older adult deficits in encoding are likely to affect memory recall despite the preservation of conceptual encoding. Craik (2023) thus affirms that there remains an interesting distinction in implicit and explicit memory performance between younger and older adults in Gopie and colleagues' (2011) study – a distinction in performance that requires further studying.

The notions of inhibition and differential encoding are not mutually exclusive. If considered in conjunction with a reduced ability to inhibit irrelevant information, fewer available attentional resources at time of encoding may be a substantial contributor to memory decline. For instance, poor inhibition may result in irrelevant information interfering with given tasks (thus accounting for better implicit retrieval), and fewer available attentional resources at encoding may prevent the explicit retrieval of information (thus accounting for the poor explicit retrieval).

It follows from this that preserving processing capacities in older adulthood would preserve explicit recall. It can be logically deduced that a better ability in efficiently directing or redirecting attentional resources on task-relevant information at encoding, or in other words better *attentional control* (Bialystok & Craik, 2022), could play a compensatory role for age-related declines of attentional resources, thus preserving explicit retrieval abilities in older adults and mitigating memory decline. Whereas attentional resources refers to the processing capacity of a given individual as a function of available neural structures involved in processing, attentional control denotes how efficiently these neural structures are utilised - not unlike the notion of cognitive reserve (Stern, 2002).

As a result, we may be able to investigate memory decline by comparing the performance of younger and older adult groups for whom attentional control abilities are different, namely monolinguals and bilinguals (Bialystok, 2017). Bilinguals, by virtue of using more than one language system, are believed to have more experience in managing cross-linguistic interferences, ultimately resulting in more efficient attentional control (Bialystok et al., 2012; Freeman et al., 2017). It follows from this that bilingual experience may accommodate for age-related memory declines in attentional resources by more efficiently deploying said resources at time of encoding, ultimately attenuating the potential effects of age-related memory decline.

Bilinguals as a Potent Target Population

Bilinguals have been argued to benefit from some cognitive advantages over their monolingual peers in the domain of executive control (Bialystok et al., 2012; Bialystok et al., 2014; Grundy & Timmer, 2017; Luo et al., 2013). A recent framework by Bialystok and Craik (2022), based on research by Bialystok (2017), utilised the term “attentional control” as being a repertoire of processing operations that can be used to accomplish various goals. They argued that the broader construct of attentional control provided a satisfactory framework to interpret bilingual benefits in various tasks (for framework and review see Bialystok & Craik, 2022). To this extent, they suggest that behavioural differences between monolinguals and bilinguals in various tasks can be accounted for by their respective abilities to deploy and efficiently utilise available attentional resources. Bialystok and Craik (2022) explain that bilinguals are unlikely to possess more attentional resources than monolinguals, but rather that bilinguals more efficiently utilise these resources as a result of a continuous need to manage two languages.

Although bilinguals have been shown to possess more efficient attentional control than their monolingual peers, performance differences are not always readily observable. In a study assessing the attentional control capabilities of children, young adults, middle-aged adults, and older adults, Bialystok and colleagues (2005) found that bilinguals significantly outperformed their monolingual peers in all age groups except in young adults, where there were no difference in performance. Bialystok and colleagues (2005) speculated that performance in young adulthood is at peak efficiency, and that bilingual experience could in turn provide no additional performance benefits. It follows from this, however, that tasks applying additional pressures on attentional resources (more difficult tasks) could reveal the benefits of bilingual's efficient attentional control, even in young adults. A recent study assessing the performance of monolingual and bilingual young adults on progressively more difficult tasks demonstrated that the performance of monolinguals declined faster than that of bilinguals as task difficulty increased (Comishen & Bialystok, 2021). Thus, behavioural differences in performance between monolingual and bilingual young adults most saliently surface as task difficulty increases.

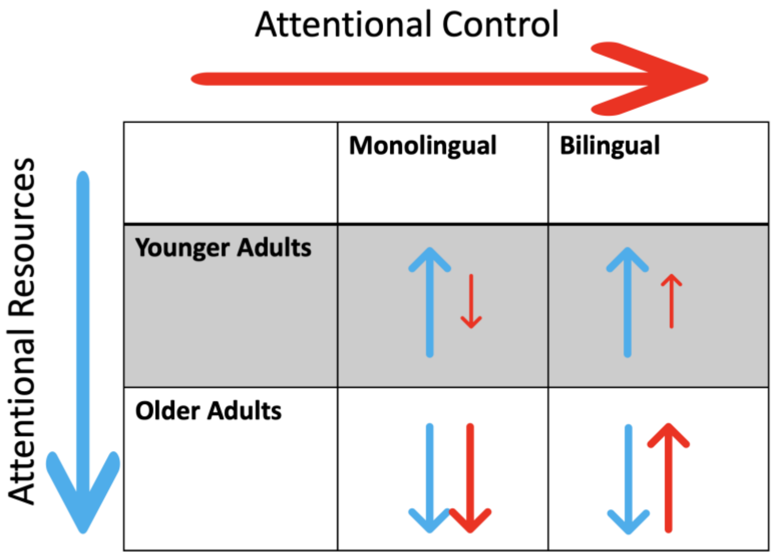
There are also drawbacks associated with the bilingual experience. While experience in managing two distinct languages have been associated with more efficient attentional control, between-language interference may also be the catalyst of lexical access difficulties in bilinguals (Sandoval et al., 2010). Studies demonstrate that bilingual individuals not only name fewer pictures on standardised naming tests (Roberts et al., 2002), but that they are also slower to do so than their monolingual peers (Gollan et al., 2005). These bilingual disadvantages are not limited to single word naming, as they have also been observed in the spoken production of noun phrases (Sadat et al., 2012) and in college-level writing tasks (Anderson et al., 2013). As a result of these verbal disadvantages, attentional control competencies of bilinguals are commonly measured and assessed with non-verbal tasks (notably Simon, Stroop, and Flanker tasks) to avoid cross-linguistic interferences (Zhou & Krott, 2016).

Present Study

The goal of the present study is to investigate the influence of attentional control on available attentional resources in implicit and explicit memory retrieval. To do so, the present study makes use of the incidental encoding task used in Gopie and colleagues (2011). In their study, participants were tasked to identify the font colour of words appearing on a screen (phase 1: word colour identification), and to then complete word fragments based on words from the word colour identification task (phase 2: word fragment completion). Similarly to Gopie and colleagues' (2011) paradigm, our word fragment completion task was divided in two conditions: implicit, in which participants were not told that some of the word fragments were previously seen, and explicit, in which participants were made aware of the fragments' relationship to the word colour identification task. Similarly to Gopie and colleagues' (2011) results, younger adults are expected to outperform their older adult counterparts in explicit trials, and older adults are expected to outperform their younger peers in implicit trials. We anticipate these results because more available attentional resources at encoding have been argued to facilitate explicit recall, and fewer attentional resources at encoding have been argued to facilitate implicit retrieval (Craik et al., 1994). Anticipated results are illustrated below by the blue arrows in Figure 1.

Figure 1.

Visual Representation of Anticipated Memory Performance.



Note: Red arrows denote the effect of attentional control, and blue arrows denote the effect of attentional resources. More arrows pointing down indicate worse explicit performance (but better implicit performance) and more arrows pointing up indicates better explicit performance (but worse implicit performance). Size of arrow is proportional to potential effect.

Bilinguals are at a significant disadvantage to their monolingual peers in verbal tasks as a result of lexical access difficulties. We anticipate that this factor will affect performance differences in two ways depending on age group membership and the task condition. Given that attentional resources in young adulthood are already at peak efficiency, thus preventing efficient attentional control from providing significant benefits in performance, we would typically expect young monolinguals to only slightly outperform bilinguals in the implicit condition, and with bilinguals to only slightly outperform monolinguals in the explicit condition. However, we hypothesise that ease of lexical access in monolinguals will offset potential attentional control benefits associated to bilingualism. In the implicit condition, monolinguals are expected to benefit from a slight increase in performance given their ability to more easily retrieve lexical information than bilinguals. This is anticipated to result in a greater performance disparity between monolinguals and bilinguals in the implicit condition. In contrast, monolingual ease of lexical access is expected to reduced performance differences between language groups in the explicit condition. Thus, we expect a significant difference in performance between young monolinguals and bilinguals in the implicit condition, but not in the explicit one.

In older adults, bilingual experience is expected to yield a different pattern. Given older adults' reduced attentional resources, we anticipate that the better attentional control abilities of bilinguals will facilitate explicit retrieval, but not implicit recall. Contrarily to younger adult anticipated results, we speculate that monolinguals' ease of lexical access in older adults will not offset the effects of more efficient attentional control in explicit retrieval, we do however expect that ease of lexical access will reduce performance differences between language groups in the implicit condition. Thus, we expect a significant difference in performance between older monolinguals and bilinguals in the explicit condition, but not in the implicit condition.

Anticipated results are illustrated above by the red arrows in Figure 1.

To account for lexical access difficulties, the present study also made use of a modified version of the shape change detection task, a non-verbal implicit and explicit memory competencies, conceptualised by Plebanek and Sloutsky (2017). Here, participants will be required to make judgements about implicit and explicit image pairs shown in quick succession. Similarly to the anticipated results from the incidental encoding task (Figure 1), younger adults are expected to significantly outperform their older adult peers in the explicit condition, though older adults are expected to significantly outperform their younger peers in the implicit condition. Older bilinguals are expected to significantly outperform older monolinguals in the explicit condition, though the opposite is expected to be the case in implicit trials. As a result of their available attentional resources, attentional control capabilities of younger adults are not expected to result in better implicit non-verbal task performance, but are expected to result in marginal differences in explicit trial performance with bilinguals outperforming monolinguals.

According to Luk and Bialystok (2013), bilingualism is a multi-dimensional construct that must be assessed as a continuous variable to effectively capture bilingual experience. They suggest that bilingual experience is composed of various components (e.g., daily bilingual usage and English proficiency) that must be taken into consideration to measure the consequences of bilingual experience. Solely assessing bilingual experience categorically may therefore fail to capture individual differences in bilingual usage. To account for the individual nuances of bilingual experience, we also assessed bilingual experience as a continuous variable in our analyses. For the verbal task, we expect to detect significant correlations between bilingual experience and explicit memory performance in older adults, but not in younger adults because of monolingual ease of lexical access. In the non-verbal task, we expect to detect significant correlations between bilingual experience and explicit memory performance.

In summary, age-related memory declines are often attributed to a reduced ability to inhibit the intake and interference of irrelevant information, as posited by the inhibition theory, though recent evidence may suggest that additional mechanisms are at play. In the study by Gopie and colleagues (2011), older adults performed better than younger adults in implicit memory tasks, though the opposite proved to be the case in the explicit task. Here they theorised that available attentional resources at time of encoding dictated how information is likely to be retrieved, whereby fewer attentional resources facilitated implicit retrieval, and greater attentional resources facilitated explicit retrieval. Following this logic, few available attentional resources at encoding may be a contributing factor to memory decline. Evidence from bilingualism research suggest that experience managing languages leads to more efficient attentional control, often associated with cognitive task performance. It remains unclear, however, to what extent attentional control efficiency can preserve explicit memory retrieval in spite of age-related declines in attentional resources. The present study aims at providing insights on the underlying mitigating factors of age-related memory decline by focusing on the attentional control efficiency of monolinguals and bilinguals, in conjunction with the attentional resource capacities of younger and older adults, and how those relate to memory retrieval.

