

THE ROLE OF ATTENTION AND RESPONSE BASED LEARNING IN THE
VISUOSPATIAL HEBB SUPRA-SPAN SEQUENCE LEARNING TASK:
INVESTIGATING AGE-RELATED LEARNING DEFICITS

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GENERAL THESIS ABSTRACT

Using Hebb's (1961) paradigm, it has been shown that older adults (OAs) fail to learn recurrent visuospatial supra-span sequence information (Turcotte, Gagnon, & Poirier, 2005); a deficit which has not been demonstrated on verbal versions of the same task or in younger adults (YAs). Since the Hebb paradigm is thought to rely on working memory and thus attention (Conway & Engle, 1996), one interpretation concerns an OA's capacity to allocate the necessary attentional resources to carry out the various components of the task. Five studies investigated this proposal. The first three (Article 1) examined attention in a general manner by reducing the amount of attentional resources that a YA could devote to carrying out the visuospatial Hebb supra-span sequence learning task through the implementation of a verbal dual task (DT) procedure. The fourth (Article 2) further investigated the role of attention by using a DT induced at retrieval that overlapped extensively with the requirements (spatial and response features) of the visuospatial Hebb task. The final study (Article 3) aimed to use our previous findings to demonstrate learning among OAs in a visuospatial Hebb learning paradigm in which the motor response was replaced by a verbal response. Our findings confirm that attentional resources employed at the retrieval phase of the task appear to be particularly important for the demonstration of visuospatial sequence learning. The inclusion of a spatial and motor based DT at recall eliminated learning of the repeated sequence in YAs. Interestingly, the learning deficit of OAs was partially eliminated when the motor and spatial requirements at retrieval were reduced. Our findings offer strong support to the contention that supra-span learning of the Hebb type is not altered by the effect of age. However, learning deficits can be observed among OAs when the retrieval

component of the task overly taxes attention-related processes. In the case of the visuospatial sequences, the basis of the deficit likely concerns an individual's capacity to discriminate between responses made to previously presented sequences versus those that need to be made in reaction to the just seen sequence.

CO-AUTHORSHIP STATEMENT

In all cases, the key ideas, primary contributions, experimental designs, data analysis, interpretations, and the written portion were carried out by the author. Aside from Sylvain Gagnon, the contribution of any co-authors mentioned in this manuscript was primarily through the provision of hands on research assistance, as opposed to data analysis, literature review and manuscript preparation. Sylvain Gagnon provided substantial changes to and in-depth feedback on the manuscript. I am aware of the University of Ottawa's Policy on Authorship and I certify that I have properly acknowledged the contribution of other researchers to my thesis. I certify that with the above qualification, this thesis, and the research to which it refers, is the product of my own work.

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DEDICATION

To my loving parents who never stop believing in me.

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LIST OF ABBREVIATIONS

ASRTT: Alternating serial reaction time task

DT: Dual-task

ISR: Immediate serial recall

LTM: Long-term memory

OA: Older adult

RT: Response time

SRTT: Serial reaction time task

TS: Touch screen

VR: Verbal response

YA: Younger adult

1. CHAPTER ONE

1.1. General Introduction

Canada is experiencing a remarkable change in its demographic composition, in part, due to an enormous growth in the older adult population. Whereas in 1951, roughly 7.8% of the population was 65 of older, by 2005, this value had almost doubled to 13% (Statistics Canada, 2006). Notably, comparable demographic changes are apparent in many industrialized countries all around the world (Organisation for economic co-operation and development, 1998), and there is no indication that this growth is going to slow anytime soon. One key contributor to this growth is increased longevity. Importantly, age-related changes in a variety of cognitive domains, including language, memory, executive functioning, and attention have been well documented (c.f. Brayne et al., 1999, Craik & Byrd, 1982; Hamninen et al., 1997; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Perfect & Maylor, 2000; Salthouse, Atkinson, & Berish, 2003; Zacks, Hasher & Li, 2000; see also Drag & Bieliauskas, 2009 for a review). Accordingly, it is suspected that with this improvement in life span, the incidence of individuals experiencing issues with cognitive processes will also augment (Lamdin & Fugate, 1997; Rowe & Kahn, 1997). This has inevitably elevated the amount of energy devoted to investigating the impact of aging on cognition, particularly within the areas of learning and memory, since both these essential processes are known to experience substantial deficits with age (Craik & Jennings, 1992).

1.1.1. Aging and Sequence Learning

Memory and learning are intrinsically linked and so the differences between them can easily become blurred, but they are generally considered different constructs (c.f. Kausler,

1994). As a result, numerous definitions have been put forth for each of the concepts. Theorists like Kandel, Kupferman, and Iverson (2000) define learning as “the process by which we acquire knowledge about the world” and memory as “the process by which that knowledge is encoded, stored, and later retrieved” (p.1228). Others like Kimble (1961), contend that learning is the acquisition of new information or skills leading to a rather permanent change in behaviour/performance because of repetition, practice, or experience, while memory is the retention over time of this change in behaviour or acquired knowledge/skill set. Importantly, with normal aging, not all forms of learning and memory experience the same levels of deterioration, or in some cases, any deterioration at all (Craig, 1977a; Craig, Anderson, Kerr, & Li, 1995; Craig & Jennings, 1992; Kausler, 1994; Smith, 1996). One process that is shown to be particularly affected by the aging process, is the ability to learn sequential information (c.f. Gagnon, Bedard, & Turcotte, 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte, Gagnon, & Poirier, 2005). Research regarding the impact of aging in this area is especially important, particularly because the ability to sequence behavior is essential for carrying out virtually any daily activity (Buchner & Frensch, 1997; Lashley, 1951; Schumacher & Schwarb, 2009; Soetens, Melis, & Noebaert, 2004; Whittlesea & Wright, 1997). For example, the development of language, which entails among other things the aptitude to predict what comes next, in order to put together a sequence of words to form a sentence, relies on sequencing ability. Sequential organization is also indispensable for the development of motor skills, such as learning how to drive a motor vehicle, use a telephone, play a musical instrument, type a text, or even coordinate leg or hand movements.

Traditionally, sequence learning is assessed using paradigms such as the serial reaction time task (SRTT; Nissen & Bullemer, 1987), the alternating serial reaction time task (ASRTT; Howard & Howard, 1997), or the Hebb (1961) paradigm (for reviews, see Cleeremans, Destrebecqz, & Boyer, 1998; Frensch, 1998; and Seger, 1994). These tasks involve presenting individuals with a repeated sequence of material that is typically embedded among random items. Since the repeated sequence of material is presented a number of times, the understanding is that a participant demonstrates learning through a significant improvement in performance of the repeated material, when compared to the improvement in performance for the random material. The Hebb supra-span learning paradigm was originally developed by Donald O. Hebb to study long-term memory trace formation and is especially useful in this area of research. Firstly, the same paradigm can be employed to investigate sequence learning within two different modalities: verbal and visuospatial. That is, verbal material such as digits, letters, words, or pseudo-words, as well as visuospatial material, typically based on the Corsi (1972) block tapping task where randomly positioned blocks are presented on a board or computer screen, can be employed using the same model. As a result, direct comparisons amongst the two forms can be made, providing a means by which to examine how learning varies based on the nature of the stimuli employed. Secondly, because the Hebb task is thought to encompass both short-term maintenance of sequences and long-term memory (LTM), it allows one to examine the potential interaction between these two processes.

In the traditional Hebb learning task (verbal or visuospatial form), the participant is required to perform immediate serial recall (ISR; verbal or mechanical depending on the version) of 24 sequences of material, each of which is typically made up of nine items.

Among the 24 sequences, there are 16 random sequences, as well as one sequence which is repeated every third trial (3, 6, 9 ...24), for a total of eight times. In the classic paradigm, participants are not informed of the presence of this repeated sequence; meaning that they are simply asked to encode and then perform explicit ISR of each given sequence. Learning is thus evident when a Hebb effect occurs, which is indicated by an improvement in ISR performance of the repeated sequence, relative to that of the random sequences. Using the verbal Hebb task (c.f. Caird, 1964, 1966; Gagnon & Winocur, 1996; Heron & Craik, 1964; Turcotte, 2002; Turcotte et al., 2005), it has been observed that both younger and older adults demonstrate learning of sequential material when it is verbal in nature (for similar results using the artificial grammar paradigm see Meulemans & Van der Linden, 1997; using the SRTT see Bo and Seidler, 2010; Cunningham, Healy & Williams, 1984; Howard & Howard, 1989, 1992; Milner, 1971; Sechler & Watkins, 1991; or using a similar paradigm see Nejati, Garusi-Farshi, Ashayari, & Aghdasi, 2008). For example, Caird (1966) explored the impact of aging on the Hebb effect by recruiting 120 male and female individuals between the ages of 11 and 70 years old whom were then divided equally into six age-groupings (ages 11-20, 21-30, 31-40, 41-50, 51-60 and 61-70). After matching the participants in terms of forward digit span, Caird had each individual complete a slightly modified version of the Hebb task, in which 30 eight-digit long verbal sequences were presented, with a repeated sequence appearing on every third trial. Results using the proportion of digits recalled in their correct serial position, as the indicator for recall accuracy, indicated that the repetition effect was observed for all six age groups. Comparable results have also been observed by Heron and Craik (1964, Experiment 3) in ten younger (aged 20-35 years old) and 10 older (aged 60-70 years old) male adults who completed a similar digit verbal Hebb task.

While verbal Hebb sequence learning is apparent for both younger and older adults, research using the visuospatial Hebb (1961) supra-span sequence learning task has not shown equivalent learning among older and younger adults. In fact, the dissociation between the processes underlying verbal and visuospatial becomes evident, as younger (c.f. Couture, Lafond & Tremblay, 2008; Couture & Tremblay, 2006; Lafond, Tremblay, & Parmentier, 2010; Turcotte et al., 2005), but not older adults demonstrate learning when visuospatial material is instead employed (c.f. Gagnon et al., 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte et al., 2005). An example of this is provided by Gagnon and Winocur (1996), who had 48 healthy older (aged 65-90 years old) and 47 healthy younger (aged 18-35 years old) adults complete a modified verbal and visuospatial sequence learning Hebb task (i.e. the Supra-span Hebb). In their revised Hebb task, the researchers followed the methods proposed by Weschler (1944), and adjusted the number of items presented within a sequence, so that it reflected the span capacity of the particular individual completing the task (see also Belleville, Rouleau & Caza, 1998). This modification was especially useful for two reasons. Firstly, research shows that with age individuals may experience a decline in their working memory capacity (Bopp & Verhaegen, 2005; Peterson & Peterson, 1959; Salthouse, 1991b, 1994, 1996; Wingfield, Stine, Lahar & Aberdeen, 1988). Secondly, research also indicates that working memory capacity is highly individualistic, differing from person to person (Conway & Engle, 1996; Just & Carpenter, 1992; Rypma & D'Esposito, 1999). Therefore, without an adjustment based on span, difficulty of the Hebb task may influence performance, resulting in an inadequate assessment of sequence learning ability among both younger and older individuals. Accordingly, using these revised methods, the researchers found that while normal learning of the repeated sequence was apparent in both age groups when the verbal

form was employed, only the younger adults demonstrated a Hebb effect when the visuospatial Hebb task was the required task.

More recent research using computerized versions of the Hebb task, carried out by Turcotte (2002), Gagnon and colleagues (2005), as well as Turcotte and colleagues (2005), has also provided comparable results. For instance, Turcotte examined visuospatial sequence learning in 34 older (aged 64-79 years old) and 38 younger (aged 19-33 years old) healthy adult participants with similar levels of education and verbal intelligence. Results indicated that as early as the first repetition, a strong Hebb effect was present among the younger adult participant group. Conversely, and in corroboration with the findings of Gagnon and Winocur (1996), a much weaker repetition effect was seen among the older participant group. However, Turcotte did note that baseline performance of the older adults was quite low. As such, one potential confound in their study may have been the fact that span was not individually adjusted. This could suggest that task difficulty may have influenced performance. Accordingly, in a subsequent study, using a span adjusted visuospatial Hebb sequence learning task, Turcotte and colleagues (Experiment 2) confirmed that younger, but not older adult participants show a strong repetition effect.

1.1.2. Deficits in Sequence Learning and the Role of Familiarity

Although to date, minimal research has been carried out in this area, some key proposals have been put forward to try to explain why it is that older adults demonstrate some difficulty when faced with learning sequences made up of visuospatial stimuli. For example, one line of investigation has focused on determining whether a lack of familiarity with the material might play a role (c.f. Heron & Craik, 1964; Turcotte, 2002; Turcotte et al.,

2005). This is a proposal premised on the idea that compared to the stimuli encountered in the verbal Hebb, stimuli within the visuospatial Hebb may be less familiar to an individual, because of the requirement to manipulate more abstract stimuli (i.e. randomly positioned boxes on a computer screen). Indeed, an issue with familiarity is important, since it would be expected to infringe on an individual's capacity to attach meaning to the presented material, which is an ability that appears to be crucial for learning to take place (c.f. Craik & Lockhart, 1972). Thus, the familiarity proposal put forth suggested that a lack of familiarity with visuospatial material effects the learning of such material; a situation which for reasons unbeknownst to us at this time, impacts older more than younger adults.

Research carried out by Heron and Craik (1964) examining the effects of foreign language on learning verbal sequence material, provided some initial support for this familiarity proposal. For example, in a first study where twenty younger (17-27 years old), and twenty older (51-60 years old) Finnish speaking individuals completed two English verbal non-span adjusted Hebb tasks (the first containing 24, five-digit long sequences, and the second containing 24, six-digit long sequences), Heron and Craik observed cumulative learning for the younger, but not for the older group of adults. Likewise, in a second investigation where ten older (aged 60-70 years old), and ten younger (aged 20-35 years old) adult male Anglophones completed a Finnish version of the verbal non-span adjusted Hebb task, cumulative learning was observed for the younger adults. Conversely, for the older adults, learning was only evident up until the third occurrence of the repetition, after which point, performance dropped off. However, one noted issue with Heron and Craik's research, is that span was not adjusted on an individual basis within the Hebb task. This fact is significant since, in the first investigation, a standard number of five or six digit sequences

were employed and the average English span capacity of both the older and younger Finnish participants was found to be below this value (4 for the younger and 3.7 for the older participants). Likewise, in the second investigation, six digit long sequences were employed and average Finnish span capacity of both the older and younger English participants was only found to be around 3 (older had a slightly lower average span). Therefore, because the participants were all presented with a standard number of stimuli, difficulty of the task cannot be ruled out as an alternative interpretation of the findings.

In spite of the fact that span was not adjusted for within Heron and Craik's (1964) research, Turcotte (2002) took their findings as an indication that familiarity might play a role in the age-related visuospatial sequence learning deficit. More specifically, using Heron and Craik's results, Turcotte put forward the idea that older adults may experience more difficulty with processing less familiar material than younger adults. Accordingly, Turcotte and colleagues (2005; Experiment 1) investigated the impact of using pseudo-words within the supra-span verbal Hebb task. In their study, 30 older (aged 64-85 years old) and 30 younger (aged 19-29 years old) healthy individuals with comparable levels of education (younger adults had slightly more years of education) and verbal intelligence, completed two versions of the verbal supra-span Hebb task: one containing highly familiar words like 'continent', and one containing highly unfamiliar words (pseudo-words) like 'mougrun'. Each of the selected words and pseudo-words began with a different letter and had the same average reading time. Contrary to the findings of Heron and Craik (1964), results indicated that on both verbal versions of the Hebb task (words and pseudo-words) older and younger adult participants demonstrated a significant Hebb repetition effect. One explanation for the diverging results may be the fact that in Turcotte and colleagues' research, a span-adjusted

Hebb task was employed, while in Heron and Craik's research, no adjustment to span was made. Accordingly, using a more valid assessment of verbal sequence learning, Turcotte and colleagues failed to demonstrate that familiarity with the material influences learning. However, it must be taken into consideration that the methods used by Heron and Craik, as well as Turcotte and colleagues, may not be exhaustive or even representative of the abstract stimuli that are studied within the visuospatial Hebb paradigm. That is, use of pseudo-words or words that are presented in an unfamiliar language, may fail to appropriately tap the novelty of stimuli employed within the visuospatial Hebb paradigm.

1.1.3. Working Memory and the Role of Awareness in Sequence Learning

Working memory is concerned with the temporary storage, manipulation and maintenance of information in a rather "active" state in order to accomplish the task at hand (Engle, Tuholski, Laughlin, & Conway, 1999a). It is also thought to be responsible for either discarding or processing information further into a LTM representation, so that it can be stored more permanently (Engle, Tuholski, Laughlin, & Conway, 1999a; Shelton, Elliot, & Cowan, 2008). Some even claim that working memory is simply LTM in an active form (c.f. Cowan, 1988, 1995, 1999; Ericsson & Kintsch, 1995; Engle et al., 1999a). Likewise, others refer to the similarity in the underlying brain structures that are associated with working memory and LTM as support that the two constructs are one and the same (c.f. Ruchkin, Grafman, Cameron, & Berndt, 2003). These latter researchers put forth the idea that LTM activations associated with the posterior cortical regions of the brain actually provide the representational basis for working memory. With this in mind, when one considers the processing that is required to demonstrate learning when using the Hebb task, it becomes

evident that working memory is likely involved for a number of reasons. For one, the temporary storage of information on each trial is necessary, as a participant must hold within memory, each presented element within a sequence in its correct temporal position. Secondly, manipulation of the information in memory is necessary in order for the individual to use the temporary memory to recall the just presented sequence by appropriately selecting each element composing the sequence in its correct order. Thirdly, a LTM trace of the repeated sequence must be formed. Finally, within each of these tasks, there is some indication that information must be made active. For instance, to accomplish the first two steps, an active representation of the just encoded sequence must be made available so that participants can determine the order of the elements. Similarly, when it comes to forming a LTM trace of the sequence information, as well as using said memory trace to demonstrate learning, again activation seems necessary. However, it is unclear how exactly this unfolds. Accordingly, given the description above of the processes required to carry out the Hebb task, it seems logical that working memory would be involved (for a similar proposal see Conway & Engle, 1996; Gagnon et al., 2005; Weitz, O'Shea, Zook, & Needham, 2011; see also Pascual-Leone, 1970).

Implicating working memory within the Hebb task, although logical based on the above arguments, does bring with it some concerns. Foremost, it is commonly accepted that within the Hebb task and other similar sequence learning paradigms (e.g. SRTT and ASRTT), learning is thought to be largely implicit in nature, occurring devoid of participant awareness (for reviews, c.f. Cleeremans et al., 1998; Cleeremans, 1993; Dienes & Berry, 1997; Frensch, 1998; Nissen & Bullemer, 1987; Reber, 1993; Seger, 1994). Conversely, working memory is thought to rely on conscious processing (Baars, 2003; Baars & Franklin,

2003; Frensch & Runger, 2003; Jacoby, 1998; Allwood, Granhag, & Johansson, 2000). In fact, Baddeley's (2000, 2001) most recent addition of the episodic buffer to his working memory framework, highlights the importance of being aware of the information that is stored in LTM. Specifically, he stipulates that the episodic buffer is a limited capacity storage component that is thought to bridge the gap between LTM and working memory by holding information from LTM in an active state. He proposes that awareness of the contents of this buffer is what actually allows the individual to activate this material, so that it can be compared with incoming information (Baddeley, 2000). This activation would also allow the individual to anticipate the presentation of the repeated sequence. In fact, according to Baddeley (2006), the episodic buffer is the basis of "conscious awareness" (p.24). If this interpretation is correct, working memory and more specifically the episodic buffer would likely play a key role in sequence learning. Therefore, accepting that working memory may play a role in sequence learning would also mean that, performance on the Hebb could not be considered as strictly unconscious or implicit in nature. In truth, such a view would advocate that awareness of the repetition is necessary in order to prompt the engagement of working memory related processing required to organize, memorize, monitor, or elaborate material. Ultimately, it could be that awareness of the repetition influences whether a LTM trace is formed, and/or retrievable to accomplish a current goal (c.f. Cantor & Engle, 1993). Indeed, this is a consideration that is supported by research indicating that awareness of the repetition may actually occur when completing the Hebb task (for a similar proposition see also Bower & Winzenz, 1969; Cohen, Ivry, & Keele, 1990; Frensch, Buchner & Lin, 1994; Kidd & Greenwald 1988; Melton, 1967; Sechler & Watkins, 1991; Willingham, Nissen, & Bullemer, 1989). It is also in line with the work of Destrebecqz and colleagues (2005; see also

Destrebecqz & Cleeremans, 2001), who advocate that sequence learning likely involves both implicit and explicit memory processes. Consequently, if younger, but not older adults are more likely to become aware of the repetition and thus “activate” the contents of the episodic buffer, this may help explain why an age-related sequence learning deficit becomes apparent when using the Hebb.

1.1.4. Similarity, Task Difficulty, Awareness and Sequence Learning

If the awareness proposal is to be considered however, two pertinent questions must first be addressed: Why is awareness of the repetition achieved in younger, but not older adults? Why is awareness impacted in the visuospatial Hebb, but not in the verbal Hebb? The answer to both questions may be tied to age-related declines in cognitive functioning. For instance, it was mentioned earlier, that cognitive processes such as attention, and executive functioning are negatively affected by aging (c.f. Brayne et al., 1999; Craik, & Salthouse, 2000; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Perfect & Maylor, 2000; Reuter-Lorenz et al., 2000; Zacks et al., 2000). Declines in these areas (or other cognitive functions known to experience decrement with age) might therefore affect an older adult’s ability to automatically perceive and thus become aware of the repetition. One reason this deficit might be evident when processing visuospatial stimuli, but not verbal stimuli, may have to do with a difference in the nature of the stimuli. Indeed, it has been shown that both younger and older adult participants demonstrate shorter span capacity when tested with visuospatial versus verbal sequence material (c.f. Turcotte, et al., 2005; Gagnon et al., 2005), which suggests that visuospatial stimuli are for some reason more challenging to process.

According to Lustig, May, and Hasher, (2001), Turcotte (2002), as well as Turcotte and colleagues (2005), processing visuospatial sequence material is more challenging than processing verbal sequence material, because the former contains items that share greater similarity with one another, which may ultimately decrease one's ability to differentiate between the items. For instance, since identical squares are used to form the sequences, only spatial location can be used as a differentiator within the visuospatial Hebb. Conversely, items forming verbal sequences tend to differ substantially from each other, a factor which naturally increases their distinctiveness. Take the verbal presentation of two letters B and N for example; it is clear that phonetically they are quite different. Likewise, if these letters were instead visually presented, their noticeably dissimilar forms could be used as markers for differentiation. The grounds for this greater similarity proposition follow from Conrad and Hull's (1964) work on the phonological similarity effect, in which it is detailed that the more items sound similar, the harder it becomes to correctly recall them. In line with this proposal is the work of Schonfield (1967), who alongside a verbal version of the Hebb, had participants perform a recognition task, in which participants were presented with sequences that became increasingly similar to the repeated sequence. Schonfield observed that participant performance was negatively impacted, as the discriminability between the random and repeated sequences decreased. He concluded that task difficulty increases as discriminability between items decreases. Although a verbal version of the Hebb was employed in Schonfield's investigation, the results do suggest that similar effects would be observed in a task such as the visuospatial Hebb, where items composing the sequences differ only in their spatial location (for a similar proposal see Baddeley, 1966; Conrad, 1964; Horton, Hay, & Smyth, 2008), and item distinctiveness could be considered low.

From a processing point of view, this also makes sense. For instance, it is proposed that verbal information can be processed in three different ways: structurally, phonemically, or semantically (Sonderegger, 1998). In structural encoding, which is considered the shallowest form of processing, emphasis is on the physical characteristics of the stimuli. In phonemic encoding, which is considered an intermediate level of processing, emphasis is on the sound of the stimuli. Finally, in semantic encoding, which is considered the deepest level of processing, emphasis is on the meaning of the stimuli. Applying this framework to visuospatial material, it can be suggested that such stimuli would be processed at what would be considered a much shallower level because of a lack of discriminating features. Faubert's (2002) work on visual perception also provides some support here. In his review, Faubert discusses that aging negatively influences visual perception, especially when the items to be perceived are considered complex. Although Faubert's definition of what makes an item more complex, concerns images and revolves around factors such as luminance, color, motion, texture and depth, applying the main principles to the current work, one could suggest that perception of the regularity may be more affected in the visuospatial realm, simply because of the nature of the stimuli employed.

Work using the ASRTT also advances the similarity proposal (c.f. Howard and Howard, 1997; Howard, Howard, Japinske, DiYanni, Thompson, & Somberg, 2004). The ASRTT is an adapted version of the SRTT, in which participants are presented with a computer screen containing four boxes, along with a four-button keypad that corresponds to each of the four boxes displayed on the screen. Each time a visual stimulus (an asterisk) appears in one of the boxes, the participant must manually press the corresponding button on the key pad. Only when the correct button is pressed, does the stimulus disappear and does a

new stimulus appear, once again requiring that the participant press on the corresponding button. Unlike the Hebb, which requires recall of an entire sequence of material, this is a choice reaction time task and therefore, participants must select which item was just presented from amongst the four boxes displayed on the screen. Additionally, participants are not presented with repeated and random sequences separately; instead, random items are interleaved with items composing the repeated sequence. Using a four item verbal repeated sequence of A, B, C, D as an example, this would involve presenting the repeated sequence in the following manner: **A**, E, **B**, D, C, B, **D**, A, **A**, D, **B**, E, C, A, **D**, B; where the bolded letters make up the repeated sequence, and the non-bolded form the randomized interleaving items. Conversely, like in the Hebb, the individual is not informed that a repeated sequence of material will be presented. Using the ASRTT, Howard and Howard (1997; Howard et al., 2004) demonstrated that the more that random items were embedded among a repeated sequence, the more “noisy” the sequence became, making it more challenging to notice the repeated pattern. Specifically, they found that this interleaving affected older adults’ sequence learning substantially and even reduced the learning of the younger adult participants to an extent. Comparably, the stimuli used within the visuospatial Hebb may influence the level of noise, ultimately making it more challenging for the individual to notice and become aware of the repetition. Based on the results of Howard and Howard, one could even suggest that this would affect older adult participants more than their younger counterparts, an idea which could explain why an age-related deficit is observed.