Methods

Participants

To qualify for our study, participants had to be free of any neurological episodes in the past 5 years (e.g., epilepsy or strokes), free of any cognitive impairments (e.g., diagnoses or concussions), have normal or corrected vision, and could not be colourblind. Eighty-nine young adults were recruited through York University’s Undergraduate Research Participant Pool

(URPP) and 43 healthy older adults were recruited from the community and through a participant contact list provided by the Rotman Research Institute at the Baycrest center. From recruited young adults, 13 were omitted from the analyses either due to not meeting the study requirements (*n* = 4) or due to technical error (*n* = 9). No older adult participants were excluded from our analyses. The final sample included 76 young adults and 43 older adults.

All participants were administered the Language and Social Background Questionnaire (LSBQ), a measure that assesses the degree to which participants utilise different languages in their everyday lives (Anderson et al., 2018). Given that bilingual experience is expressed differently between younger and older adults (see Anderson et al., 2020) a younger adult version[1] and an older adult version[2] of the LSBQ were administered to their respective age groups with the assistance of a research assistant via a Qualtrics survey. Although the questionnaire for younger and older adults differed both in the way questions were asked, and how they were scored, both instruments produced a Composite Factor Scores (CFS) reflecting bilingual experience (Anderson et al., 2020). CFS were computed individually for each participant in both age groups by weighing English Proficiency, Non-English Social Use, and Non-English Home Use and Proficiency (see Table 1 for scores). LSBQ outputs were standardised and rescaled on a scale ranging from 1 to 10 in which 1 indicates limited or no bilingual experience, and 10 indicates more bilingual experience. A median split of Non-English Home Use and Proficiency scores was conducted to categorise participants as either monolingual or bilingual (see Table 2 for data; for non-median split data, see supplementary Table 10 in Appendix B).

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[1] Younger adult questionnaire can be obtained here: https://doi.org/10.6084/m9.figshare.3972486.v1

[2] Older adult questionnaire can be obtained here: https://figshare.com/s/d6a203559d8e4905b5bb

Table 1.

Participant LSBQ scores by age group.

	Age Groups					
	Younger Adults (*n* = 76)			Older Adults (*n* = 43)		
LSBQ	*M*	Range	*SD*	*M*	Range	*SD*
English Proficiency	6.83	1.42 to 8.45	1.85	7.29	2.81 to 8.26	1.65
Non-English Social Use	3.22	1.12 to 9.93	1.84	2.62	1.82 to 7.74	1.49
Non-English Home Use and Proficiency	5.55	1.07 to 9.06	2.07	4.03	3.17 to 6.00	0.98
Rescaled CFS	5.35	1.94 to 9.87	1.60	4.39	3.2 to 7.14	0.91

Note: Scores range from 1 to 10.

Table 2.

Demographic Characteristics by Age and Language.

	Age (Years)		
Age Groups	*M*	Range	*SD*
Young Adults			
Monolingual (*n* = 38)	19	18-22	1.17
Bilingual (*n* = 38)	20	18-24	1.54
Older Adults			
Monolingual (*n* = 22)	71	61-82	7.08
Bilingual (*n* = 21)	71	60-79	5.79

Note: Participants of each age group were categorised as monolingual or bilingual by conducting a median split of Non-English Home Use and Proficiency scores

Procedure and Stimuli

Participants took part in five tasks: Word Colour Identification, Word Fragment Completion, Shape Change Detection, Simon Arrows, and N-Back task. There were two possible orders in which tasks were presented: (1) Word Colour Identification, Simon Arrows, N-Back, Word Fragment Completion, Shape Change Detection, or (2) Shape Change Detection, Word

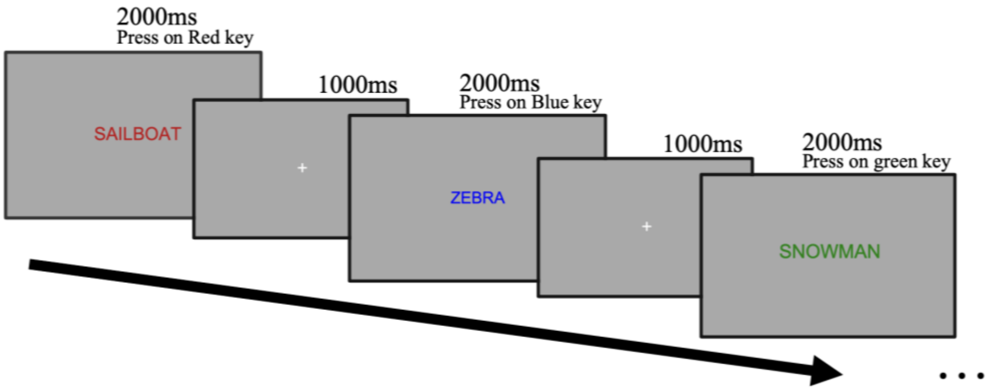
Colour Identification, N-Back, Simon Arrows, Word Fragment Completion. In each age group, half of participants completed the tasks in order 1, and half completed them in order 2. Consent forms were always signed before taking part in the tasks, and the LSBQ questionnaire was always administered after taking part in the tasks. Although we administered the Simon Arrows and N-Back tasks, they were not included in our analyses and discussion as their results were beyond the scope of the present thesis. All tasks, with the exception of N-Back, were programmed and executed in PsychoPy (Version 2021.2.3, Peirce et al., 2019). Our N-Back task was programmed and executed with Inquisit 6 (Version 6.6.1 64bit, Inquisit 6, 2022).

Verbal Task: Word Fragment Completion

Phase 1: Word Colour Identification. Methods and stimuli for this task paralleled that of Gopie and colleagues' (2011) incidental encoding task. Participants were presented with a total of 52 words appearing in 1 of 4 possible colours (red, green, blue, or yellow) each associated to a keyboard key. Once the activity began, participants were given instructions about finger placement on the keyboard. This was followed by a series of instructions about which colour is associated to which keyboard key (red to Q, green to W, blue to O, and yellow to P). Coloured stickers were placed over each respective key. Participants then engaged in a scripted practice phase where they were given the opportunity to properly associate colours to the corresponding keys. Once completed, participants begin the activity. A fixation cross first appeared for 1000ms, after which a coloured word was displayed on the screen for 2000ms; participants had 2000ms to press on the corresponding key. After this 2000ms elapsed, the word disappeared, and the fixation cross reappeared once again for 1000ms, which was then followed by the next trial. If participants pressed on one of the keys before the 2000ms fully elapsed, the next trial would start (Figure 2). This process was repeated until all trials were completed.

Figure 2.

Sample Word Colour Identification Trials.



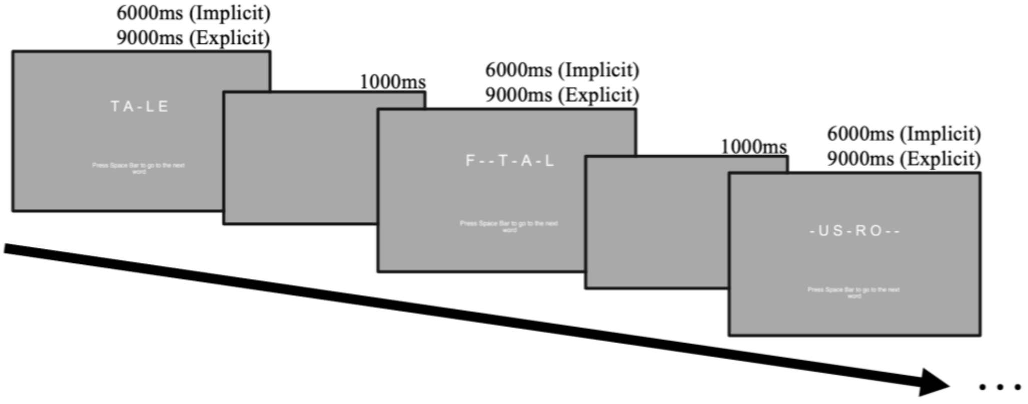
Stimuli were words borrowed from the Rajaram and Roediger (1993) implicit word fragment completion task and used to create four blocks, A, B, C, and D, each consisting of 10 words. In addition to these four blocks, a filler word list composed of 58 words was also created, producing a total of 98 possible words. Of the 52 words administered to participants, 20 were from a combination of two of the blocks A, B, C, or D (see Appendix A1 for word blocks) and 32 were from the filler block (6 were used at the beginning of the experiment to account for primacy, and 6 were used at the end to account for recency; see Appendix A2 for a schematic of word selection and randomisation). Other than the words accounting for primacy and recency, selected words were re-organised in a random fashion. The colours of the words were also randomised such that each participant had their own unique set of randomized words and colour combinations. Words were overlayed on a light grey background to facilitate the legibility of coloured words (i.e., yellow words are hard to read on a white background, red and blue are more difficult to read on a black background).

Phase 2: Word Fragment Completion. This task was separated into two conditions – an implicit condition followed by an explicit condition. In the implicit condition, participants were instructed that no keyboard inputs were necessary, but that they were required to utter their answers out-loud. Following practice trials to clarify the goal of the activity, the test trials began. Participants were first shown a blank screen for 1000ms, after which a word fragment from their randomised fragment list was shown on the screen for 6000ms. Participants were required to provide their answers within this time frame. Participant answers for target words were marked as “correct” if they matched their corresponding word cued in the Word Colour Identification task, or as “incorrect” if their answer did not match the corresponding cued word or if no answer was provided. Participant answers for non-target words were marked as “correct” if the provided response matched the fragment (several possible answers), or as “incorrect” if their answer did not match the fragment or if no answer was provided (for scoring sheet example, see Appendix A5). After 6000ms, another blank screen was shown for 1000ms, after which the next trial began. Participants could press on the spacebar if they wished to go to the next trial without waiting for the allocated time to fully elapse (Figure 3). This process was repeated until the participants had gone through the 30 trials of the implicit condition.

In the explicit condition, participants were informed that word fragments were based on words that they had previously seen during the Word Colour Identification task. In addition to this, participants were informed that they had more time to give their answers, in this case, 9000ms (Figure 3). Additional time was provided given that the task was explicit in nature and could require more processing to retrieve words that they had previously seen.

Figure 3.

Sample Word Fragment Completion Trials.



There were 96 word fragments based on words from Phase 1 (see Appendix A3 for word fragment lists), also borrowed from Rajaram and Roedinger (1993). Word difficulty was determined by the difficulty of their respective word fragment completion counterparts. “Easy words”, based on words from the filler list, missed fewer letters in their respective fragments, thus making their completion simpler than hard words. Participants were shown 30 word fragments in each of the implicit and explicit conditions, for a total of 60 different word fragments. In each condition, 10 words were from a Block that was previously used in Phase 1, 10 were from a new unused Block, and 10 were randomly chosen from the filler word list (see Appendix A4 for schematic). The fragments themselves were written in white on a light grey background to facilitate legibility and prevent eye fatigue.

Non-Verbal Task: Shape Change Detection

Stimuli and methods for this task were borrowed from the Plebanek and Sloutsky (2017) Change Detection task. In total, there were 70 images organised into 35 image pairs that could be selected and shown to participants, each composed of a red shape (explicit target) and green shape (implicit target) overlayed on a white background. Here, 11 image pairs had different red shapes but identical green shapes (explicit trials), 15 had the same red and green shapes within their pair set (no change trials), and 9 image pairs had identical red shapes, but different green shapes (implicit trials)[3].