1.1.5. The Implicit/Explicit Debate: Implicating Awareness

Given the considerable debate regarding the implicitness or explicitness of the

sequence learning task, numerous studies have been carried out to investigate the concept of awareness. Unfortunately, to date, findings in this area have failed to conclusively provide evidence that a lack of awareness of the repetition is in fact the key to explaining this age-related deficit. The topic has been investigated from various angles, including the examination of sequence learning in amnesic patients. Using a manual visuospatial version of the Hebb (1961), Milberg, Alexander, Charness, McGlinchey-Berroth, and Barrett (1988) found that one of two amnesic patients could demonstrate learning of the repeated sequence. Similarly, in 1990, Rausch and Ary observed that amnesic patients with unilateral (right or left) anterior temporal lobe resections (containing extensive removal of the hippocampus), retained the capacity to learn the recurrent pattern in both the verbal and visuospatial versions of the Hebb. Finally, using four different versions of the supra-span sequence learning Hebb paradigm (digits, spatial locations, words, and pseudo words), as well as the SRTT (Nissen & Bullemer, 1987), Gagnon, Foster, Turcotte, and Jongenelis (2004) tested one 48 year old densely amnesic patient (SJ), with substantial bilateral lesions of the hippocampus, and 12 control participants matched for age and education. Results indicated that learning of the recurrent sequence remained intact on all four forms of the Hebb, as well as on the SRTT, for both the controls and the densely amnesic individual. In fact, SJ was capable of recalling close to 80% of the items in the repeated sequence and a little over half of the items in the random sequences, across all the tasks. In line with these results, are findings obtained concerning performance of amnesic patients with hippocampal damage using the SRTT (c.f. Nissen & Bullemer; Nissen, Knopman, & Schacter, 1987; and Reber & Squire, 1994, 1998).

The above research implies that learning of supra-span sequences is not influenced by awareness of the repetition. However, as is typical in this area of research, several researchers testing amnesic patients have provided conflicting results. Specifically, learning deficits have been observed on either verbal and/or visuospatial versions of the Hebb paradigm (Baddeley & Warrington, 1970; Caird, 1964; Charness & Campbell, 1988; Drachman & Arbit, 1966; Milner, 1971). An example of this is Caird's research using "memory disordered" patients. Using a verbal version of the Hebb, Caird (1964) compared a group of twenty memory-disordered older adult psychiatric patients to a group of twenty non-memory disordered older adult psychiatric patients on their ISR performance of 30, six digit long verbally presented sequences among which a repeated sequence appeared every third trial. All participants were between the ages of 72 and 87 years old and were matched across the groups in terms of age, verbal intelligence, and forward digit scores. Results using the proportion of digits recalled in their correct serial position as an indicator of performance accuracy showed that the Hebb effect was demonstrated by the non-memory disordered group, but not the memory-disordered group. However, because the author failed to provide specifics regarding the psychiatric patients, it is unclear what was meant by memory-disordered. Therefore, it is possible that the discrepancy in results is simply due to the fact that different aspects of cognition were evaluated in the various outlined studies.

Work using the Hebb has also provided conflicting results when it comes to determining the role of awareness of the repetition within the learning process. For instance, McKelvie (1987) used a verbal digit-version of the Hebb task as well as a post-experimental questionnaire to assess awareness of the repetition, and reported that both aware and unaware younger participants were able to demonstrate the Hebb effect to the same degree. This

discovery suggests that conscious knowledge of the repeated sequence is not necessary for the repetition effect to be revealed. Likewise, in two experiments, Couture and Tremblay (2006) had younger adult participants perform a visuospatial Hebb like task (non-span adjusted), followed by a recognition task, as well as a survey containing one ambiguous question: “Did you notice anything particular about the procedure?” (taken from McKelvie’s research). In the visuospatial task, participants were shown 50 sequences, with each containing seven-items (single dots), each individually presented in a different location on a 17x17cm computer screen. Among the sequences, one seven-dot configuration was re-presented on every fourth trial, for a total of 12 times. Following the presentation of a complete sequence of items, participants were shown a screen containing all seven dots and were required to recall the order in which the dots had previously been presented, by clicking on them in the correct order. After the presentation of all 50 sequences, participants were asked the ambiguous question, which was then followed by the recognition task. These two elements were used to group subjects as aware or unaware. In the recognition task, subjects were presented with four different sequence configurations on a screen and were asked to identify the repeated sequence. In order to accomplish this task, participants had to be intentionally informed that a repeated sequence had been presented in the previous task. Results indicated that there was no difference in learning ability between the younger adults categorized as aware versus those categorized as unaware. In agreement with these findings is also the work of Sechler and Watkins (1991) who used a verbal Hebb learning task followed by both a recognition and frequency estimation task. In their study, participants were required to state: 1) if they recognized a sequence as being previously presented, and 2) how many times the sequence had been presented. Results showed that although some

participants were aware of the repetition, this did not appear to influence learning.

Research that has focused on both older and younger adults using a non-span adjusted visuospatial version of the Hebb paradigm, has also failed to confirm a concrete link between awareness of the repetition and learning. Specifically, in Turcotte's (2002) study detailed briefly earlier (see p.6), following the visuospatial Hebb task, older and younger adults were also asked to complete a post-experimental awareness questionnaire. Participants were asked to indicate if, as well as when, they became aware of the repeated sequence. Based on their responses, participants were grouped as early or late-aware subjects. Results showed, that younger adult participants demonstrated a strong repetition effect, while older adult participants demonstrated a shallow repetition effect, regardless of their awareness status (i.e. aware, unaware, early or late aware). However, one issue with the study is the fact that no adjustment to span was employed, suggesting that the results could in fact reflect task difficulty, rather than actual learning capacity.

Given the potential impact of span on memory and learning performance, Turcotte and colleagues (2005, Experiment 2) replicated Turcotte's (2002) research using a span-adjusted Hebb. In the investigation, 36 younger (aged 20-31 years old) and 36 community dwelling older (aged 65-80 years old) healthy adults, with comparable levels of education (younger adults had slightly more years of education than the older adults), and verbal intelligence, completed the visuospatial Hebb supra-span sequence learning task (25 sequences were presented instead of 24 to ensure that the final presented sequence was not the repeated, as well as to facilitate analyses of learning). They then answered a post-experimental questionnaire assessing awareness. Participants were classified as aware or unaware of the repetition, based on their response to the question: "Did you notice that a

sequence of blocks was repeated many times?” Now with the confound of task difficulty eliminated, results once again indicated that younger adults demonstrated a strong repetition effect, while older adults failed to do so regardless of their state of awareness, or at which point they became aware of the repetition.

In spite of a lack of a clear association between awareness of the repetition and learning, in Turcotte’s (2002), as well as Turcotte et al.’s (2005) studies just reported, a significant number of younger (79% and 81% respectively), as well as older (76% and 67% respectively) participants reported that they noticed the regularity. Therefore, although awareness of the repeated sequence does not appear to be necessary for learning to occur, it does appear to take place. This may indicate, as was suggested earlier, that there are at least two routes by which sequence learning can occur: a conscious and an unconscious one; a supposition that may help unite the inconsistency of the findings obtained within this area of research (for a similar proposition see Gagnon et al., 2005). However, drawing such a conclusion based on the results of these studies remains problematic. Indeed, aside from Couture and Tremblay’s (2006) study (in which a recognition task was employed), awareness of the repetition was not objectively assessed in all the reported studies thus far. Evaluation of awareness of the repetition relied strictly on participants’ self-report. This method may not accurately identify if participants became aware, and/or if awareness of the repetition actually influences learning.

Cognizant of the subjective/objective debate, Gagnon and colleagues (2005) carried out an investigation using a visuospatial Hebb sequence learning task, in which half the participants were explicitly informed of the inclusion of a repeated sequence. They had 45 younger (aged 18-32 years old) and 47 older (aged 66-80 years old) healthy adults with

comparable levels of education (younger had slightly more years of education) and verbal intelligence, complete a 25 sequence span-adjusted visuospatial Hebb task. In the study, both older and younger adults were randomly assigned to either: A) the *intentional* condition, which entailed that the participant be deliberately informed when a sequence would recur or to B) the *incidental* condition within which the participant was not informed of the recurrence. The learning analysis revealed that while younger adults benefited from being in the intentional condition, as demonstrated by their improved ISR performance for the recurrent sequence, the older adults did not. In fact, learning was found to be marginal under both types of instructions for the older adults. However, one key discovery relates to the younger adults performance in the study. Learning improved significantly for this group, when placed in the intentional condition.

1.1.6. Limitations in Working Memory

The findings of Gagnon and colleagues (2005) build upon those of Turcotte (2002) and Turcotte et al. (2005), in that they again suggest an associated learning benefit with awareness; supporting earlier claims made by Kidd and Greenwald (1988), as well as Sechler and Watkins (1991), that awareness of the repetition plays a substantial role in the production of the Hebb effect. The fact that younger adults demonstrate learning in the incidental condition, and superior learning in the intentional condition, suggest that awareness of the repetition likely enhances learning by promoting elaborating strategic processing within working memory. This is a finding that is in partial agreement with Cunningham and colleagues (1984), as well as Frensch et al.'s (2002) stipulation that more active elaborative processing, underlies the repetition effect (see Gagnon et al., 2005 for a similar proposal).

According to this proposal, knowledge of the repetition may have allowed younger adults to employ rehearsal strategies (see Cunningham et al.), or strategies such as chunking, which are techniques that has been shown to improve learning (c.f. O'Shea & Clegg, 2006). A similar interpretation has been put forth by Gagnon and colleagues (2005) who suggested that incidental (unconscious) learning is involved in the retrieval of the last seen sequence, while elaborative strategies, and thus more conscious processing underlies the encoding and retrieval of the repeated sequence of material. Therefore, the commonly accepted view that within the Hebb and SRTT, learning of regularities occurs incidentally may be incomplete. Our description of the above findings, highlight the fact that awareness of the repeated sequence appears to be prominent, even improving the expression of learning in some cases.

The results of Gagnon and colleagues (2005) point to an age-related limitation in working memory as an explanation of older adults' deficits on the Visuospatial Hebb supra-span sequence learning task. Older adults may in reality become aware of the regularity, but because of cognitive limitations, likely within the realm of working memory, they are simply unable to use such knowledge to engage in the necessary strategic processing. In fact, it has been speculated that individual differences in the operation of working memory components may impact awareness of the repeated sequence within the Hebb task (c.f. Baddeley, 2003; Baddeley & Andrade, 2000; Weitz et al., 2011), bringing into view the idea that a more limited working memory capacity may be what is mediating older adult performance on the Hebb task (O'Shea & Clegg, 2006). Specifically, working memory capacity may restrict their ability to actually become aware of the repetition and/or alternatively the ability to employ the necessary resources to manipulate and process the material, even within an intentional situation. Indeed, as was mentioned earlier, working memory capacity is known

to differ from one individual to another (Conway & Engle, 1996; Just & Carpenter, 1992; Rypma & D'Esposito, 1999), as well as between age groups, with older showing larger deficits than younger adults in working memory capacity (Bopp & Verhaegen, 2005; Salthouse, 1991b, 1994, 1996; Wingfield et al., 1988). Therefore, rather than awareness impacting working memory processing, it may working memory capacity which limits one's awareness of the repetition and/or an individual's ability to allocate the necessary resources for adequate strategic processing to ensue (c.f. Weitz et al., 2011).

1.1.7. Working Memory and the Role of Attention and Inhibition

Earlier, we mentioned that aging impacts a variety of cognitive functions. Attention is one such function that has been shown to experience changes with age (c.f. Castel & Craik, 2003; Craik, 1977a; 1982; Craik & Byrd, 1982; Hunt & Herzog, 1981; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991a). Of course, attention is a complex function, and one that appears to encompass a variety of both top-down (i.e. attentional control, selective attention) and bottom-up (e.g. stimulus-driven, visual attention, spatial attention) processes. Therefore, even though age-related changes in attention have been noted, one must consider that age may not impact all aspects of attention in a similar manner. Nevertheless, a role of attention has been consistently implicated in working memory processing (c.f. Baddeley, 1986, 1996, 2000; Baddeley & Hitch, 1974; Coolidge & Wynn, 2005; Cowan, 1988, 1995; Engle, 2001; Engle et al., 1999a; Kane & Engle, 2002; Shallice and Burgess, 1998). For instance, at the heart of many proposed working memory models is an attentional system. In Shallice and Burgess's (1998) model for example, there is a proposed supervisory control system. Similarly, Baddeley and Hitch

(1974; see also Baddeley, 1986, 1996, 2000) describe a central executive (CE) within their working memory framework (see also Cowan, 1988, 1995), also referred to as the “Attentional Controller” (c.f. Baddeley & Hitch; Coolidge & Wynn, 2005) or executive attention (c.f. Engle, 2001; Engle et al., 1999a; Kane & Engle, 2002). According to Baddeley, it is this CE, which is said to coordinate and balance the processing and storage actions of the two short-term storage slave systems (i.e. the phonological loop and visuospatial sketchpad). It is also the role of the CE to determine how to expend cognitive resources, as well as how to suppress irrelevant information that would otherwise consume resources. As can be seen, the aspect of attention being referred to here, likely concerns top-down, rather than bottom-up attention processes. However, one cannot rule out that bottom-up, stimulus driven attention aspects may also be involved.

Coinciding with the implication of attention in working memory frameworks, neuropsychological evidence suggests the existence of similar underlying neural substrates (e.g. dorsolateral prefrontal cortex) serving both working memory and attention functions (e.g. Baddeley, 1986; Cohen & Servan-Schreiber, 1992; MacDonald, Cohen, Stenger, & Carter, 2000; Milham et al., 2002; Posner & Dehaene, 1994; Taylor, Kornblum, & Lauber, 1997; Wagner, 1999). According to Milham and colleagues (2002), these shared neurological underpinnings imply that working memory and attention have mutually dependent roles:

Working memory maintains representations of current task demands. Such representations are crucial to attentional processes responsible for selecting task-relevant representations and actions. Likewise, selective attention acts to limit the contents of working memory to task-relevant representations and actions. Furthermore, it can aid in prioritizing the contents of working memory (p.278).