Participants were given instructions on how to place their fingers on the keyboard; the right shift-key was designated “Yes” and the left-shift key was designated “No”. Participants were then asked two task-irrelevant questions in order to practice with the “Yes” and “No” keys. After being shown each image pair, participants were asked to answer two questions: (1) “Was the red shape in the second image symmetrical?” (distractor question), and (2) “Did the images change?” (see Figure 4 below). The task began with a practice phase in which participants were shown 5 image pairs where red shapes were different within their respective pairs, but the green shapes were the same (drawn randomly from image set range 1 to 11). Participants were shown the first image of the pair for 1000ms. This was followed by a fixation cross for 500ms, and then by the second image of the pair for another 1000ms. Participants were then prompted with the question: “Was the second red shape symmetrical?”. Upon the key press answer, a new question was prompted: “Did the image change?”. Upon key press, the next trial started (Figure 4). This went on until the 6th trial, where the task seamlessly transitioned from the cueing phase to the test phase. During the test phase, participants were to assess 15 image pairs (5 pairs randomly selected from each trial type pool), each trial was of the same duration as in the cueing phase.

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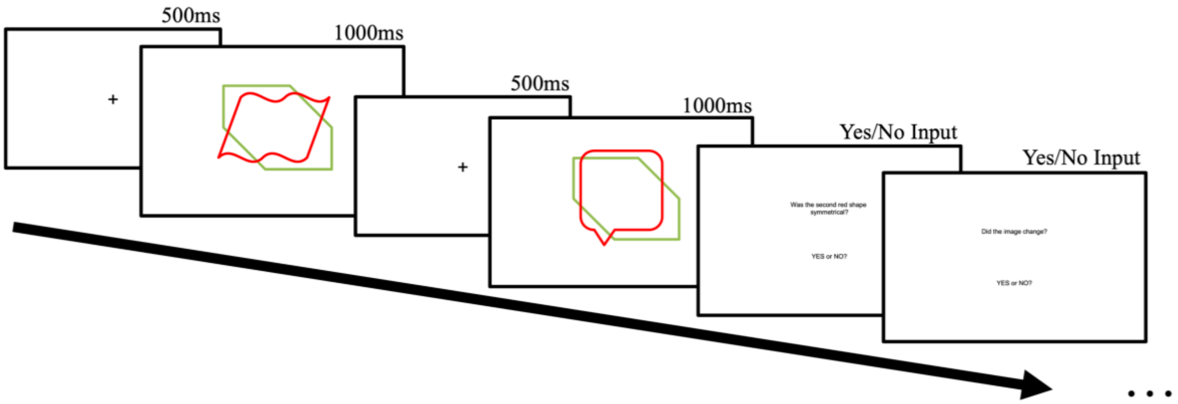
[3] Stimuli can be obtained here: https://doi.org/10.7910/DVN/7TA47E

Figure 4.

Sample Shape Change Detection Trial.



Note: Second red shape is not symmetrical (first response should be "no"), and the image did change (second response should be "yes").

Results

Given the unbalanced number of participants between younger and older adult median split groups, all of our analysis of variance (ANOVA) analyses were conducted with hierarchal/ partially sequential sum of squares (Type II). Type II sum of squares has been argued to be preferable when conducting ANOVA with unbalanced sample sizes (see Langsrud, 2003). Omega squared (ω^2) was calculated as an estimate of our effect sizes. Omega squared has been argued to be less biased than eta squared in relatively small samples (Levine & Hullett, 2002; Olejnik & Algina, 2003), and was thus favored for our analyses. In terms of effect size, $\omega^2 = 0.01$ was considered small, $\omega^2 = 0.06$ was considered moderate, and $\omega^2 = 0.14$ was considered large (Goss-Sampson, 2019). Correlational analyses computed between task performance and LSBQ scores and its subcomponents were one-sided given our a priori directional hypotheses. More specifically, we exclusively assessed the positive correlations (one-sided alternative hypothesis in which the correlation is greater than 0) between non-English competency (Non-English Social Use, Non-English Home Use and Proficiency, and CFS scores) and explicit performance, and between English Proficiency and implicit performance. We also exclusively assessed the negative correlations (one-sided alternative hypothesis in which the correlation is lower than 0) between non-English proficiency and implicit performance, and between English proficiency and explicit performance. All analyses were performed in JASP (Version 0.18.1, JASP Team, 2023).

Word Fragment Completion

Scores for target fragment completion were computed by assessing the proportion of successful fragment completion that were previously primed during the word colour identification task. Control fragment completion scores were computed by assessing the proportion of successful word fragment completion of words not previously seen by participants during the word colour identification task. Proportions were calculated by dividing successful fragment completions by 10 (total possible correct fragment completion). Memory performance scores were computed by subtracting control scores from target scores following Gopie and colleagues' (2011) approach (see Table 3; for non-median split data, see supplementary Table 11

Table 3.

Mean Proportions (Standard Deviations) of Target and Control Word Fragment Completion and Memory Performance by Age and Language.

	Younger Adults (*n* = 76)		Older Adults (*n* = 43)	
Measures	Monolingual	Bilingual	Monolingual	Bilingual
Target Completion				
Implicit	.21 (.15)	.15 (.13)	.16 (.11)	.25 (.15)
Explicit	.25 (.17)	.19 (.15)	.19 (.15)	.18 (.15)
Control Completion				
Implicit	.16 (.13)	.13 (.10)	.14 (.10)	.15 (.09)
Explicit	.16 (.13)	.12 (.13)	.22 (.15)	.14 (.15)
Memory Performance (Target – Control)				
Implicit	.05 (.18)	.02 (.16)	.02 (.13)	.10 (.16)
Explicit	.09 (.21)	.07 (.20)	-.04 (.17)	.03 (.14)

Note: Monolingual YA (n = 38), Bilingual YA (n = 38), Monolingual OA (n = 22), Bilingual OA (n = 21), based on Non-English Home Use and Proficiency median split.

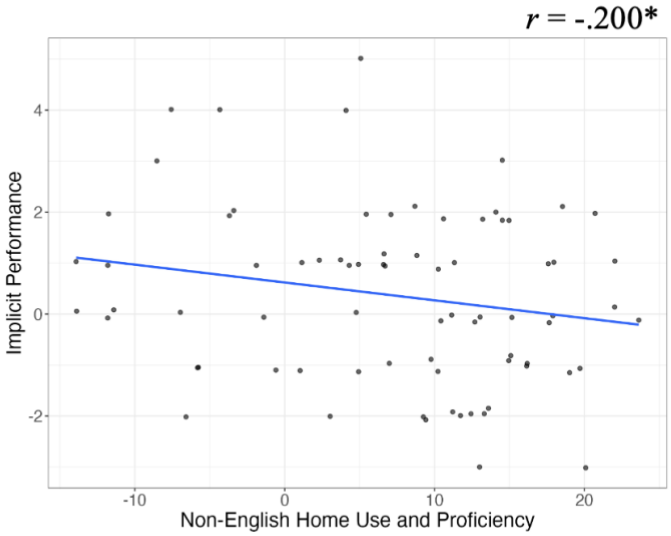
in Appendix B). Target and control completion scores were not submitted to further analyses.

We submitted the Memory Performance scores (Target – Control) to a 2 (Condition: implicit, explicit) x 2 (age: younger, older) x 2 (language: monolingual, bilingual) repeated measures ANOVA. There was a significant Condition x Age interaction, $F(1, 115) = 5.14$, $p = .025$, $\omega^2 = .017$, and an Age x Language interaction, $F(1, 115) = 5.06$, $p = .026$, $\omega^2 = .017$. There was no main effect of Condition, and no Condition x Language, or Condition x Age x Language interactions. To follow up these significant interactions, we conducted 2 (Age: younger, older) x 2 (Language: monolingual, bilingual) ANOVAs for the implicit and explicit memory performance scores separately. For the implicit memory scores, there was a significant Age x Language *disordinal* interaction, $F(1, 115) = 4.90$, $p = .029$, $\omega^2 = .032$. Follow-up simple main effect analyses revealed that there was a significant effect of Age on the implicit memory performance of bilinguals, $F(1) = 4.18$, $p = .043$, in which older bilinguals outperformed younger bilinguals. In addition, there was a simple main effect of Language on the implicit memory performance of young adults, $F(1) = 6.64$, $p = .011$, in which monolingual young adults outperformed bilingual young adults. For the explicit memory performance scores, there was a significant main effect of Age group, $F(1, 115) = 5.26$, $p = .024$, $\omega^2 = .035$, in which younger adults outperformed older adults. There were no main effect of Language group and no Age group x Language group interaction.

Correlational analyses were conducted in order to assess the potential relation between bilingual experience and memory performance. A Pearson coefficient was computed to assess the linear relationship between bilingual experience and implicit memory performance scores with the prediction being that individuals with more bilingual experience would perform worse in the implicit condition than more monolingual participants. In young adults, there was a significant negative correlation between Non-English Home Use and Proficiency and implicit memory scores in young adults, *r*(74) = -.20, *p* = .04, indicating that bilingual proficiency was associated with lower implicit scores (see Figure 5). There were no significant correlations for older adults. Pearson coefficients were also computed to assess the linear relationship between bilingual experience and explicit memory performance scores, with the prediction being that participants with more bilingual experience would perform better in the explicit condition than more monolingual participants. There were no significant positive correlation between English Proficiency and explicit memory scores in younger adults. However, explicit memory performance in older adults were found to have significant positive correlations with Non-English Home Use and Proficiency, *r*(41) = .259, *p* = .047 (see Figure 6A), and overall LSBQ composite factor scores, *r*(41) = .288, *p* = .031 (see Figure 6B), indicating that bilingual proficiency was associated with better explicit performance in older adults.

Figure 5.

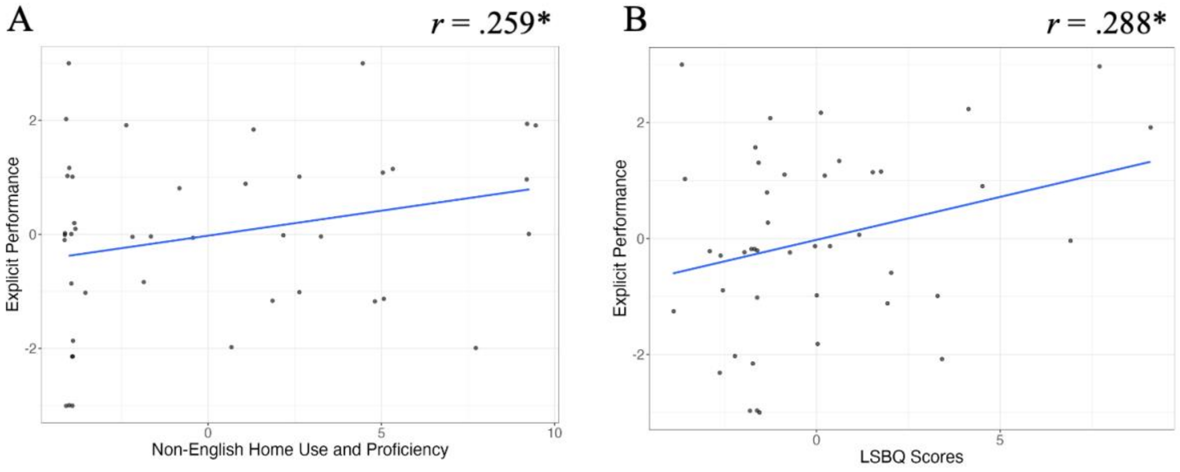
Young Adult Correlation Between Implicit Scores and Non-English Home Use and Proficiency.



Note: One-sided, * p < .05, ** p < .01, *** p < .001.