Not surprisingly therefore, the *General capacity hypothesis* proposed by Conway and Engle (1996), as well as the *Processing resource account* of Hebb learning, put forward by Weitz and colleagues (2011), both highlight that working memory relies to a large extent on an individual's attentional resources. The greater the amount of attentional resources, the more capable the individual will be at devoting resources to processing incoming stimuli and thus the more likely they will become aware of the regularity. Taking a slightly different perspective, one could also propose that the more attentional resources an individual has available, the more capable they will be at inhibiting irrelevant interfering material and at actively maintaining task relevant material (c.f. Milham et al., 2002; Rabbitt, 1997). This ability is more commonly referred to as attentional control, a concept which many models of attention posit is responsible for inhibitory functions (e.g., Banich et al., 2000a, 2000b; Carter, Mintun, & Cohen, 1995; MacDonald et al., 2000; Posner & Dehaene, 1994), such as preventing irrelevant information from impeding performance.

Along similar lines, researchers like Engle and colleagues (1999a) argue that working memory span tests tap an individual's ability to control attention. This would suggest that individuals with lower working memory spans (i.e. working memory capacity) may show reduced performance on complex cognition measures, simply because of issues with the controlled attention component of working memory (see also Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2003). Therefore, according to these researchers, having a high working memory span may not indicate an ability to store a larger amount of information, but rather the capacity to actively maintain relevant information in the face of interference rich conditions. They contend that this is achieved because of an enhanced ability to control attention, which likely allows the individual to suppress or inhibit irrelevant information or

responses. This view advocates that an individual's working memory capacity may affect the availability of attentional resources (for a similar proposal see Engle, 2002; Engle, Kane, & Tuholski, 1999b). This therefore suggests that older adults, whom are known to experience working memory capacity limitations and attentional issues, may be at a unique disadvantage when it comes to attentional performance, especially when working memory capacity is satiated (c.f. Castel & Craik, 2003; Craik, 1977a; 1982; Craik & Byrd, 1982; Hunt & Herzog, 1981; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991a).

A variety of behavioural studies actually show a correlation between working memory capacity and the ability to control attention (c.f. Conway, Cowan, and Bunting, 2001; Engle, 2002; Hester & Garavan, 2005; Kane et al., 2001; Long & Prat, 2002 using the Stroop; Unsworth, Schrock, & Engle, 2004; for similar proposals implicating the executive component of working memory see Holtzer, Stern, & Rakitan, 2004; Rose, Myerson, Sommers, & Hale, 2009; Thornton & Raz, 2006). For example, using a prosaccade and antisaccade task, Kane and colleagues (2001) tested both high and low working memory span younger adults, to determine if working memory processing is associated with the ability to be attentive (attentional control) to necessary information and thus inhibit distractors. In a first experiment, 200 participants were grouped as either high or low in terms of working memory span, based on their operation-word span task (OSPAN) performance. Subjects then completed a "prosaccade task, in which a visual cue was presented in the same location as a subsequent to be-identified target letter". They also completed "an antissacade task, in which a target appeared opposite the cued location" (Kane et al., p.169). The authors postulated that while both high and low span participants would perform similarly on the

prosaccade task, on the antisaccade task, high span individuals would outperform the low span individuals. The authors claimed that such a disadvantage in performance would be observed because of an inability of the low span participants to control their attention, in the midst of interference within the antisaccade task. Results indicated that this was indeed the case, with both high and low span individuals demonstrating similar performance in the prosaccade condition, and low span individuals demonstrating slower and less accurate performance than the high span participants in the antisaccade condition.

Hester and Gravan (2005) also investigated the link between working memory and executive function, particularly within the area of attentional control. Similar to Kane and colleagues (2001), they focused on determining if working memory capacity affects an individual's control of attention. However, rather than grouping their participants as high or low in terms of working memory span, instead working memory load was manipulated within the study and participants were tested at a supra-span level. This was achieved by having subjects complete a working memory task, as well as a secondary decision making task. The working memory task required that participants memorize an increasing number of letters, which they were then tested on using a recognition task. In the recognition task, subjects were simply required to indicate if the presented letter had appeared in the previous study list. In addition, certain letters within the recognition task presentation were coloured. Participants were instructed to simply switch from performing the working memory task to performing a secondary task, whenever a coloured letter was seen. The rate of task switching was intended to be an indicator of the individual's ability to execute attentional control. The researchers hypothesized that declines in task switching would materialize as working memory load increased, and that this would indicate that working memory load impacts

attentional control. Employing this tactic stems from the work of Baddeley (1996), who suggested that as working memory load increases past the point of capacity, this will also increase the demands made on the central executive (attentional) system (for a similar proposal see also Baddeley, Chincotta, & Adlam, 2001; De Fockert, Rees, Frith, & Lavie, 2001; De Zubicaray, Andrew, Zelaya, Williams, & Dumanoir, 2000, Hester & Garavan; Mitchell, Macrae, & Gilchrist, 2002; Roberts, Hager, & Heron, 1994). Using this testing procedure, Hester and Garavan found that when working memory is at supra-span levels, executive attentional control is indeed compromised.

1.1.8. Age-Related Deficits in Attentional Control

The results of Hester and Garavan (2005) point to the possibility that attentional control may be particularly important when working memory is taxed past its capacity; a situation that obviously occurs within the Hebb task, where a supra-span level of information must be processed. Importantly, fMRI research conducted by Milham and colleagues (2002) has provided neurological evidence that attentional control appears to be impacted by the aging process. Specifically, the researchers used fMRI to investigate if there are age-related changes in the ability to engage attentional control, as well as in the neural substrates thought to underlie attentional control. The Stroop was employed in their investigation since it is considered a relatively good measure of attentional control, because of its ability to evaluate “active goal maintenance, and the blocking or inhibiting of competing stimulus representations and action plans” (Kane & Engle, 2003, p.48). Results provided behavioral, as well as neurological evidence that compared to younger adults (21-27 years old), older adults (60-75 years old) appear to be at a disadvantage when it comes to attentional control

(i.e. focusing on task relevant material; inhibiting task-irrelevant material). This finding taken together with Hester and Garavan's results may be especially useful for explaining the performance deficits observed among older adults with respect to the visuospatial Hebb.

The idea that older adults have difficulty with attentional control sits well with the widespread acceptance that attentional resources are significantly impacted with aging (c.f. Castel & Craik, 2003; Craik, 1977a; 1982; Craik & Byrd, 1982; Hunt & Herzog, 1981; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991a). It also works well with the fact that older adults are known to have difficulty with inhibiting task-irrelevant material (c.f. Burke, 1997; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; May, Zacks, Hasher & Multhaup, 1999; McDowd, 1997; McDowd, Oseas-Kreger, & Fillion, 1995; and Zacks & Hasher, 1994). An example of this latter finding is the work of May and colleagues (1999), who had younger and older adult participants, complete a garden-path sentence task (Hartman & Hasher, 1991). At training subjects were presented with incomplete sentences and asked to fill in the blank with the most likely response they could think of. For example, "lights" would be a highly probable option for completing the following sentence: "Before you go to bed, turn off the _____". They were then provided with a less likely target alternative to complete the sentence, such as "stove" in this case. In the testing phase, participants were then asked to complete the sentences using the less likely target word. This meant that they were required to suppress or inhibit their natural response, thereby allowing the task to be a measure of inhibitory efficiency. Results indicated that younger, but not older participants were "efficient at suppressing once relevant, but no longer appropriate information" (May et al., p.304).

Behavioural studies using various working memory tasks thought to tap one's ability to suppress or inhibit task-irrelevant information have also confirmed reduced performance among older adults in verbal, spatial, self-ordered, and externally ordered areas (c.f. Haut, Kuwabara, Leach, Callahan, 2000; Reuter-Lorenz et al., 2000). Findings from several sequence learning research endeavours also support the idea that older adults have an issue with attentional control, further suggesting that the inability to appropriately inhibit irrelevant information from entering working memory may be what is at the root of the age-related learning issue on the Hebb task. For instance, after examining the error pattern produced by their older participants in the visuospatial Hebb task, Turcotte (2002), as well as Turcotte et al. (2005) found that the errors generated during the recall of a repeated sequence (N), were more likely associated with the individuals recall of the previous repeated sequence (N-3), than with their recall of the preceding random sequence (N-1). Further, the analysis indicated that older adults consistently repeated the same learning mistakes when recalling the repeated sequence. According to Maylor, Vousden, and Brown (1999) this probably reflects an intrusion of previous performance, and can be interpreted as an inability to inhibit irrelevant material from working memory; a finding which works well with Hasher and Zack's (1988) contention that the aging brain has trouble preventing the entrance of irrelevant information into working memory, ultimately disrupting working memory processes.

Couture and colleagues (2008) reported similar findings after having participants perform a verbal Hebb like task in which a visuospatial response was required. Specifically, subjects were presented with 50 nine-item letter sequences of material via headphones, separated into 12 blocks of four trials. On every fourth trial, a repeated sequence of material

was presented, for a total of 12 occurrences. Following each presentation, participants were shown a visual representation of the letters composing the sequence and were required to reproduce the just heard sequence by clicking on the corresponding letters in their correct sequential order. Similar to Turcotte (2002) and Turcotte and colleagues (2005), Couture and colleagues error analysis indicated that participants tended to repeat the same errors when recalling the repeated sequence, suggesting that even younger adults experience some impairment with inhibiting previously encoded and or recalled material. However, their participants demonstrated learning, an indication that the impairment was not as severe as what has been seen among older adults. The findings indicate that a reduced ability to inhibit no longer-relevant or completely irrelevant information (see also Lafond et al., 2010 for compatible results) could contribute to the sequence learning difficulties of older individuals.

In 2005, Tremblay, Nicholls, Parmentier, and Jones, more directly investigated the role of inhibition in visuospatial serial memory using a spatial working memory task, along with a technique called the sandwich effect (e.g. Hitch, 1975). Their goal was to determine if irrelevant visual information impedes on visuospatial serial memory. In the task, young participants were presented with 30 trials of seven-item length sequences that were made up of dots. Each dot was presented in one of 289 locations (17 x 17cm matrix) on a screen, with the only limitation being that a dot within a sequence could not appear directly in the center of the screen. Subjects were told that dots presented in the center of the screen were to be ignored, as they were not part of the memory task. The participant was required to recall the sequence of seven dots that were presented while inhibiting any irrelevant dots. Fifteen of the 30 trials did not contain these “irrelevant” distractor dots, while the other 15, considered the sandwich conditions, did. Analysis of the results indicated that the distractor items had a

clear effect on serial recall performance, demonstrating that the presence of irrelevant visuospatial items (i.e. distractor dots) impacts visuospatial serial memory among a younger population.

1.1.9. Why Only a Deficit on Visuospatial?

Overall, the findings presented suggest that attention may play a pertinent role in the age-related sequence learning deficit. The question however, is why deficits are observed on the visuospatial, but not the verbal Hebb task? Two explanations implicating a role of attention can be put forth. For one, earlier it was argued that successful processing of visuospatial stimuli might be more demanding than that of verbal stimuli, suggesting that the former task may be more reliant than the latter on cognitive resources such as attention to carry out efficient processing in working memory. Evidence supporting this contention was provided by research demonstrating that both younger and older adults appear to have a shorter span capacity for visuospatial versus verbal sequence material (c.f. Turcotte, et al., 2005; Gagnon et al., 2005). The reasons why visuospatial material may be more challenging however have yet to be ascertained. As was previously suggested, visuospatial stimuli may simply share greater similarity with one another than verbal stimuli (Lustig et al., 2001; Turcotte, 2002; Turcotte et al., 2005), potentially leading to an increase in difficulty to differentiate from among the items composing a sequence.

The second explanation put forth stems from the finding that among older adults, memory appears to be better for verbal than visuospatial material. That is, although age-related declines in memory performance are observed for both visuospatial (Cherry & Park, 1993) and verbal material (Craik & McDowd, 1987), several studies show greater

impairment for visuospatial than verbal material (Jenkins, Myerson, Joerding, & Hale, 2000; Myerson, Hale, Rhee, & Jenkins, 1999; Tubi & Caley, 1989). These findings suggest that differences in performance may be observed across the board for verbal versus visuospatial material; implying that distinct working memory system components, neurological constructs and potentially therefore differing amounts of resources (i.e. attentional resources), may be involved in processing the two types of material. This interpretation works well with literature highlighting that there is a distinction made between verbal and spatial working memory systems (e.g. phonological loop and visuospatial sketchpad; c.f. Baddeley, 1986, 1996, 2006; Baddeley & Hitch, 1974; Logie, 1995; Oberauer, Süß, Schulze, Wilhelm, & Wittman, 2000; Shah & Miyake, 1996; Smith & Jonides, 1997). This also coincides with neuroimaging evidence of verbal and visuospatial memory being lateralized to different regions of the brain, with verbal memory and visuospatial memory lateralized to the left and right hemisphere respectively (c.f. D'Esposito, Aguirre, Zarahn, Ballard, Shin, & Lease, 1998; Smith & Jonides, 1999). In fact, functional magnetic resonance imaging has shown that attentional processes associated with the left inferior frontal lobe are implicated in memory for verbal material (Wagner, Poldrack, Eldridge, Desmond, Glover, & Gabrieli, 1998a; Wagner et al., 1998b), while attentional processes associated with the homologous right frontal lobe appear to be engaged during the learning of non-verbal material (Brewer, Zhao, Desmon, Glover, & Gabrieli, 1998). These differences in neurological underpinnings and processing mechanisms support the idea that older adults are simply at a disadvantage when it comes to dealing with visuospatial material, because the attentional resources required by the underlying processing mechanisms differ or are substantially larger than those required for the processing of verbal material.