Figure 6.

Older Adult Correlations with Non-English Proficiency.



Note: A – Older adult correlation between explicit performance and Non-English Home Use and Proficiency. B – Older adult correlation between explicit performance and LSBQ Composite Factor Scores. On-sided, * p < .05, ** p < .01, *** p < .001.

Shape Change Detection

In the shape change detection task, hardware malfunction resulted in the omission of 9 older adult participants. An additional older adult participant and 7 additional younger adults were also omitted from the data sample due to failure to follow instructions, or being significant outliers beyond four standard deviations from mean task scores. In sum, we used the data of 69 younger adults and of 33 older adults for our analyses.

To calculate accuracy scores in the Shape Change Detection task, we used raw score for explicit (change in red shape) and implicit (change in green shape) trials (Table 4). Each correct shape change detection awarded participants one point, with a total of five points for each the explicit and implicit trials. For the no change trials, each false alarm awarded participants one point, for a total of 5 possible points (higher scores denote a worse performance).

Table 4.

Mean (Standard Deviations) Explicit, Implicit, and No Change Scores.

	Age Groups	
Trial Type	Younger Adults (*n* = 69)	Older Adults (*n* = 33)
Implicit Change	2.00 (1.71)	1.68 (1.56)
Explicit Change	4.68 (0.58)	4.81 (0.47)
No Change	0.77 (0.94)	1.27 (1.51)

Note: These values represent the number of times (out of 5) participants said there was a change. For "no change" scores represent false alarms.

Preliminary Analyses

There was a significant positive correlation (two-sided) between performance scores of implicit and no change trials both in younger adults, $r(74) = .231$, $p = .045$, and older adults, $r(32) = .676$, $p < .001$, meaning that participants tended to consistently press the "yes" key in both the implicit and no change trials, or to consistently press the "no" key in both implicit and no change trials. This could imply the presence of a response strategy, given that perfect scores (5/5 in implicit trials, and 0/5 in no change trials) would result in a strong negative correlation. In contrast, there was a negative correlation between performance scores of explicit and no change trials in younger adults, $r(74) = -.271$, $p = .024$, but not in older adults, $r(32) = -.016$, $p = .93$, indicating that participants did not engage in such a strategy. The weaker younger adult correlation between implicit scores and no change scores suggests that younger adults were less prone to engage in such a response strategy. Though as demonstrated by the strength of the correlation between implicit scores and no change scores, it is likely that older adults strongly engaged in this response strategy. According to Henderson and colleagues (2020), older adults tend to engage in guessing strategies when flexibly allocating attentional resources between targets of varying priorities (in this case: red higher priority, green lower priority). In order to control for this, we subtracted the No Change scores of each participant from each of their explicit and implicit Scores in order to compute adjusted scores (see Table 5).

Table 5.

Mean (standard deviation) scores for Explicit and Implicit Scores with Subtracted No Change Scores by Age group and Language group.

	Younger Adults (*n* = 69)		Older Adults (*n* = 33)	
Trial Type	Monolingual	Bilingual	Monolingual	Bilingual
Implicit Change	1.36 (1.90)	1.09 (1.42)	0.24 (1.15)	0.56 (1.37)
Explicit Change	3.56 (1.42)	4.30 (0.85)	3.12 (1.80)	4.00 (1.21)

Note: Scores range from -5 to 5. Monolingual YA (n = 36), Bilingual YA (n = 33), Monolingual OA (n = 17), Bilingual OA (n = 16)

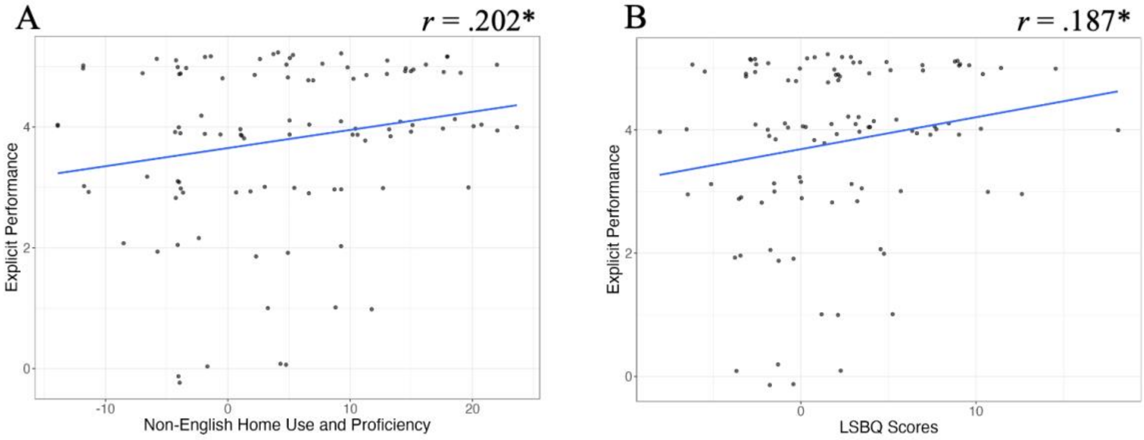
Main Analyses

We submitted the adjusted scores to a 2 (Condition: explicit, implicit) x 2 (Age: younger, older) x 2 (Language: monolingual, bilingual) repeated measures ANOVA. There was a main effect of Condition, $F(1) = 263.23$, $p < .001$, $\omega^2 = .495$, with participants performing significantly better in the explicit trials than in the implicit trials. There was no Condition x Age interaction, and no Condition x Age group x Language interaction. To assess between subject differences, we conducted 2 (Age: younger, older) x 2 (Language: monolingual, bilingual) ANOVAs for the implicit and explicit memory performance scores separately. In implicit trials, there was a significant main effect of Age, $F(1) = 15.66$, $p < .014$, $\omega^2 = .050$, in which younger adults outperformed their older adult peers. In the explicit trials, there was a significant main effect of Language, $F(1) = 9.32$, $p < .003$, $\omega^2 = .075$, in which bilinguals outperformed their monolingual peers.

Additional correlational analyses were conducted in order to capture the effect of bilingual experience. Pearson coefficients were computed to assess the linear relationship between bilingual experience and implicit scores. There were no significant negative correlation between bilingual proficiency and implicit scores. Pearson coefficients were also computed to assess the linear relationship between bilingual experience and explicit scores. Explicit trial performance was positively correlated with Non-English Home Use and Proficiency, *r*(100) = .202, *p* = .021 (Figure 7A) and with LSBQ composite factor scores, *r*(100) = .187, *p* = .030, indicating higher scores for participants with more bilingual experience (Figure 7B).

Figure 7.

Correlations Between Explicit Performance and Non-English Proficiency.



Note: A – Correlation between explicit trial performance and Non-English Home Use and Proficiency. B – Correlation between explicit trial performance and LSBQ Composite Factor Scores. One-sided, * p < .05, ** p < .01, *** p < .001.

Discussion

The present study aimed at providing insights on the underlying mitigating factors of age-related memory decline by focusing on the attentional control efficiency of monolinguals and bilinguals, in conjunction with the attentional resource capacities of younger and older adults, and how those related to memory retrieval capabilities. We recruited younger and older adults to assess the role of available attentional resources, in addition to monolinguals and bilinguals to study the role of attentional control. We administered two tasks: a verbal task, composed of a word colour identification activity in which words were primed for later retrieval in a follow-up implicit and explicit word fragment completion activity, and a non-verbal task, composed of an implicit and explicit shape change detection activity. We hypothesised that, in both tasks, younger adults would outperform their older peers in explicit trials, and that older adults would outperform their younger peers in implicit trials. We further hypothesised that, in both tasks, bilingual participants would outperform their monolingual peers in explicit trials, but that monolinguals would outperform their bilingual peers in implicit trials. We however expected that the differences between monolinguals and bilingual young adults in both tasks would remain marginal given that performance in young adulthood is at peak efficiency, ultimately preventing bilingual experience from providing additional performance benefits.

For our analyses of variance, we categorised participants as either monolingual or bilingual by conducting a median split as a function of the Non-English Home Use and Proficiency LSBQ sub-component. This however does not capture the continuous nature of language experience, and results in a reductionist interpretation of bilingualism (see Luk & Bialystok, 2013; Wagner et al., 2022). Median splits can also result in bilingual participants being categorised as monolingual if the group as a whole possesses a high degree of bilingual proficiency, and vice-versa (for an assessment of continuous variable median splits, see McClelland et al., 2015). For example, our group medians between younger and older adults were considerably different, with younger adults having a higher Non-English Home Use and Proficiency median than our older adult participants. Given how these scores were standardised, this resulted in young adults being categorised as monolingual despite older adults with same scores being categorised as bilingual. This could have affected differences in task performance between our monolingual and bilingual groups in both age groups. We therefore leveraged language experience as a continuous variable to assess implicit and explicit memory performance. We expected to detect significant correlations between bilingual experience and explicit memory performance in both our verbal and non-verbal tasks.

Verbal Task

We found that younger adults significantly outperformed their older peers in the explicit condition as predicted, but that there was no difference between age groups in the implicit condition. Results for the explicit task are consistent with differences in available attentional resources at encoding for the two age groups. In this regard, we successfully replicated the explicit condition results from Gopie and colleagues' (2011) study, though we failed to replicate their findings for the implicit condition task. We additionally found that younger monolinguals significantly outperformed their bilingual peers in the implicit condition. These results are consistent with our hypothesis that monolinguals' ease of lexical access would lead to a greater performance disparity between monolinguals and bilinguals in the implicit condition. Although young bilinguals did not outperform their monolingual peers in the explicit condition, the lack of group differences may suggest that the monolingual ease of lexical access reduced performance differences between language groups in the explicit condition – this concords to some extent with our hypothesis. Correlational analyses revealed that implicit memory performance was negatively correlated with non-English proficiency measures, but that explicit performance was not positively correlated non-English proficiency measures. In contrast, we found that explicit memory performance in older adults was correlated with non-English proficiency measures. Such results can be interpreted as suggesting that there is, in older adults, an effect of attentional control efficiency on explicit memory performance.

The fact that language experience correlates in a different manner between our younger and older adults could be interpreted as suggesting that more bilingual experience (more efficient attentional control) comes as a benefit in the explicit condition for individuals who possess fewer attentional resources (older adults), but as a detriment in the implicit condition to individuals with more available attentional resources (younger adults). Younger bilinguals seem to have been at a substantial disadvantage to their monolingual peers in the implicit condition, but there were no differences in performance in the explicit condition. In older adults, we found that there were no significant language group differences in performance in the implicit or explicit condition in the between-group analyses, but the continuous correlation analyses showed a positive correlation between bilingual experience and explicit memory performance. This concords with our hypothesis that bilingual experience would be associated with better explicit performance. These results can be interpreted as denoting a link between explicit memory recall and efficient attentional control. See Table 6 for result breakdown.

Table 6.

Verbal Task Hypotheses and Results Summary.