1.1.10. Attention, the Hebb paradigm, and the Present Research Endeavor

Up to this point, most of the discussion on attention has focused on attentional control, and thus an individual's ability to suppress/inhibit irrelevant information and focus on pertinent information to complete a task. The discussion has also been fixated on describing the role of attention within the working memory framework, and how limitations in attention might affect working memory processes and vice versa. However, this type of executive control of attention, which can be considered a top-down process (Friedman et al., 2008), is likely not the only aspect of attention that is involved in successfully demonstrating learning on the Hebb task. In fact, controlling what you pay attention to (i.e. selective attention, divided attention) and manipulating what you pay attention to (i.e. response inhibition, set shifting, updating working memory), is only a portion of what transpires when carrying out the visuospatial Hebb task. Bottom-up processes, such as visual (object) and spatial (movement) attention are also likely heavily involved. However, these aspects of attention rely more on automaticity than top-down processes, as it is the stimulus that directs where resources will be focused. As such, it is important to note that a variety of aspects of attention are involved in completing the visuospatial Hebb task and demonstrating learning.

Regardless of what specific aspects of attention are involved in visuospatial sequence learning, as well as why attention (in a general sense) might be more heavily implicated in visuospatial than verbal sequence learning, it does appear that attention likely plays a substantial role within the visuospatial sequence learning process. Although researchers have explored various interpretations in the hopes of elucidating why it is that older adults have difficulty learning sequential material that is visuospatial in nature (c.f. Gagnon et al., 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte et al., 2005), to our knowledge no

attempt has been made to investigate the role played by attention. This is especially surprising since attention is known to fluctuate with age (c.f. Castel & Craik, 2003; Craik, 1977a; 1982; Craik & Byrd, 1982; Hunt & Herzog, 1981; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991a). Accordingly, in order to bridge the gap in this area of research, we wished to explore this age-related attentional decline interpretation.

Three separate investigations, spanning five studies, were carried out to test this proposal. The first investigation took a rather broad approach and focused on examining the role of attention in a general manner. We anticipated that reducing the amount of attentional resources that a participant could allocate to carrying out the visuospatial Hebb sequence learning task would assist in identifying whether a non-specific reduction in attentional resources affects learning. A dual-task (DT) procedure that was carefully designed to not interfere with the visual, spatial, or motor components of the visuospatial task was created. This secondary task, which required that participants vocally repeat single alphabetical letters that were presented through headphones, was implemented at key processing moments within the Hebb task, where attention would likely be involved (i.e. Exp.1, encoding; Exp.2, retrieval; Exp. 3 encoding and retrieval). We felt that this approach would allow us to pinpoint where limitations in attention might impact learning. Use of a DT procedure in this area of research stems partly from the seminal work of Nissen and Bullemer (1987) who demonstrated that performing a secondary task alongside a sequence learning task impairs learning. We accepted that testing older adults within this particular context would fail to provide any valuable information, since the attentional requirements would be elevated rather than reduced. Therefore, in lieu of reducing the attentional demands

of the Hebb paradigm, with the goal of generating visuospatial sequence learning in older adults, we instead hoped to mimic in younger adults the learning deficits typically observed in older adults within this area of research.

The second investigation examined a more specific role of attention by focusing on the attentional processes associated with the recall component of the visuospatial Hebb supra-span sequence learning task. This was carried out by implementing a DT that contained overlapping processing features with the recall requirements of the visuospatial Hebb. As was done in the first three studies, the learning deficit was again explored in younger participants. In an attempt to reduce the attentional requirements at the retrieval stage of visuospatial supra-span Hebb task, in a final study, we replaced the traditional motor recall method with a verbal response recall procedure. This manipulation was designed to reduce the attention stemming from the necessity to discriminate between memory traces generated by the previous motor responses and the just seen sequences.

2. CHAPTER TWO: ARTICLE 1

Cognitive aging, attention, and sequence learning:

A look at the visuospatial Hebb supra-span sequence learning task.

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Abstract

In a series of three studies, we examined whether issues with attention might explain why older, but not younger adults have difficulty demonstrating visuospatial supra-span sequence learning of the Hebb type. In each study, a verbal dual-task procedure was used to restrict the amount of attentional resources participants could contribute to carrying out the Hebb task. In Exp.1 the dual-task was implemented at encoding, while in Exp. 2 and Exp.3 it was implemented at retrieval, and at both encoding and retrieval respectively. Results indicated that although the younger adults demonstrated learning of the repeated sequence in all conditions of all three experiments, they did show a reduction in general performance whenever the dual-task was implemented at retrieval. This suggests that attention may not play a significant role in the age-related learning deficit, but that it does play a role in general performance on the visuospatial Hebb, with a particular emphasis on the attentional requirements associated with the response phase of the task.

Keywords: Cognition, Aging, visuospatial, sequence, learning, Hebb.

Introduction

The Hebb (1961) sequence learning paradigm, which was originally developed to study long-term memory trace formation, has recently been used to examine sequence learning ability (e.g., Gagnon et al., 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte et al., 2005). This task entails that a participant perform immediate serial recall (ISR) of sequences of material. The stimuli employed can either be verbal (e.g., words, letters, etc.) or visuospatial (i.e., spatially arranged squares) in nature. In this task, the participant is required to recall the entire sequence of material immediately following its presentation. Unbeknownst to the individual however, a repeated sequence of stimuli is embedded amongst random sequences of stimuli of the same type. Learning is therefore evident, when recall performance of the repeated sequence material surpasses that of the random sequence material, indicating that the improvement in performance is not the result of a general practice effect.

Recent research using the Hebb (1961) paradigm has identified an age-related deficit in sequence learning, where older, but not younger adults are shown to have difficulty learning sequential material that is visuospatial in nature (e.g., Couture et al., 2008; Gagnon et al., 2005; Lafond et al., 2010; Turcotte et al., 2005). Several interpretations have been put forth to explain this rather specific deficit. Amongst these is the Familiarity interpretation, which proposed that an individual's lack of familiarity with visuospatial stimuli could be responsible for the observed learning deficit (e.g., Caird, 1964; Heron & Craik, 1964; Turcotte, 2002; Turcotte et al., 2005). Other research investigated the possibility that within this paradigm, awareness of the repetition plays a key role in the learning process, with younger, but not older adults demonstrating learning of the material because of their ability

to become conscious of the recurrence (e.g., Couture & Tremblay, 2006; Frensch et al., 1994; Gagnon et al., 2004; McKelvie, 1987; Turcotte et al., 2005). To date however, all investigations appear to have been unsuccessful in delineating the underpinnings of this age-associated change in learning issue.

A closer examination of the cognitive mechanisms involved in carrying out the Hebb task, suggest that working memory plays a critical role in the learning process (Conway & Engle, 1996; Gagnon et al., 2005; Weitz et al., 2011). For instance, in order to demonstrate learning, the Hebb task requires that participants maintain long sequences of stimuli (supra-span sequences) in a rather active state. Given that an attentional system is at the core of most working memory models (e.g., Baddeley's Central executive or Baddeley & Hitch's attentional controller; e.g., Baddeley, 1986, 1996, 2000; Baddeley & Hitch, 1974), it follows that working memory implicates a role of attention. This association between working memory and attention is supported by several pieces of evidence. Firstly, there is neuropsychological evidence which demonstrates that the two constructs share similar underlying neural substrates (e.g., Baddeley, 1986; Banich et al., 2000a, 2000b; MacDonald et al., 2000; Milham et al., 2002), suggesting that the two are mutually dependent. Secondly, a substantial body of literature supports the negative impact of aging on both attention and working memory (e.g., Bopp & Verhaegen, 2005; Castel & Craik, 2003; Salthouse, 1991a, 1991b, 1994, 1996). Taken together, these findings suggest that the two constructs work closely together, are mutually dependent, and may even be one and the same.

In the present context, this link between working memory and attention is not surprising. Indeed, attentional resources are thought to be responsible for inhibiting irrelevant information and for actively maintaining task relevant material (Banich et al., 2000a, 2000b;

Carter et al., 1995; MacDonald et al., 2000; Milham et al., 2002; Posner & Dehaene, 1994; Rabbitt, 1997); both of which are processes that must be effectively carried out within the Hebb task in order for sequence learning to ensue. Along these lines, Weitz and colleagues (2011) have put forward the *Processing resource account* of Hebb learning, which stipulates that the ability to successfully process incoming stimuli, as well as the ability to notice the presence of a repetition, is reliant on one's attentional resources. As a result, one could suppose that a learning impairment could result from a lack of available attentional resources, because of the impact this would have on an individual's ability to, among other things, maintain pertinent information in an active state, as well as inhibit irrelevant information.

Given that, aging is associated with decrements in attentional performance (e.g., Castel & Craik, 2003; Craik, 1977a; 1982; Parasuraman & Giambra, 1991; Salthouse, 1991a); it is plausible that differences in attention between older and younger subjects may explain age-related supra-span visuospatial sequence learning deficits. In the field of sequence learning, the role of attention has often been investigated using a dual-task (DT) paradigm, a protocol where participants complete two tasks simultaneously and thereby divide their attentional resources (e.g., Baddeley, 1996, 2001; Baddeley & Hitch, 1974; Nissen & Bullemer, 1987). Use of the DT procedure among younger adults, is also accepted by some research, as a valid method for mimicking the effects of aging on attention (Craik, 1977b, 1982, 1983; Craik & Byrd, 1982; Craik et al., 1996).

One frequently cited example of DT research in the sequence learning domain is Nissen and Bullemer's (1987) three part investigation, in which younger participants completed the Serial reaction time task (SRTT; another commonly used sequence learning

paradigm) either alone or with a tone-counting task. In the tone counting task, participants were required to keep count of low tones that were presented among a series of high tones. Results indicated that implementation of a secondary task alongside the SRTT impacted learning, with participants exposed to the DT showing no significant improvement in their recall (accuracy and latency) of the repeated sequence material when compared to their recall of the random material. According to Nissen and Bullemer, this impairment in learning was a consequence of a reduction in the amount of available resources the younger adults were able to contribute when performing the SRTT (for similar findings see also Cohen et al., 1990, Exp. 4; Frensch et al., 1999; Hartley & Little, 1999; Howard et al., 2004; Shanks & Channon, 2002). As such, one could predict that an even greater impact on learning would be observed when using the visuospatial Hebb, since the attentional and working memory requirements of the task are likely heavier than those for the SRTT. In particular, the Hebb task involves recalling complete sequences of information, following their presentation, whereas in the SRTT, participants are only required to identify one stimulus at a time. The stimulus is also still present when recall ensues in the SRTT, suggesting that although both tasks tap sequence learning ability, the two rely on substantially different levels of working memory processing.

In the following set of experiments, the general impact of attention on Hebb visuospatial sequence learning performance was tested by manipulating the attentional demands at two points where processing is considered attentionally demanding: during encoding and retrieval of the sequences. In each experiment, a DT was completed alongside the visuospatial Hebb task at a specified phase, in an attempt to impact the attentional requirements at that point. In Experiment 1, we attempted to impact the attentional

requirements at encoding, by having participants perform a DT while encoding the sequence material. In Experiment 2, the DT was performed only during the retrieval of information, and finally in Experiment 3, the DT was performed during the entirety of the task (i.e. encoding and retrieval). In all cases, a verbal DT, which consisted of orally repeating individual letters that were presented through headphones, was employed. This method was considered more attentionally demanding than the typical engagement of a tone counting task since participants were required to consistently focus on both tasks and produce an oral, as well as manual response (i.e. oral response for the DT; manual response for the Hebb). Using the outlined method, we hypothesized that younger adults in the experimental group would demonstrate a reduced Hebb repetition effect in at least one of the three experimental conditions.

Experiment 1

Several studies have shown that the encoding process requires extensive attentional resources, and is thus significantly affected by the implementation of a DT (e.g., Baddeley et al., 1984; Craik et al., 1996; Fernandes & Moscovitch, 2000, 2002; Murdock, 1965; Naveh-Benjamin, 1987; Naveh-Benjamin et al., 2000; Reinitz et al., 1994). It was therefore expected that with a DT in place at encoding, younger adults would show reduced to no learning of the repeated sequence material on the Hebb task, while those in the control group would demonstrate substantial learning. Traditionally, when using the Hebb paradigm, accuracy of ISR (item and order) performance is the measure of choice. However, a secondary goal of the investigation was to determine whether response latency (a.k.a. response time), also has the ability to reveal that learning has taken place. Similar to

accuracy measurements, learning would be evidenced by an improvement in response time for the repeated material, which exceeds that for the random material. Accordingly, both accuracy and latency measurements were recorded and analyzed in the present investigation.