Hypotheses	Results	Match?
YA would outperform OA in Explicit memory performance	YA outperformed OA in Explicit memory performance	Yes
OA would outperform YA in Implicit memory performance	OA did not outperform YA in Implicit memory performance	No
YA-Mono would outperform YA-Bi in Implicit memory performance	YA-Mono outperformed YA-Bi in Implicit memory performance	Yes
There would be no significant difference in performance between YA-Mono & YA-Bi in the explicit condition	There was no significant difference in performance between YA-Mono & YA-Bi in the explicit condition	Yes
OA-Mono would not outperform OA-Bi in Implicit memory performance	There was no significant difference in performance between OA-Mono & OA-Bi in the Implicit condition	Yes
OA-Bi would outperform OA-Mono in Explicit memory performance	There was no significant difference in performance between OA-Mono & OA-Bi in the explicit condition	No
Bi experience in YA would correlate with Explicit memory performance	Bi experience in YA did not correlate with Explicit memory performance	No
Bi experience in OA would correlate with Explicit memory performance	Bi experience in OA correlated with Explicit memory performance	Yes

Note: Young Adults (YA), Older Adults (OA), Monolingual (Mono), Bilingual (Bi). Green denotes a match between our hypothesis and our results, Red denotes a failure to match our hypotheses.

It could be extrapolated from our results that higher levels of available attentional resources (younger adults) at the time of encoding played a positive role in explicit memory performance, but that when paired with more bilingual experience (younger bilinguals), resulted in poor implicit memory retrieval. According to the differential encoding hypothesis brought forth by Gopie and colleagues (2011), if more attentional resources are available, information is argued to be more thoroughly encoded, thus facilitating explicit retrieval. However if fewer attentional resources are available, information is said to be shallowly encoded, thus preventing explicit retrieval. It follows that younger adults from both language groups thoroughly encoded information; this is congruent with our explicit performance results. One reason as to why younger monolinguals significantly outperformed their bilingual peers on the implicit condition may reside in the nature of the task itself – that is, it is largely reliant on lexical access. Decades of research have continuously provided evidence that bilinguals require significantly more time than their monolingual peers in retrieving lexical information as they must select and control for the intrusion of competitor words from the non-target language (Bialystok et al., 2008; Gollan et al., 2005; Roberts et al., 2002). When administering a word fragment completion task for previously seen words to participants, Vander Beken and Brysbaert (2018) found that L2 free-recall of words matching fragments performance was significantly lower than when recalling words from their L1 language. This ultimately concords with our correlational analyses that demonstrated that high levels of Non-English Home Use and Proficiency negatively correlated with implicit word fragment completion performance. It is likely, and strongly substantiated, that monolingual experience facilitates implicit memory retrieval in spite of available attentional resources at the time of encoding. In sum, these young adult result interpretations indicate that attentional control may not be the catalyst of the substantial difference in performance between monolinguals and bilinguals in our implicit condition, but rather that bilingual experience interferes with implicit word fragment completion.

In contrast to our younger adult results, fewer available attentional resources (older adults) at the time of encoding is interpreted to having played a negative role in explicit memory retrieval, but that when paired with more efficient attentional control (older bilinguals), seemed to mitigate the negative effects of sparse attentional resources on explicit memory retrieval. These results are in line with our expectations and can be explained by the interactions between attentional resources and attentional control. If viewed through the lens of the differential encoding hypothesis, we can interpret the absence of significant group differences in the implicit condition as being the result of the fewer available attentional resources at the time of encoding. As per the explicit condition performance of older adults, explicit word fragment completion scores correlated with non-English proficiency, which we interpret as being a proxy for more efficient attentional control.

Verbal Task Limitations

There were important limitations to the methodological integrity of the word fragment completion task. Participant *target* word responses were considered correct if, and only if, their response matched the target word cued in the word colour identification task. Often, more than one word could complete word fragments. Consider for instance the fragment “-o-s-”. In this case, the only correct answer that counted as a successful target fragment completion was “house” given that it was primed in the word colour identification task. However, the fragment “-o-s-” can actually be completed by a wide array of responses such as “goose”, “loose”, “moose”, “horse”, “morse”, and potentially many more. Any of these words, however, could be used to successfully complete the word fragment when it was a novel *non-target* word. This means that participants had far more opportunities to successfully complete word fragments for novel words than they had for completing target words. This may thus have resulted in significantly lower memory scores than if fragments permitted only one possible correct response in all cases.

In addition to this, the task itself was also very difficult – while that is to be expected from a task that relies on cued words for implicit and explicit memory retrieval, mean memory performance proportions remained considerably low. While no quantitative or qualitative data was recorded to assess participants' perceived difficulty of the word fragment completion task, it must be anecdotally noted that an overwhelming majority of participants voiced their discontent as a result of the task's difficult nature. Given the large number of administered tasks, it is possible that mental fatigue, in conjunction with task difficulty, resulted in task disengagement. As demonstrated in previous studies, task difficulty leading to mental fatigue is often associated with task disengagement (Hopstaken et al., 2015). Considering that so few words were correctly completed by participants, it is also possible that a perceived lack of progress or accomplishment in the task resulted in lower participant motivation (see Barber et al., 2012), potentially resulting in faster task abandonment. That being said, a third of the word fragments presented to the participants were considered "easy", which could have maintained participant motivation through the task. This interpretation of low participant scores as a result of cognitive fatigue, task disengagement, and individual motivation remains speculative, as no data was collected to assess this potential interaction.

It may also be possible that the task's difficulty led to particularly poor task performance; baseline words in each conditions appeared to be prone to a floor effect in which a large of a proportion of participants achieved the lowest possible performance. This floor effect was less evident in experimental trials. That being said, it is possible that some word fragments were too difficult to complete at times – with some words being correctly completed by only a few participants. This floor effect could have been avoided if fragments were simpler. Easier fragments may have allowed for a better delineation between younger and older adults of both language groups, and allowed for more insightful results.

At several instances during our data collection, more bilingual participants informed us that they often involuntarily attempted to verbally complete word fragments with their non-English dominant language (again, no quantitative data was explicitly collected to assess cross-linguistic interference, though it remains a point of interest). As previously discussed, monolinguals have a considerable advantage on their bilingual peers in verbal tasks (Anderson et al., 2013; Sadat, et al., 2012; Sandoval et al., 2010). This monolingual advantage in verbal tasks may thus have skewed performance in their favor, as has been the case in other studies. In order to account for this confound in task performance, we also opted to conduct a non-verbal implicit and explicit memory performance task.

Non-Verbal Task

There was an effect of age for implicit trials in which young adults outperformed older adults, but there was no effect of age for explicit trials. This is inconsistent with our hypothesis that older adults would outperform younger adults in the implicit condition. There was also a correlation between bilingual experience and explicit memory performance which we interpret as suggesting that efficient attentional control can facilitate explicit memory retrieval, which concords with our hypothesis. When converted into A` (A prime) non-parametric sensitivity coefficients, our younger adult mean scores for explicit, implicit, and no change trials, closely mirror that of younger adults from Plebanek and Sloutsky (2017), from which we based our shape change detection task (for mean A` scores, see supplementary Table 12 in Appendix B). In other words, we successfully replicated their young adult results. In accordance with our hypotheses we found that bilinguals significantly outperformed monolinguals in explicit trials. However, contrary to our predictions, younger adults significantly outperformed older adults in the implicit condition. According to previous research, fewer available attentional resources (characteristic of older adults) at the time of encoding should in theory result in better implicit memory retrieval (Craik et al., 1994; Gopie et al., 2011). In addition to this, we expected monolinguals to significantly outperform their bilingual peers in the implicit trials, though no such pattern was found. See Table 7 for result breakdown.

Table 7.

Non-Verbal Task Hypotheses and Results Summary.

Hypotheses	Results	Match?
YA would outperform OA in Explicit memory performance	YA did not outperform OA in Explicit memory performance	No
OA would outperform YA in Implicit memory performance	YA outperformed OA in Implicit memory performance	No
No difference in Implicit performance between YA-Mono and YA-Bi	There was no difference in Implicit performance between YA-Mono and YA-Bi	Yes
YA-Bi would outperform YA-Mono in Explicit memory performance	YA-Bi did not outperform YA-Mono in Explicit memory performance, but bilinguals outperformed monolinguals in the explicit trials*	
OA-Mono would outperform OA-Bi in Implicit memory performance	There was no significant difference in performance between OA-Mono & OA-Bi in the Implicit condition	No
OA-Bi would outperform OA-Mono in Explicit memory performance	OA-Bi did not outperform OA-Mono in Explicit memory performance, but bilinguals outperformed monolinguals in the explicit trials*	
Bi experience would correlate with Explicit memory performance	Bi experience correlated with Explicit memory performance	Yes

Note: Young Adults (YA), Older Adults (OA), Monolingual (Mono), Bilingual (Bi). Green denotes a match between our hypothesis and our results, Red denotes no match, and Blue denotes evidence pointing towards a potential effect). * There was a between age group effect of language, but no within Age group differences.

We interpret these results as suggesting that attentional resources did not influence performance in the explicit condition, but that, in accordance with our hypotheses, better attentional control (characteristic of bilinguals) led to better explicit performance. Contrary to our hypotheses, fewer attentional resources (characteristic of older adults) did not lead to better implicit performance. Is there a reason why younger adults outperformed older adults in the implicit condition? There is substantial evidence that point to the possibility that older adults are at a significant disadvantage when it comes to making short-term memory judgements about visual information. Prior fMRI research conducted by Madden and colleagues (2004), in which younger and older adult participants took part in a visual target detection task, suggested that age-related decline in visual information processing efficiency resulted in significantly slower processing speeds. An additional study by Ebaid and Crewther (2019) investigated the differences in visual information processing speeds of younger and older adults by administrating both a change detection task and a semantic text-reading task. Their results demonstrated that older adults were slower to attend to and identify newly presented visual stimuli in change detection tasks, but performed similarly to younger adults in semantic text-reading tasks. Costello and colleagues (2010) also found age-related declines in detection efficiency on speeded presentations of displays, which they argued was the result of older adults' slower processing speeds. They further argued that the memory demands of comparing pre-change and post-change displays further strained processing resources, which may have led to further decrease in detection efficiency (Costello et al., 2010). Given the evidence brought forth by these studies, whose tasks share similarities with our non-verbal task, it may be the case that older adults are at a significant disadvantage when it comes to processing non-verbal visual information that are presented for a very short amount of time. Although participants in our study had as much time as desired to provide their responses, visual stimuli were only present on the screen for a brief amount of time. This time frame may have been too brief and thus may have not provided older participants with enough time to pick up on non-target information in the first place (Costello et al., 2010).

While this decline in processing speed may explain the decrease in performance for older adults in the implicit condition, it does not explain why we found no age group differences in the explicit trials. If older adults really are at a disadvantage in change detection tasks, then we should also expect them to perform poorly explicit trials. In a change detection task of their own, Henderson and colleagues (2020) demonstrated that older adults attributed more attentional resources towards stimuli that were given relative priority, thus leading them to engage in more change detection errors for non-priority items (see also Emrich et al., 2017). They also found that older adults were more prone to engage in guessing strategies and displayed poorer performance for non-priority items (Henderson et al., 2020). Their study may help us better understand our own results.

First, we explicitly informed participants to “Pay attention to the red shape”. Thus, in the explicit trials, this may have resulted in more attentional resources directed towards the high priority red shape, and ultimately in better performance for both age groups. That being said, the better attentional control abilities of bilinguals may have resulted in more efficient attentional resources allocation for the red shapes, which could explain why bilinguals outperformed monolinguals regardless of age group. Second, similarly to Henderson and colleagues’ (2020) study, our older participants also engaged in what seemed to be a guessing strategy for trials that did not involve a change of red shape (consistently pressing either the “yes” or “no” key in both implicit and no change trials). This seems to concord with how participants may have allocated their attentional resources. Given that 1) older adults' attention was not drawn to implicit changes in green shape, and 2) that their sparse attentional resources were already strained by a task previously argued to place older adults at a significant disadvantage to their younger peers (rapid changes in visual stimuli), it is possible that judgements about implicit shape changes may have exceeded the attentional resource capacities, and attentional control capabilities, of our monolingual and bilingual older adult participants. Our data does corroborate such an interpretation, as younger adults significantly outperformed older adults on the implicit condition. As demonstrated by Gopie and colleagues (2011), dividing attention at encoding strained the available attentional resources of younger adults, improving their implicit retrieval memory. By dividing older adults' attention at encoding on an already demanding task, it is plausible that identifying the red shape as a priority led to poorer performance and higher rates of guessing at retrieval.