Method

Participants. Sixty-eight social science undergraduate students (52 Females, 16 Males), between the ages of 18 and 33 ($M = 19.59$; $SD = 3.06$) were recruited for this experiment and randomly assigned as either a control (27 Females, 7 Males), or an experimental (25 Females, 9 Males) participant. English speaking participants were recruited through the University of Ottawa's School of Psychology's Integrated System of Participation in Research (ISPR) recruiting system, as well as via a voluntary response to advertisements that were placed throughout the University of Ottawa campus and in two local Ottawa and Gatineau newspapers (see Appendix A for advertisements for all experiments; see Appendix B for telephone recruitment script for all experiments). At the time of the experiment, all of the participants described themselves as fluent in English, and as healthy (i.e. free of any major health problems, neurological antecedents, or psychiatric disorders). All participants also presented with normal vision and hearing, and none of the participants reported having a history of alcoholism or drug abuse. Individuals recruited via the ISPR system received course credit for participating, while individuals recruited via flyers and newspaper ads were given 5\$ for their participation in the 35-minute testing session.

Materials. Each participant completed a demographic questionnaire (see Appendix C for all experiments), a consent form (see Appendix D for all experiments), a computerized

spatial span assessment test (SAT; Brooks & Watkins, 1990; Watkins, 1977), and a computerized version of the visuospatial Hebb supra-span sequence learning task (Hebb, 1961; Corsi, 1972) paradigm. In addition, those assigned to the experimental condition completed a verbal DT. Computerized versions of the SAT and Hebb were used to ensure control over the timing parameters. This included the duration of sequence presentation, the presentation time of each item within a sequence, the inter-item interval, the time allocated to recall each sequence, and within the Hebb, the delay between occurrences of the repeated sequence. This procedure was necessary, given that these elements have been identified as modulators of the Hebb effect and thus would be confounds within the present study (Bower & Winzenz, 1969; Melton, 1963).

Stimuli and apparatus. A 17-inch NEC AccuSync LCD 72vx monitor linked to a Pentium (R) 4 IBM Think Centre CPU was programmed using E-builder to present and score all portions of the experiment, except for the DT, which was presented via headphones. For the DT, a tape recorder was used to confirm the verbal responses made by the participant. In both the SAT and visuospatial Hebb, black squares that were randomly positioned on a light grey background computer screen served as stimuli. Each square was 2.54 cm². The sequential presentation of the squares was signalled by a colour change from black to white (with a black contour). Each square presented on the screen was approximately 3 cm away from any other square. A buzzer sounded at the end of the presentation of each sequence to signal the start of the recall phase. Participants used a mouse to perform ISR, by clicking on each of the squares.

Spatial span assessment task (SAT). Using Permutation 1.0 software, ten sequences of spatial locations (squares) were randomly generated for sequence lengths ranging from three to 13, for a total of 110 sequences. It was ensured that no sequence formed a shape or any recognizable pattern. In addition, no sequence presented was the same as those later used in the visuospatial Hebb. Using E-builder, the computer was programmed to select a sequence no more than once from the data set. This was done to ensure that a sequence was not shown more than once to the same participant. Other than this restriction, selection from the particular sequence length data set was programmed to be random. Thirteen squares always appeared on the display, and only those encompassing the sequence lit up. Therefore, only one display containing 13 squares was created for the task.

Visuospatial Hebb supra-span sequence learning task. Production of the sequence material for the Visuospatial Hebb supra-span sequence learning task followed the methods employed by Gagnon and colleagues (2005). The only difference here being that Permutation 1.0 software was used to randomly generate two sets (set A and set B), as opposed to four sets of 18 sequences of spatial locations (squares), for each sequence length (5-13 squares), totalling 324 sequences. Again, it was ensured that no sequence formed a shape or any recognizable pattern. The number of squares presented was based on the individual's calculated supra-span ($\text{span} + 2$), and along with the spatial positioning of the squares, this element remained constant between trials. Only the number of squares required to compose the sequence was displayed on the screen. As an example, if an individual's span was assessed as being five, then only seven ($\text{span} + 2$) squares were presented on the display.

Verbal dual-task. An audio recording consisting of individual letters from the English alphabet (A-Z, excluding any letters that were phonetically similar) was prepared for administration to the participants. Inter-item presentation was 2000 milliseconds and letters were presented in a random order. Headphones were used to present the recording.

Procedure. The entire experiment lasted 35 minutes and each participant was tested on an individual basis, following the exact same procedure as the other participants within the group (control or experimental) to which they were randomly assigned. Each participant was seated comfortably at a distance of 65 cm from the computer screen, and proceeded to complete the SAT (Watkins, 1977), followed by the visuospatial Hebb (1961) task (Corsi, 1972). Instructions for both the SAT and visuospatial Hebb were displayed directly on a white computer screen using large black font (New York, size 40), and on each instruction screen, participants were informed that they could request clarification from the experimenter. For all participants, the DT was implemented during the encoding phase of both the SAT and visuospatial Hebb; however, only those in the experimental group were required to complete the DT. The investigator remained in the testing room for the duration of the experiment, to ensure that all aspects ran smoothly (see Appendix E for a copy of the investigators script used for experiment 1, 2, 3, and 5; see Appendix F for a copy of the debriefing script respectively used for all experiments).

Span assessment task (SAT). The staircase method developed by Watkins (1977) was used to obtain an estimate of an individual's span in the SAT. Participants were told that squares would appear on the computer display, and that each would light up one after the other, by changing from black to white. Following a buzzer, they would need to use

the mouse to recall the order in which the squares had lit up, by clicking on them. If they could not recall which square lit up next in a sequence, they were encouraged to take their best guess, or to press the space bar, which would leave that position blank. They were also informed, that the number of squares presented within a sequence, could increase or decrease from trial to trial. However, they were not told that this depended on their performance. That is a correct response would result in one additional square being presented on the next trial; while an incorrect response would result in one less square being presented on the subsequent trial (see Appendix G for a copy of the instructions presented to participants for experiment 1-3).

Participants received three trials of training. Each contained a sequence of four squares. Following this, the testing phase began. Aside from the following differences, within the testing phase, presentation of the sequence elements (e.g., timing and order) followed the methods employed by Gagnon and colleagues (2005). Firstly, the display presented was white and contained black squares, as opposed to the light grey display with dark grey squares used in Gagnon and colleagues research. Secondly, during the recall phase, a number was placed at the top of the computer screen, which indicated how many squares the participant had already selected. Once the correct number of squares had been selected, the trial ended, and the next trial automatically began. The calculation of span was also calculated using the same procedures as Gagnon and colleagues. This estimate of span was then used in the visuospatial Hebb learning task that followed.

Visuospatial Hebb supra-span sequence learning task. Aside from the following differences, the procedure used for the Hebb supra-span learning task was identical

to that of the SAT. Firstly, participants were shown 25, rather than 16 sequences (trials) of material. Second, a repeated sequence, about which participants were not informed, was presented on every third trial. Third, participants were told that, unlike in the SAT, the number of squares in the Hebb task would remain constant from trial to trial. Finally, 20, as opposed to 30 seconds, were awarded for recall (see Appendix H for a copy of instructions presented to participants for experiment 1-3).

Verbal dual-task. Individual alphabetical letters were presented orally via headphones, every 2000 milliseconds, during the encoding phase of both the SAT and visuospatial Hebb. Only experimental participants were required to verbally repeat each letter directly following its presentation, while the control subjects were simply told to ignore the DT. The researcher ensured that a correct response was made.

Scoring. In visuospatial supra-span sequence Hebb learning task, the primary measure of performance involves calculating the proportion of correctly recalled squares in their appropriate serial position (item and order). With each subsequent presentation of the repeated sequence, it is expected that recall performance will improve substantially for the repeated sequence, but not for the random sequences and that, subsequently this would provide an indication of learning. This requires a comparison of learning at several times throughout the task. Consistent with previous research, the data was grouped into blocks for this purpose (e.g., Fallon & Tehan, 2001; Turcotte et al., 2005). A set of blocks was created for the random, as well as the repeated sequence performance data. A Comparison of the repeated and random material on each block, as well as between blocks was conducted. The baseline block consisted of the average serial recall on trials 2-4. At this point all sequences

would be considered random, even though a repeated sequence was presented. Block 1 for the random material contained the average serial recall of trials 5 and 7, while for the repeated material, it contained the average serial recall of trial 6. Block 2 for the random material contained the average serial recall of trials 8, 10, 11, 13, 14, and 16, while for the repeated material, it consisted of data from trials 9, 12 and 15. Finally block 3 for the random material contained the average serial recall of trials 17, 19, 20, 22, 23, and 25, while for the repeated material, it consisted of data from trials 18, 21 and 24. The data were also grouped in several ways (see the seven block procedure adopted by Gagnon et al., 2005), but the analyses of these alternate groupings did not yield significantly different results.

In order to provide a complete assessment of learning, both the average of the participants' performance in terms of accuracy, as well as latency, across the repeated and random sequences was examined.

Results & Discussion

Span assessment task. To confirm that prior to the learning phase participants had equivalent short-term retention of spatial positions, an independent samples t-test assessing group differences on average span was carried out. Results indicated that span did not significantly differ between the two groups, with both control ($M = 6.06$, $SD = 0.69$) and experimental ($M = 5.85$, $SD = 0.82$) displaying similar average span scores $t(66) = 1.12$, $p = .268$, $d = .649$.

Visuospatial Hebb supra-span learning task.

Baseline performance. In order to examine if baseline performance differed amongst the two age groups, two separate independent t-test analyses were executed: one on

accuracy, as well as one on RT scores. The accuracy analysis indicated that at baseline the control ($M = 0.66$, $SD = 0.21$) and experimental group ($M = 0.59$, $SD = 0.19$) recalled material with similar accuracy, $t(66) = 1.54$, $p = .129$, $d = 2.76$. The analysis computed on RT scores yielded the same pattern of results with the control ($M = 9345.98$, $SD = 2485.10$) and experimental groups ($M = 9799.80$, $SD = 2734.80$) recalling material at a similar average speed, $t(66) = -0.72$, $p = .476$, $d = -.010$.

Learning of the repeated sequence. The ISR performance of the control and experimental groups on the repeated and random sequences in block 1, 2, and 3, when a DT is implemented at encoding is depicted in Figure 1 for accuracy presented as a proportion, and in Figure 2 for RT presented in milliseconds. Inspection of these figures suggests that both the control and experimental groups' demonstrated superior recall of the repeated compared to the random sequence. Two mixed design Group (control vs. experimental) x Sequence type (random vs. repeated) x Block of trials (block 2-4) ANOVAs were conducted using RT performance in one case and accuracy performance in the other. The between-subjects factor in both ANOVAs was Group.

Learning of the repeated sequence through accuracy performance. The analysis of accuracy performance indicated that the Group effect was non-significant (control: $M = .71$, $SE = .02$; experimental: $M = .68$, $SE = .02$), $F(1, 66) = 0.57$, $p = .451$, $\eta_p^2 = .009$, power = .116. Both within-subjects factors reached significance, namely Sequence (random: $M = .62$, $SE = .01$; repeated: $M = .76$, $SE = .02$), $F(1, 66) = 39.96$, $p < .001$, $\eta_p^2 = .377$, power = 1.00, and Block (block 1: $M = .65$, $SE = .02$; block 2: $M = .70$, $SE = .02$; block 3: $M = .73$, $SE = .02$), $F(1, 66) = 20.91$, $p < .001$, $\eta_p^2 = .241$, power = .995. Post-hoc pair-wise

contrasts using the Tukey HSD test, indicated that in general participants were significantly more accurate in their recall performance across both the average of the random and repeated sequences, as they progressed from block 1 to block 2 ($p = .030$), and from block 1 to block 3 ($p < .001$). Taken together with the finding that no Sequence x Block interaction was obtained, these results indicated that learning was occurring as early as the first block. Additionally, the hypothesized three-way interaction between Sequence, Block, and Group did not reach significance, $F(1, 66) = 0.27, p = .608, \eta_p^2 = .004$, power = .080, as nor did any other interactions (see Figure 1). Given the absence of any group interactions, this analysis indicated that there was no significant difference in the magnitude of performance between the control and experimental group. That is, there was a clear repetition effect in both groups. Consequently, we failed to support our main hypothesis that the experimental groups' learning would suffer because of the DT in place, when accuracy is used as an indicator of learning.

Learning of the repeated sequence through RT performance. The analysis of RT performance revealed that the difference between the two groups did not reach significance (control: $M = 8827.18, SD = 322.52$; experimental: $M = 8945.18, SD = 322.52$), $F(1, 66) = 0.07, p = .797, \eta_p^2 = .001$, power = .057. This finding indicated that, in terms of response time, the two groups did not differ in their mean general speed performance across the sequence type and block of trials. Both within-subjects factors, namely Sequence (random: $M = 9126.26, SE = 242.24$; repeated: $M = 8646.11, SE = 244.95$), $F(1,66) = 7.86, p = .007, \eta_p^2 = .106$, power = .789, and Block (block 1: $M = 9585.14, SE = 305.62$; block 2: $M = 8770.45, SE = 253.78$; block 3: $M = 8302.95, SE = 213.56$), $F(1,66) = 27.66, p < .001, \eta_p^2$

$= .295$, power = .999, were found to be statistically significant. This indicated that both groups were significantly faster in terms of their general average recall of the repeated, compared to the random sequences, across all three blocks. This also indicated that together, both groups were in general significantly faster in their recall of the average of both sequence types, as they progressed across the blocks.