Non-Verbal Task Limitations

Although the shape change detection task adapted from Plebanek and Sloutsky (2017) seemed promising, we faced significant hurdles in adapting some aspects of their methodology. In their work, participants were first asked whether the second red shape (that is, in the second picture) was "familiar" before then being asked whether or not the image pairs were the same ("Did the picture change?"). We found that this first question, which was a distraction question to redirect participant attention towards red shapes, was ambiguous as it was unclear what was being meant by "familiar". We chose to substitute this first question with "Was the second red shape symmetrical?" (participants were given instructions on how to assess shapes as symmetrical or non-symmetrical). It is possible, however, that this question posed an additional challenge to our participants as it is arguably more resource demanding than a familiarity judgement (despite this familiarity judgement being ambiguous).

Another potential limitation is that of the task's difficulty – while the implicit trials appear to have been difficult for participants of all age ranges and language profiles (as denoted by the significant difference in performance between the implicit and explicit trial performance), the explicit trials may have been too easy. In fact, our explicit trial performance appeared to be prone to a ceiling effect in which a proportion of participants achieved the highest possible performance. This may have affected results by limiting the extent to which young adults and bilinguals outperformed older adults or monolinguals. Prior research in monolingual and bilingual populations suggest that bilinguals only tend to outperform monolinguals as task difficulty increases (Comishen & Bialystok, 2021). If a task is too easy, monolinguals and bilinguals tend to perform similarly. This could suggest that, had the explicit trials been more difficult, a more powerful correlation between bilingual experience and explicit performance could have been detected. Given its ease, the explicit memory performance scores may not necessarily denote "explicit" memory, but instead serve as a marker of the extent to which participants paid attention to the task. Therefore, to more thoroughly assess explicit memory performance non-verbally, the explicit trials should have been more difficult. This ceiling effect appears to be an issue that specifically affected the non-verbal task explicit trials, as the verbal task implicit and explicit trials, and non-verbal implicit trials, appear to have been difficult enough to avoid ceiling effects.

Synthesis and Key Takeaways

The present thesis aimed to assess the potential role of efficient attentional control on explicit memory retrieval in older adulthood. In our verbal task, we were able to demonstrate that age had an effect on explicit memory performance, in which younger adults outperformed their older peers. We interpreted these results as indicating that more available attentional resources at encoding facilitates explicit memory retrieval, which corroborates the assertions discussed by Gopie and colleagues (2011). In contrast, we did not find such a pattern in our non-verbal task. That being said, we consistently detected significant correlations between bilingual experience and explicit memory performance in our older adult participants. We interpreted these results as suggesting that efficient attentional control could be a potent factor in mitigating the negative side effects of age-related declines in attentional resources.

How do our results fit in the greater age-related memory decline literature? Our results can be interpreted through the lens of various frameworks; that is, assuming that our selection of younger and older adult participants served as an accurate proxy for available attentional resources, and if bilingual experience served as an accurate proxy of efficient attentional control. Thus, from here, our results pertaining to age differences will be discussed as being differences in attentional resources, and our results pertaining to bilingual experience as being differences in attentional control efficiency.

The present study expands upon the differential-encoding hypothesis discussed in Gopie and colleagues' (2011) paper. In this thesis, we discussed the salient distinction between the role of attentional resources (proxied by age) and of attentional control (proxied by bilingual experience), and how those could relate to memory retrieval. Our results suggest that explicit retrieval does not exclusively hinge on available attentional resources, but also on attentional control efficiency. We can interpret our results as demonstrating that, as attentional control efficiency increases, explicit recall also increases. Following the notion that age-related memory decline is the result of an inability to retrieve information explicitly, it can be extrapolated from our results that efficiency in managing attentional resources could play a crucial role in mitigating age-related memory declines derived from decreases in available attentional resources. In this case, efficient attentional control could have resulted in more thorough processing of information at encoding, thus facilitating explicit retrieval. The underlying mechanisms for this, however, are not entirely understood.

The present interpretation that efficient attentional control facilitates explicit memory retrieval is not mutually exclusive with the notion of cluttered memory representations. We argue here that the evidence from our study actually bolsters aspects of the cluttered memory representation framework. For instance, we found that there were no differences in performance between monolingual and bilingual older adults in implicit trials. This can be interpreted as suggesting that both monolingual and bilingual older adults were equally likely to retrieve information implicitly – perhaps as a resulted of poorer inhibition of irrelevant information at retrieval. Our evidence and interpretations also provides a potential explanation as to why older adults are less likely to retrieve information explicitly; that is, available attentional resources and attention control efficiency at encoding could modulate how information is retrieved. That being said, some of our results also contradict some aspects of the cluttered memory interpretation of age-related memory decline. For instance, there were no differences in implicit performance in our verbal task between younger and older adults, and surprisingly, younger adults outperformed their older peers in the non-verbal implicit tasks. This could be interpreted as suggesting that younger adults are not always necessarily better at filtering out information. While Amer and colleagues (2022) suggest that younger adults are better at suppressing information that was unintentionally picked up from their environments (in large part preventing implicit retrieval), we failed to demonstrate that older adults had better implicit memory than younger adults. This, however, also poses a challenge to the differential-encoding hypothesis since older adults would also be expected to significantly outperform younger adults in implicit trials. As a result it is difficult to make any concrete assessment about these frameworks given the results we obtained.

Conclusion

Evidence suggests that declining attentional resources could play a central role in its prominence in older adults. With many nations gradually inching towards an ever aging population (see Gu et al., 2021; Marois et al., 2020), and as a result of increased Alzheimer and Dementia rates (see Javaid et al., 2021; Nichols & Vos, 2021), there is a growing urgency to better understand memory decline and the potential lifestyle factors that could modulate this decline. It was argued in this thesis that, if diminishing attentional resources over the life span is an inevitable fact of life, better understanding the roles of efficient attentional control in healthy aging may prove to be of paramount importance in staving off age-related memory declines. Many studies have also suggested that language experience plays a significant role in staving off cognitive decline (see Berkes et al., 2020; Chertkow et al., 2010; Craik et al., 2010; Mendez et al., 2020). By better understanding how bilingual experience (and by extension efficient attentional control) promotes explicit memory retrieval and preventing memory decline, we can further develop preventative measures to counteract the dire consequences of our aging population. Future studies should incorporate both neuroimaging techniques and behavioural assessments of implicit and explicit memory retrieval to better understand the potential links between memory preservation in older adulthood and neural substrates. By doing so, it may be easier to establish robust causal links between memory preservation and neural substrates. Future studies should also consider how their results complement different accounts of age-related memory decline instead of abiding to singular frameworks or theories.

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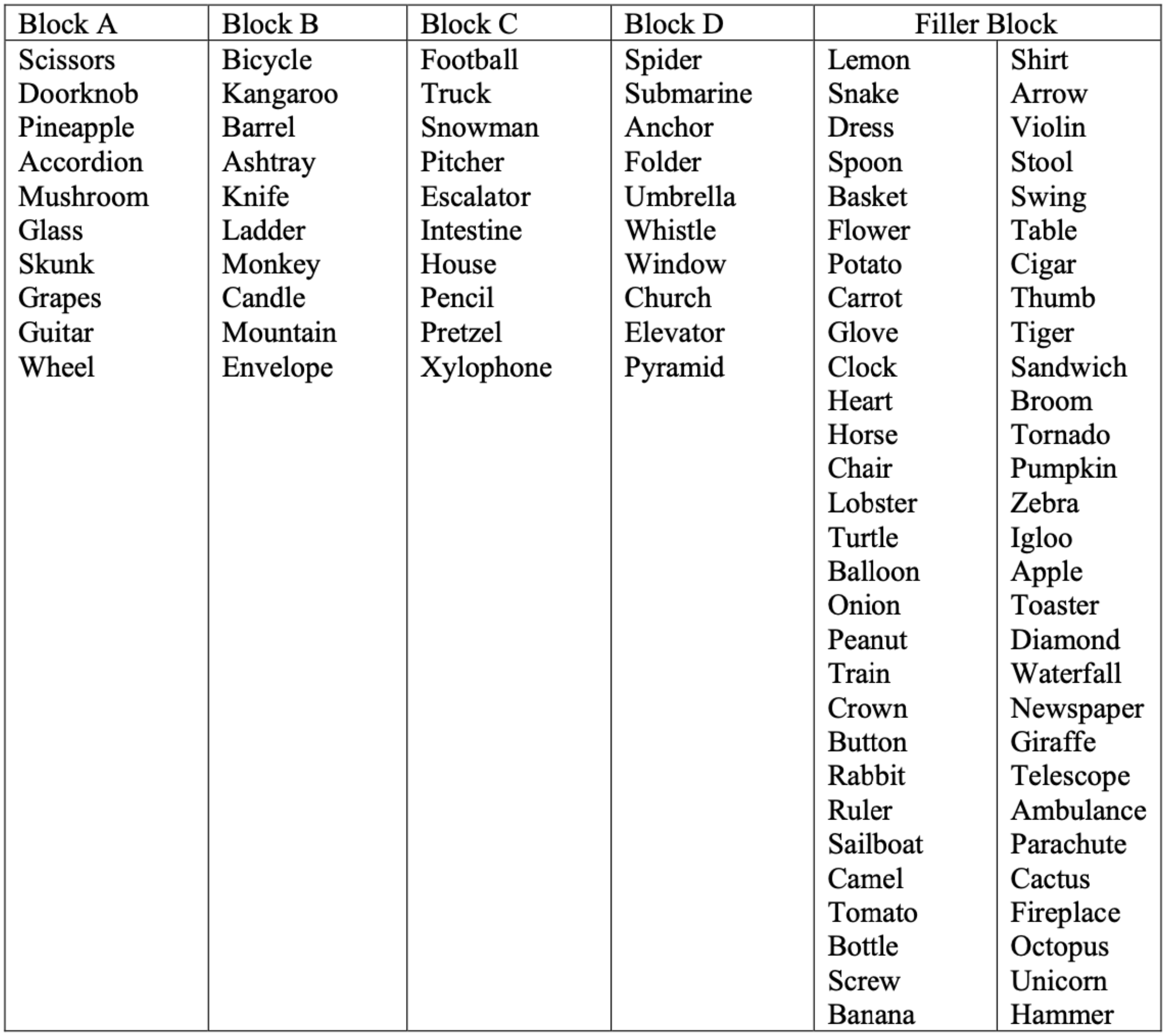
Appendices

Appendix A – Word Fragment Completion

Table 8.

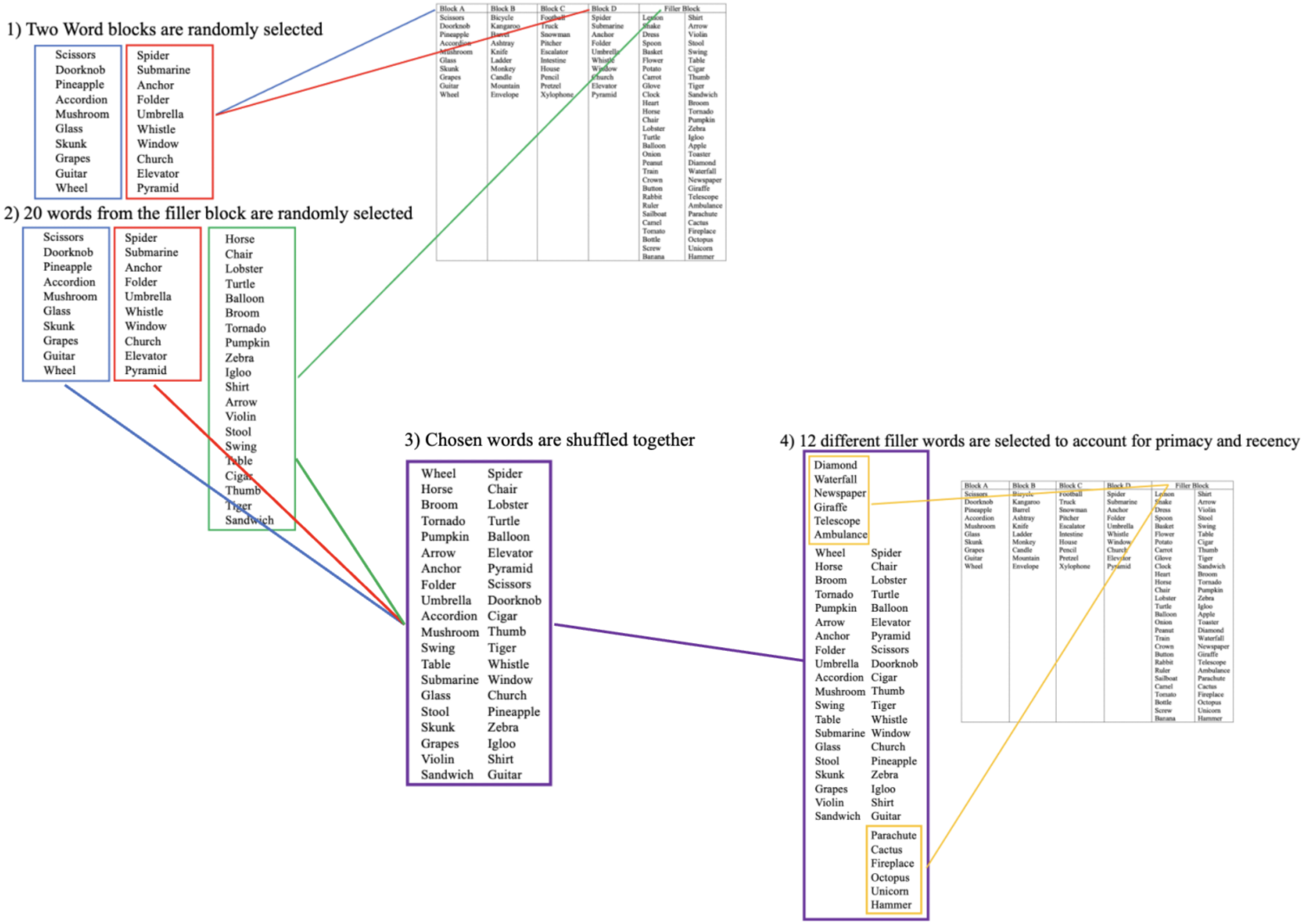
Word Blocks.



Block A	Block B	Block C	Block D	Filler Block	
Scissors	Bicycle	Football	Spider	Lemon	Shirt
Doorknob	Kangaroo	Truck	Submarine	Snake	Arrow
Pineapple	Barrel	Snowman	Anchor	Dress	Violin
Accordion	Ashtray	Pitcher	Folder	Spoon	Stool
Mushroom	Knife	Escalator	Umbrella	Basket	Swing
Glass	Ladder	Intestine	Whistle	Flower	Table
Skunk	Monkey	House	Window	Potato	Cigar
Grapes	Candle	Pencil	Church	Carrot	Thumb
Guitar	Mountain	Pretzel	Elevator	Glove	Tiger
Wheel	Envelope	Xylophone	Pyramid	Clock	Sandwich
				Heart	Broom
				Horse	Tornado
				Chair	Pumpkin
				Lobster	Zebra
				Turtle	Igloo
				Balloon	Apple
				Onion	Toaster
				Peanut	Diamond
				Train	Waterfall
				Crown	Newspaper
				Button	Giraffe
				Rabbit	Telescope
				Ruler	Ambulance
				Sailboat	Parachute
				Camel	Cactus
				Tomato	Fireplace
				Bottle	Octopus
				Screw	Unicorn
				Banana	Hammer

Figure 8.

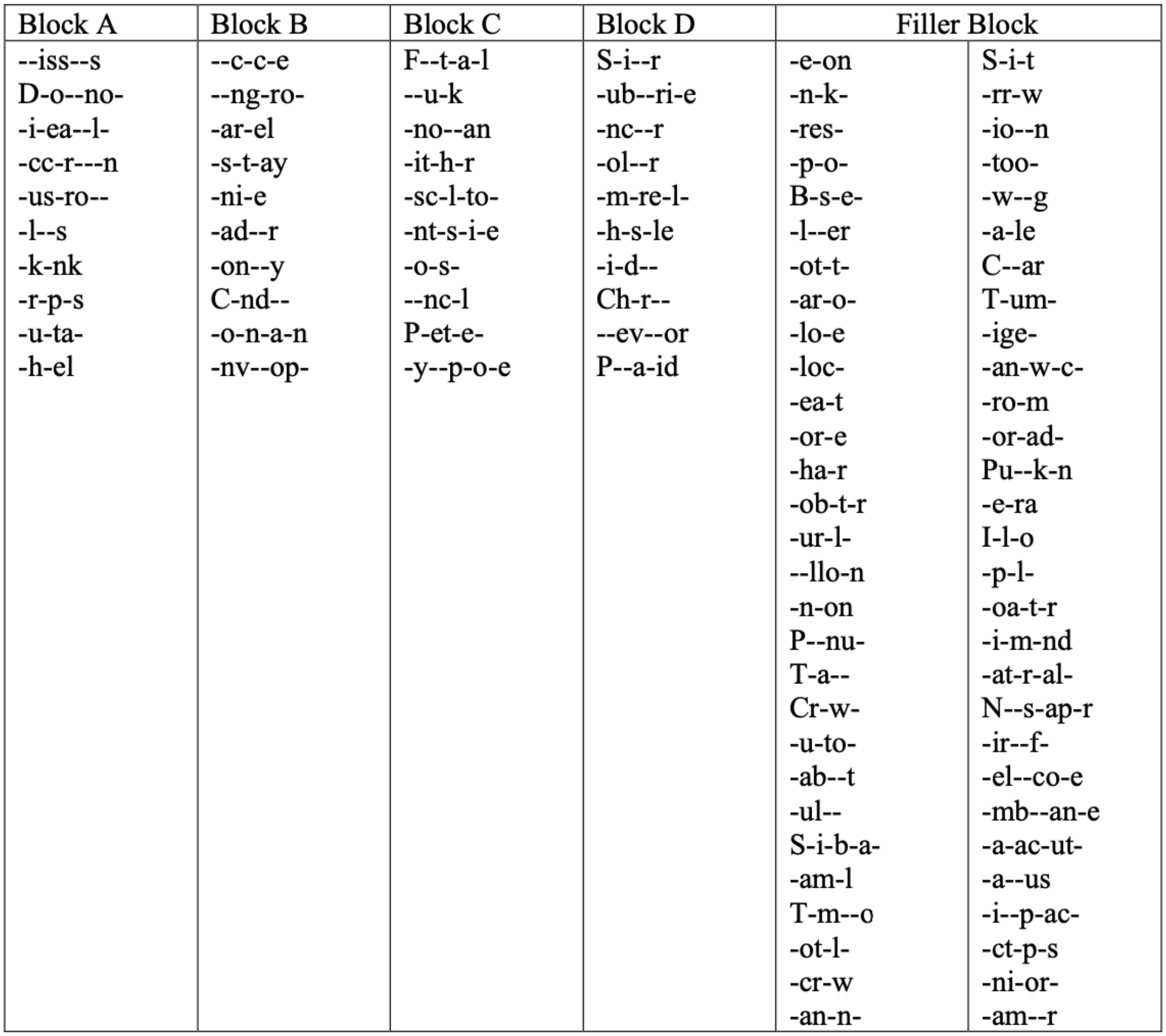
Word Randomisation Schematic.



Block A	Block B	Block C	Block D	Filler Block	
Scissors	Bicycle	Football	Spider	Lemon	Shirt
Doorknob	Kangaroo	Truck	Submarine	Snake	Arrow
Pineapple	Barrel	Snowman	Anchor	Dress	Violin
Accordion	Ashtray	Pitcher	Folder	Spoon	Stool
Mushroom	Knife	Escalator	Umbrella	Basket	Swing
Glass	Ladder	Intestine	Whistle	Flower	Table
Skunk	Monkey	House	Window	Potato	Cigar
Grapes	Candle	Pencil	Church	Carrot	Thumb
Guitar	Mountain	Pretzel	Elevator	Glove	Tiger
Wheel	Envelope	Xylophone	Pyramid	Clock	Sandwich
				Heart	Broom
				Horse	Tornado
				Chair	Pumpkin
				Lobster	Zebra
				Turtle	Igloo
				Balloon	Apple
				Onion	Toaster
				Peanut	Diamond
				Train	Waterfall
				Crown	Newspaper
				Button	Giraffe
				Rabbit	Telescope
				Ruler	Ambulance
				Sailboat	Parachute
				Camel	Cactus
				Tomato	Fireplace
				Bottle	Octopus
				Screw	Unicorn
				Banana	Hammer

Table 9.

Word Fragment Blocks.



Block A	Block B	Block C	Block D	Filler Block	
--iss--s	--c-c-e	F--t-a-l	S-i--r	-e-on	S-i-t
D-o--no-	--ng-ro-	--u-k	-ub--ri-e	-n-k-	-rr-w
-i-ea--l-	-ar-el	-no--an	-nc--r	-res-	-io--n
-cc-r---n	-s-t-ay	-it-h-r	-ol--r	-p-o-	-too-
-us-ro--	-ni-e	-sc-l-to-	-m-re-l-	B-s-e-	-w--g
-l--s	-ad--r	-nt-s-i-e	-h-s-le	-l--er	-a-le
-k-nk	-on--y	-o-s-	-i-d--	-ot-t-	C--ar
-r-p-s	C-nd--	--nc-l	Ch-r--	-ar-o-	T-um-
-u-ta-	-o-n-a-n	P-et-e-	--ev--or	-lo-e	-ige-
-h-el	-nv--op-	-y--p-o-e	P--a-id	-loc-	-an-w-c-
				-ea-t	-ro-m
				-or-e	-or-ad-
				-ha-r	Pu--k-n
				-ob-t-r	-e-ra
				-ur-l-	I-l-o
				--llo-n	-p-l-
				-n-on	-oa-t-r
				P--nu-	-i-m-nd
				T-a--	-at-r-al-
				Cr-w-	N--s-ap-r
				-u-to-	-ir--f-
				-ab--t	-el--co-e
				-ul--	-mb--an-e
				S-i-b-a-	-a-ac-ut-
				-am-l	-a--us
				T-m--o	-i--p-ac-
				-ot-l-	-ct-p-s
				-cr-w	-ni-or-
				-an-n-	-am--r

Figure 9.