The ANOVA also yielded a statistically significant Sequence x Block interaction, $F(1, 66) = 7.18$, $p = .009$, $\eta_p^2 = .098$, power = .752, indicating that the effects of block on RT, depend on the sequence type being recalled. Follow-up analyses using the Tukey HSD test, confirmed this effect of Block, showing that recall of the repeated sequence was significantly faster, as the participants progressed across the experiment. That is, recall of the repeated was significantly faster on block 2 than block 1 ($p = .010$), on block 3 than block 2 ($p = .007$), as well as on block 3 than block 1 ($p < .001$), as revealed by post-hoc contrasts. Similarly, it was observed that recall of the random sequence was also significantly quicker on block 3 than block 1 ($p = .009$), but performance even though faster on block 2 than block 1, and on block 3 than block 2, these did not reach significance ($p = .214$ and $p = .290$ respectively). Pair-wise comparisons of the Block x Sequence interaction also indicated a difference in recall for the repeated versus the random sequences, as participants moved from block 1 to block 3. Specifically, on both block 2, as well as on block 3, recall of the repeated sequence was significantly faster than recall of the random sequences ($p = .001$ and $p < .001$ respectively), while on block 1, although non-significant, general recall of the repeated sequences was actually slower than that of the random sequences ($p = .719$).

These analyses indicate that learning was evident by block 2, since recall of the repeated sequence was significantly faster than recall of the random sequences, from that

point on. Moreover, the hypothesized three-way interaction between Sequence, Block, and Group, did not reach significance, $F(1, 66) = 0.44$, $p = .507$, $\eta_p^2 = .007$, power = .101 (see Figure 2), as nor did any other interactions. Therefore, given the absence of any interactions involving the Group factor, this analysis revealed that there was no statistically significant difference in the magnitude of performance between the groups. There was a clear repetition effect occurring, and it was to the same degree for both groups. Accordingly, using RT as an indicator of learning, we once again failed to support our main hypothesis that the experimental groups' learning would suffer because of the DT in place at encoding.

Experiment 2

The objective of the first experiment was to investigate if attention plays a role in the age-related visuospatial sequence learning deficit. Both accuracy and latency results indicated that the attentional manipulation employed did not impact learning in young adult subjects. This could indicate that the attentional requirements at the encoding phase are quite low and therefore not of major significance to the learning process within the Hebb task. It is conceivable that the attentional requirements may be greater at retrieval than at encoding. This interpretation is motivated in part by the error pattern analysis of older adults' responses that was performed by Turcotte and her colleagues (2005; see also the work of Turcotte, 2002). Specifically, they concluded that older adults' responses contained traces of interference which was associated with their previous erroneous recall of the repeated sequence (see also Couture et al., 2008; Estes, 1991; as well as Lafond et al., 2010 for similar interpretations). If this is in fact the case, the DT would need to be implemented at the point when participants reproduce the sequences. Accordingly, the DT was implemented during the retrieval phase in Experiment 2. It was expected that if there is indeed a role played by

attention during the retrieval process, then younger participants in the experimental group would demonstrate inferior to no learning of the repeated sequence.

Given the results regarding the effect of learning on RT performance in Experiment 1, we again recorded and examined both accuracy and RT data. Based on the findings of Experiment 1, it was expected that similar results to those observed for accuracy performance would be observed when RT was the measure of choice.

Method

Participants. Forty-seven (38 Females, 9 Males) social science undergraduate students between the ages of 20 and 29 ($M = 21.96$, $SD = 2.156$) were recruited for this experiment and randomly assigned as either a control (16 Females, 7 Males), or an experimental (22 Females, 2 Males) participant. Recruiting methods, exclusionary and inclusionary criteria, as well as compensation and testing methods used were identical to those outlined in Experiment 1. The only divergence in this study was that the DT was implemented at the retrieval, rather than the encoding phase.

Materials, procedure, and scoring. All components were identical to those used in Experiment 1. A computerized SAT (Watkins, 1977; Brooks & Watkins, 1990) was once again administered, and this was followed by the computerized version of the visuospatial Hebb (1961) paradigm (Corsi, 1972). However, in this case the DT was implemented at the retrieval phase of the both the SAT and visuospatial Hebb. As such, participants in the experimental group were required to recall the sequences while simultaneously repeating the letters heard through the earphones.

Results & Discussion

Span assessment task. Results of an independent samples *t*-test, assessing group differences on average span, indicated that span did not statistically significantly differ between the two groups, with both control ($M = 5.96$, $SD = 0.77$) and experimental ($M = 6.00$, $SD = 0.88$) displaying similar average span scores $t(45) = -.180$, $p = .858$, $d = -.104$. This confirmed that before the learning phase, participants in both groups expressed equivalent short-term retention of spatial positions.

Visuospatial Hebb supra-span learning task.

Baseline performance. The independent *t*-test analysis executed on accuracy scores, indicated that at baseline the control ($M = 0.60$, $SD = 0.17$) and experimental ($M = 0.50$, $SD = 0.25$) group recalled material similarly in terms of accuracy, $t(45) = 1.54$, $p = .130$, $d = 2.95$. Alternatively, the analysis computed on RT scores, indicated that the control ($M = 9763.45$, $SD = 2607.50$) and experimental groups ($M = 7944.09$, $SD = 1702.61$), differed in their average response speed for recalling the material, $t(45) = 2.84$, $p = .007$, $d = .043$. This indicated that within the first four trials, where all sequences presented would be regarded as random, both groups achieved similar levels of accuracy performance, while experimental participants responded faster than the control subjects.

Learning of the repeated sequence. ISR performance of the control and experimental groups on the repeated and random sequences in block 1, 2, and 3 is depicted in Figure 3 for accuracy, presented as a proportion, and in Figure 4 for RT, presented in milliseconds.

Learning of the repeated sequence through accuracy performance. The analysis indicated a statistically significant difference between the control ($M = 0.66$, $SE = 0.03$) and experimental groups ($M = 0.53$, $SE = 0.03$), $F(1,45) = 8.05$, $p = .007$; partial eta squared = .152, power = .793. The control group was significantly more accurate than the experimental group throughout the experiment, regardless of sequence type and block. Additionally, as was seen in Experiment 1, both within-subjects factors, namely Sequence (random: $M = 0.53$, $SE = 0.02$; repeated: $M = 0.65$, $SE = 0.04$), $F(1,45) = 9.28$, $p = .004$, $\eta_p^2 = .171$, power = .846, and Block (block 1: $M = 0.53$, $SE = 0.03$; block 2: $M = 0.62$, $SE = 0.03$; block 3: $M = 0.63$, $SE = 0.02$), $F(1,48) = 10.66$, $p = .002$, $\eta_p^2 = .191$, power = .891, reached significance. This indicated that together both groups were significantly more accurate in recalling the repeated compared to the random sequences across all three blocks. This also indicated that they were significantly more accurate in their overall response (on the average of both random and repeated sequences) as they progressed across the blocks.

The ANOVA also yielded a statistically significant Sequence x Block interaction, $F(1, 45) = 10.15$, $p = .003$, $\eta_p^2 = .184$, power = .876, indicating that the effects of block on accuracy depended on the sequence type being recalled. Follow-up analyses (pair-wise comparisons using the Tukey HSD test) demonstrated that recall of the repeated sequence was statistically significantly more accurate on block 2 than block 1 ($p = .022$), on block 3 than block 2 ($p = .038$) and on block 3 than block 1 ($p = .001$). That is, overall performance on recall of the repeated sequences by both groups improved as they moved from block 1 to block 2 to block 3. Conversely, only minor and insignificant improvement was seen in the general recall of the random sequences from block 1 to block 2 ($p = .471$), and then from block 2 to block 3 ($p = .085$). Pair-wise comparisons of the Block x Sequence interaction

also indicated that on all three blocks, participants were in general more accurate on the repeated compared to the random sequences, with this difference in accuracy performance on the two types of sequences being significant in block 2 ($p = .030$) and block 3 ($p < .001$) only. This indicated that participants were significantly more accurate in recalling the repeated versus the random sequences by block 2 suggesting that specific learning of the repeated sequence was observed midway through the task. Finally, once again the hypothesized three-way interaction between Sequence, Block, and Group did not reach significance, $F(1, 45) = 1.23, p = .274, \eta_p^2 = .027, \text{power} = .192$, as nor did any other interactions (see Figure 3).

Our findings confirmed the presence of a clear repetition effect among both groups. However, the significant Group effect indicates that there was a difference in the magnitude of accuracy performance between the control and the experimental group, with the control group being significantly more accurate than the experimental group overall. This difference in performance appears to be mostly attributable to the presence of the DT at retrieval.

Learning of the repeated sequence through RT performance. The analysis revealed that the differences between the two groups reached significance (control: $M = 8758.75, SE = 287.00$; experimental: $M = 7622.78, SE = 280.96$), $F(1, 45) = 8.00, p = .007, \eta_p^2 = .151, \text{power} = .790$, indicating that the experimental group was significantly faster than the control group, in their overall response performance. This superior speed performance may have been the result of the experimental participant's attempt to recall the sequences as quickly as possible, in order to avoid interference imposed by performing the DT. The faster they recalled the sequence, the less DT material they would be required to process. This

finding may also reflect the attentional demand at retrieval on the Hebb learning task.

Additionally, one of the within-subjects factors, namely Block (block 1: $M = 8483.53$, $SE = 217.32$; block 2: $M = 8236.41$, $SE = 228.33$; block 3: $M = 7852.37$, $SE = 231.24$), $F(1, 45) = 8.64$, $p = .005$, $\eta_p^2 = .161$, power = .820, was found to be significant. This indicated that both groups were on average significantly faster in their recall of the average of both sequence types as they progressed from block 2 to block 3 ($p = .027$), as well as from block 1 to block 3 ($p = .016$). The lack of a sequence effect indicated that recall speed of the random and repeated sequences was comparable throughout the experiment. These results suggested that, even though recall speed performance improved as participants progressed, their recall of the repeated compared to the random sequences remained similar, implying that learning was not properly reflected using RT. Additionally, the hypothesized three-way interaction between Sequence, Block, and Group did not reach significance, $F(1,45) = 1.25$, $p = .269$, $\eta_p^2 = .027$, power = .19, as nor did any other interactions (see Figure 4).

The findings clearly demonstrate that among the experimental participants, RT performance was moderated by the implementation of the DT at retrieval. Right from the start their performance approached ceiling and did not improve while responding to the remaining sequences. This phenomenon can be explained by the participants' attempt to avoid the DT related interference by reproducing the sequence faster; the faster they recalled the sequence, the less DT material they would be presented with. In this context, it appears that RT performance loses its ability to appropriately evaluate learning. Importantly, this effect on RT also appears to have negatively impacted accuracy performance, with data indicating a reduction in accurate recall of the sequence material, among the experimental participants.

In sum, the attention manipulation influenced overall recall performance significantly but seemed to have no impact on learning of the repeated sequence. As was observed in Experiment 1, apart from the overall reduction in performance, participants in both control and experimental groups showed learning of the repeated sequence. Thus, the Hebb effect seems to be resistant to reduced attention at retrieval. However, the observed reduction in accuracy performance and speeded response time performance that was observed among the experimental participants, does suggest that the attentional requirements at retrieval appear to be substantially greater than those at encoding.

In the present experiment, the attentional manipulation was only administered during one of the two processing phases; however, if one agrees with the interpretation that older age diminishes the available attentional resources, this effect should likely play a role across the full execution of the task. Accordingly, it is possible that attention is required at both encoding and retrieval stages, and therefore that only when both phases are impacted would the decrement in learning of the repeated sequence be observed. Fittingly, the study that follows investigated the role of a DT implemented at both encoding and retrieval.

Experiment 3

In this investigation, the DT was implemented at both encoding and retrieval. Once again, it was expected that the control group would show a normal Hebb effect while learning among the experimental group would be reduced or absent. In terms of RT performance, we expected that the presence of a DT at retrieval would again speed up the response time performance of those participants subjected to the DT while completing the Visuospatial Hebb supra-span sequence learning task.

Method

Participants. Sixty-Six (49 Females, 17 Males) social science undergraduate students between the ages of 18 and 35 ($M = 21.47$, $SD = 2.68$) were recruited for this experiment, and randomly assigned as either a control (26 Females, 7 Males) or an experimental (23 Females, 10 Males) participant. Recruiting methods, exclusionary and inclusionary criteria, as well as compensation and testing methods used, were identical to those outlined in Experiment 1. The only divergence in this study was that, the DT was implemented at both the encoding and retrieval phases.

Materials, procedure, and scoring. All these components were identical to those used in Experiment 1, as well as Experiment 2. The computerized SAT (Watkins, 1977; Brooks & Watkins, 1990) followed by the computerized version of the visuospatial Hebb (1961) sequence learning task (Corsi, 1972) were administered. In this case, the DT was implemented at both the encoding and the retrieval phase of both the SAT and visuospatial Hebb. Participants in the experimental group were required to encode, as well as recall the sequences, while simultaneously repeating the letters heard through the earphones.

Results & Discussion

Span assessment task. Results of an independent samples t -test assessing group differences on average span indicated that, span significantly differed among the two groups, with the control group ($M = 6.09$, $SD = .84$) achieving a slightly higher average span than the experimental group ($M = 5.58$, $SD = .83$), $t(64) = 2.50$, $p = .015$, $d = 1.46$. This confirmed that before the learning phase, the control participants expressed slightly greater short-term

retention of spatial positions. It also indicated that the DT had an effect on recall performance. Given this finding, it was determined that it would be inappropriate to analyze the response time performance data, since on average, the control participants would be required to process more stimuli than their experimental counterparts, which would undoubtedly take more time.