Word Fragment Completion Task Schematic.

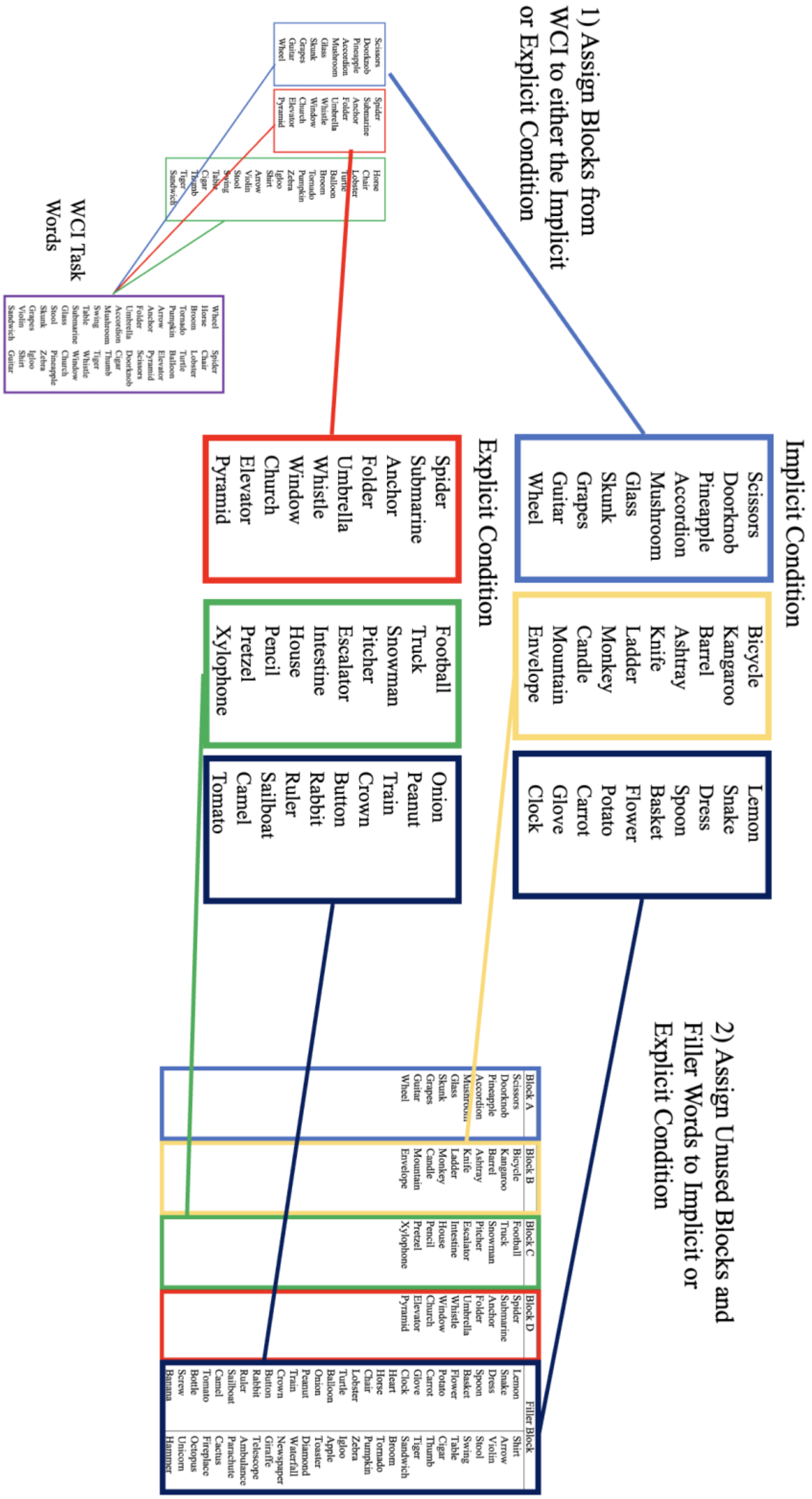
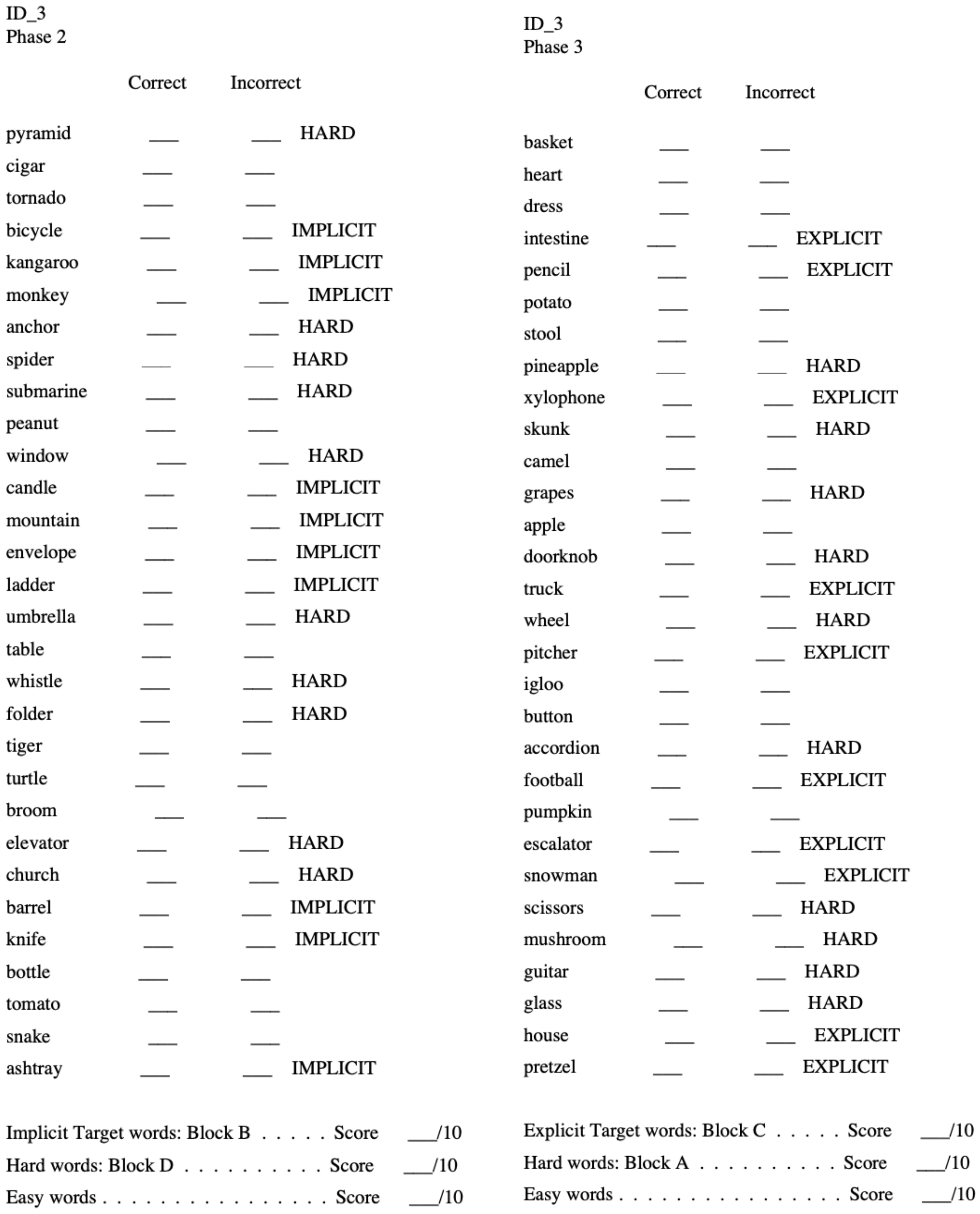


Figure 10.

Word Fragment Completion Scoring Sheet Sample.



ID_3
Phase 2

	Correct	Incorrect	
pyramid	___	___	HARD
cigar	___	___	
tornado	___	___	
bicycle	___	___	IMPLICIT
kangaroo	___	___	IMPLICIT
monkey	___	___	IMPLICIT
anchor	___	___	HARD
spider	___	___	HARD
submarine	___	___	HARD
peanut	___	___	
window	___	___	HARD
candle	___	___	IMPLICIT
mountain	___	___	IMPLICIT
envelope	___	___	IMPLICIT
ladder	___	___	IMPLICIT
umbrella	___	___	HARD
table	___	___	
whistle	___	___	HARD
folder	___	___	HARD
tiger	___	___	
turtle	___	___	
broom	___	___	
elevator	___	___	HARD
church	___	___	HARD
barrel	___	___	IMPLICIT
knife	___	___	IMPLICIT
bottle	___	___	
tomato	___	___	
snake	___	___	
ashtray	___	___	IMPLICIT

Implicit Target words: Block B . . . . . Score ___/10
Hard words: Block D . . . . Score ___/10
Easy words . . . . Score ___/10

ID_3
Phase 3

	Correct	Incorrect	
basket	___	___	
heart	___	___	
dress	___	___	
intestine	___	___	EXPLICIT
pencil	___	___	EXPLICIT
potato	___	___	
stool	___	___	
pineapple	___	___	HARD
xylophone	___	___	EXPLICIT
skunk	___	___	HARD
camel	___	___	
grapes	___	___	HARD
apple	___	___	
doorknob	___	___	HARD
truck	___	___	EXPLICIT
wheel	___	___	HARD
pitcher	___	___	EXPLICIT
igloo	___	___	
button	___	___	
accordion	___	___	HARD
football	___	___	EXPLICIT
pumpkin	___	___	
escalator	___	___	EXPLICIT
snowman	___	___	EXPLICIT
scissors	___	___	HARD
mushroom	___	___	HARD
guitar	___	___	HARD
glass	___	___	HARD
house	___	___	EXPLICIT
pretzel	___	___	EXPLICIT

Explicit Target words: Block C . . . . . Score ___/10
Hard words: Block A . . . . Score ___/10
Easy words . . . . Score ___/10

Appendix B – Supplementary Tables

Table 10.

Demographic Characteristics by age group.

	Age (Years)		
Age Group	*M*	Range	*SD*
Younger Adults (*n* = 76)	19.6	18-23	1.4
Older Adults (*n* = 43)	70.8	60-81	6.4

Note. Participants experienced no neurological episodes in the past 5 years (e.g., epilepsy or strokes), had no cognitive impairments (e.g., diagnoses or concussions), had normal or corrected vision, and were not colourblind. Those that did not meet the above requirements

Table 11.

Mean Proportions (Standard Deviations) of Target and Control Word Fragment Completion and Task Memory Performance.

Measures	Younger Adults (*n* = 76)	Older Adults (*n* = 43)
Target Completion		
Implicit	.18 (.14)	.20 (.13)
Explicit	.22 (.16)	.18 (.14)
Control Completion		
Implicit	.14 (.16)	.14 (.10)
Explicit	.14 (.13)	.18 (.14)
Memory Performance (Target – Control)		
Implicit	.04 (.17)	.06 (.15)
Explicit	.08 (.21)	.00 (.15)

Table 12.

Mean (Standard Deviations) Explicit, Implicit, and No Change A` scores.

	Age Groups	
Trial Type	Younger Adults (*n* = 69)	Older Adults (*n* = 33)
Implicit Change	.41 (.34)	.33 (.30)
Explicit Change	.91 (.08)	.93 (.07)
No Change	.16 (.17)	.26 (.29)

Note: Scores out of 5 for each trial types.