Visuospatial Hebb supra-span learning task.

Baseline performance. The independent *t*-test analysis executed on accuracy scores, indicated that at baseline, the control ($M = .67$, $SD = .15$) and experimental ($M = .64$, $SD = .22$) groups, recalled material similarly in terms of accuracy, $t(64) = .56$, $p = .575$, $d = .979$.

Learning of the repeated sequence. ISR accuracy performance of the control and experimental groups on the repeated and random sequences in blocks 1, 2, and 3, is depicted in Figure 5.

Learning of the repeated sequence through accuracy performance. The analysis of accuracy performance revealed that the difference between the two groups did not reach significance (control: $M = 0.68$, $SE = 0.02$; experimental: $M = 0.70$, $SE = 0.02$), $F(1, 64) = 0.42$, $p = .518$, $\eta_p^2 = .007$, power = .098. Only one within-subjects factor, namely Sequence (random: $M = 0.63$, $SE = 0.01$; repeated: $M = 0.75$, $SE = 0.02$), was found to be significant, $F(1, 64) = 25.15$, $p < .001$, $\eta_p^2 = .282$, power = .999. This indicated that in general, both groups were more accurate in terms of their response performance on the repeated compared to the random sequences, across the experiment. The hypothesized three-

way interaction between Sequence, Block, and Group did not reach significance, $F(1,64) = 0.07, p = .796, \eta_p^2 = .001$, power = .057, as nor did any other interactions (see Figure 5). These results indicated that control and experimental participants recalled the repeated sequences more accurately than the random sequences, throughout the blocks. This implies that learning occurred early on and remained stable across the remaining blocks of trials. Therefore, we once again failed to support our main hypothesis regarding the effect of DT on accuracy.

General Discussion

Our leading hypothesis stipulated that attention plays a significant role in visuospatial supra-span sequence learning, and one which may be at least partially responsible for the age-related sequence learning deficits that have been documented. We anticipated that implementation of a DT at various phases (encoding, retrieval or both) within a visuospatial version of the Hebb paradigm would impact learning of a repeated sequence among a younger adult population, potentially to a similar degree to what has been observed in older adults (e.g., Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005). It was expected that reductions in accuracy performance would translate into reduced learning of the repeated sequence. Response time was also expected not to differ between the repeated and the random sequences. Evidently, we predicted that a normal Hebb effect in the control participants would be replicated (see the results of Couture & Tremblay, 2006; Gagnon et al., 2005; Tremblay et al., 2005; Turcotte et al., 2005). Finally, we also sought to examine whether RT performance could be used as an indicator of learning, which was an element that, to our knowledge, had not been previously investigated.

Accuracy Performance as an Indicator of Learning

Using accuracy performance, we did not observe an elimination of the Hebb effect among the experimental participants in any of the three experiments. Thus, we were unable to replicate the findings typically observed among older adults when employing this task (e.g. Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005). Accordingly, using this particular DT, we were unsuccessful in supporting our hypothesis that attention plays a key role in the visuospatial sequence learning deficit observed among older adults. However, as was expected, in all three investigations learning of the repeated sequence unfolded normally in the younger participant control group. This is in agreement with previous performance findings concerning younger adults on the visuospatial Hebb (e.g., Corsi, 1972; Couture & Tremblay, 2006; Gagnon et al., 2005; Gagnon & Winocur, 1996; Milner, 1971; Tremblay et al., 2005; Turcotte, 2002; Turcotte et al., 2005). Consequently, the results concerning the control group imply that the task appropriately evaluated visuospatial supra-span sequence learning. This is a finding, which highlights the appropriateness of our computerized supra-span learning task.

Latency Performance as an Indicator of Learning

Although learning performance was not impacted in the expected manner, our findings expand the knowledge within this area. In addition to evaluating performance in terms of accuracy, we also assessed performance in terms of RT (latency) in order to determine whether this measure can also be used as a viable indicator of sequence learning. In Experiment # 1 where the DT was implemented solely at encoding, it was observed that both accuracy and latency performance provided evidence of a clear repetition effect among

the experimental and control younger adult participants. That is, using either accuracy or latency as the measure of performance, an improvement in recall, beyond a practice effect, was observed for the repeated material. Thus, the RT performance findings replicated those found using accuracy performance, suggesting that RT performance may be an appropriate and valid indicator of learning in a context that does not elicit a speeded response. Indeed, the results obtained in Experiment 2 provide evidence that the reliability of RT as an indicator of learning is limited to circumstances that do not provoke participants to accelerate the recall of the just seen sequences.

Specifically, in Experiment 2, it was found that although learning was evident in both experimental and control groups when accuracy was used as the measure of performance, RT results indicated that performance was significantly affected. To our surprise, speed of response was in general faster for the experimental than the control participants, and there was no clear improvement in response time for the repeated material when compared to that of the random material for those exposed to the DT. The presence of a DT at retrieval even caused participants to be less accurate. This performance trade-off is simply explained by the attentional demands of the main task and the desire to keep any given retrieval phase as short as possible. The faster the experimental participants respond, the less DT material they would be required to deal with (i.e. the quicker their response, the fewer letters they would need to repeat). In fact, RT performance in Experiment 1 and #2 supports the idea that the supra-span learning task is very demanding in terms of attention. In particular, the results of Experiment 2 demonstrate that when a rather simple dual- task is implemented at retrieval, it influences performance, reducing accuracy in general and speeding up the recall process.

The Impacts of a Verbal Dual-Task

Based on an age-related attentional decline interpretation, it was expected that implementation of a divided attention task should be an effective means to mimic the effects of aging on attention in a younger adult (e.g. Craik, 1977b, 1982, 1983; Craik & Byrd, 1982; Craik et al., 1996). This approach was selected as a first step in order to identify the basis of the learning deficit, while maintaining the integrity of the task (instruction and stimuli wise). In previous research where the familiarity or the awareness interpretations were investigated, unfamiliar verbal stimuli, or an alteration in the instructions (making the participant aware of the repetition) were employed. Testing participants under DT instructions allowed us to determine whether a reduction in attention devoted to the main task would interfere with learning. However, such an effect should only occur when the cognitive task at hand strongly depends on attentional resources in order to achieve optimal performance. In the present endeavour, it was hypothesized that visuospatial supra-span sequence learning is reliant on attentional resources. As described previously, the findings of our three experiments clearly indicate that this is not the case. Accordingly, if we are to maintain that attention plays a role in visuospatial sequence learning, it becomes necessary to rationalize why the DT did not have the intended impact in the present investigation.

A potential interpretation is that the DT task simply did not impact attention as it was intended to, perhaps because it failed to challenge the participants adequately. For example, it could be suggested that participants were not sufficiently pressured by the task because they were given ample time to repeat each of the letters (2.5 seconds). The results presented here, however, do not support this interpretation. Specifically, implementation of the DT at retrieval (i.e. Experiment 2) did impact response speed as well as lower accuracy, insinuating

that the DT did sufficiently pressure participants, but potentially not to an extent where learning of the repeated sequence was abolished. The fact that span was assessed while the DT was enforced may explain this reduced DT effect. Specifically, it is possible that participants were simply not challenged enough when the DT was employed during the Hebb task because it was adjusted to a level they could handle. The results of Experiment 1 and #2 indicate that the spans of both control and experimental participants did not differ. However, when the DT was instilled at both encoding and retrieval stages (Experiment 3), span was found to be significantly lower in the experimental group. This finding suggests that the DT may be challenging only when it is implemented at both processing phases. However, the findings of Experiment 3 indicate that the difficulty level of the DT task was still insufficient to impact learning.

An alternative interpretation revolves around the modality of the employed DT. Specifically, one could argue that the secondary task had only a slight affect (if any) in reducing attention, simply because the stimuli were relayed through different perceptual modalities. Hartley and Little (1999) have proposed that a DT is more likely to have an impact on performance if it overlaps with the main task in terms of sensory modality (i.e. verbal and visuospatial; see also Baddeley & Hitch, 1974 for a similar proposal). This modality interpretation is in accordance with the work of Harrington and Haaland (1992), who observed that learning in older adults was reduced when they were required to make complex movements while performing an SRTT, where little working memory and therefore, attentional resources are likely required. These results suggest that a visuospatial DT would impact visuospatial sequence learning in an even more profound, yet similar manner. Therefore, since the DT implemented in the present study was verbal, while the main task

was visuospatial, it is conceivable that an effect on learning was not observed, simply because of the non-overlapping modalities.

Conclusion

While the above mentioned data illustrate that we failed to mimic the age-related visuospatial sequence learning deficits that are typically observed among older adults, we were able to support the idea that the Hebb effect is resilient to a general attentional manipulation. Our findings suggest that the deficit seen in older adults is specific to the nature of the processed information. Such an interpretation also fits well with the ‘dissociation’ found in the aging literature on the Hebb supra-span learning effect, demonstrating that older adults are able to learn sequences that are composed of verbal stimuli (e.g., Caird, 1964, 1966; Gagnon & Winocur, 1996; Heron & Craik, 1964; Turcotte, 2002; Turcotte et al., 2005). We also demonstrated that while the verbal DT did not impact learning performance, it did impact general response time (recall performance), with participants’ responses being speeded when the DT was implemented at retrieval (see Experiment 2). Overall accuracy was also found to be affected by the DT (Experiment 2). As such, the above findings advocate for greater attentional demands at retrieval.

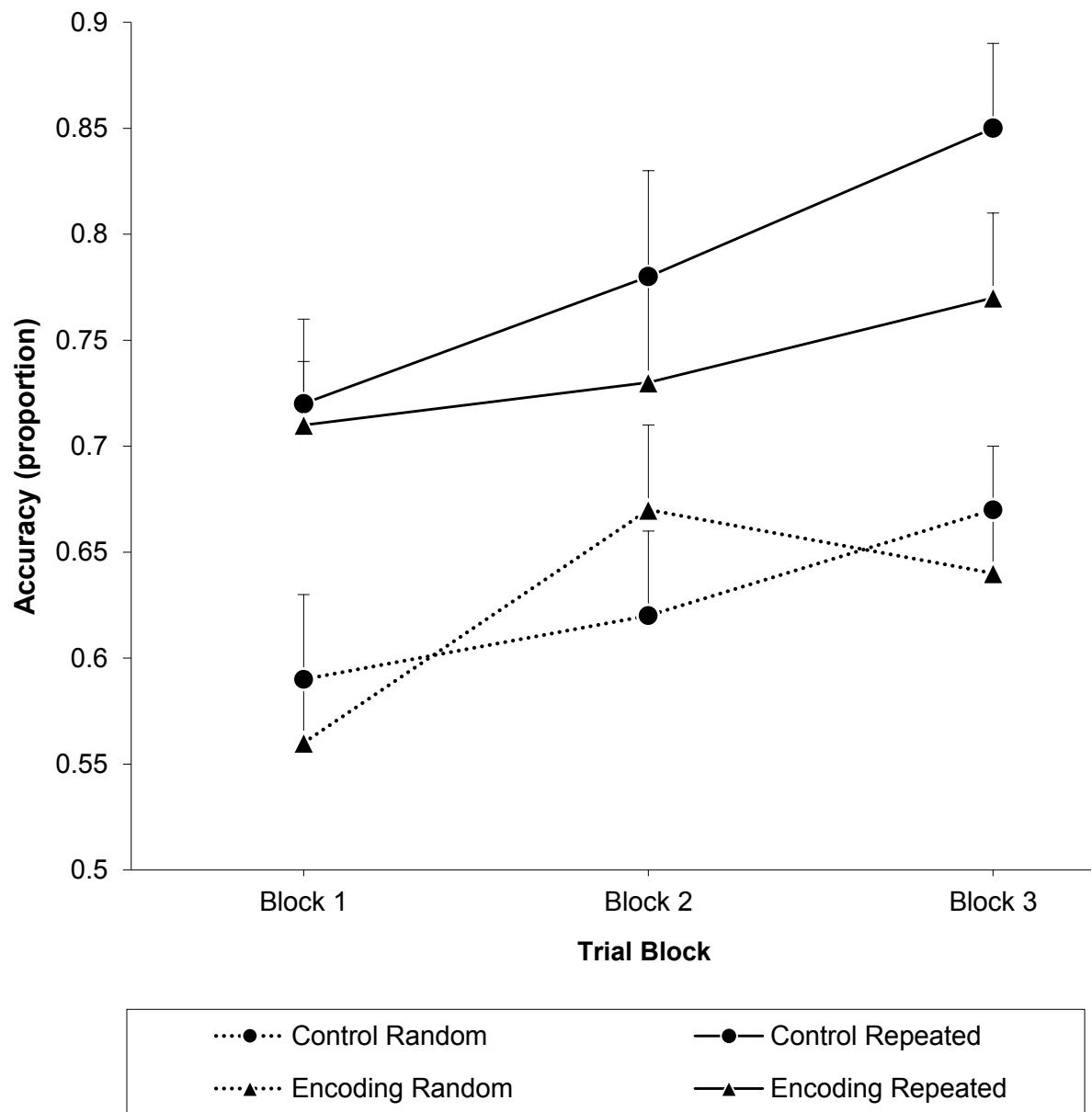


Figure 1. Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for control participants and those tested under verbal dual-task conditions implemented at encoding in Experiment 1. Standard errors are represented in the figure by the error bars attached to each marker.

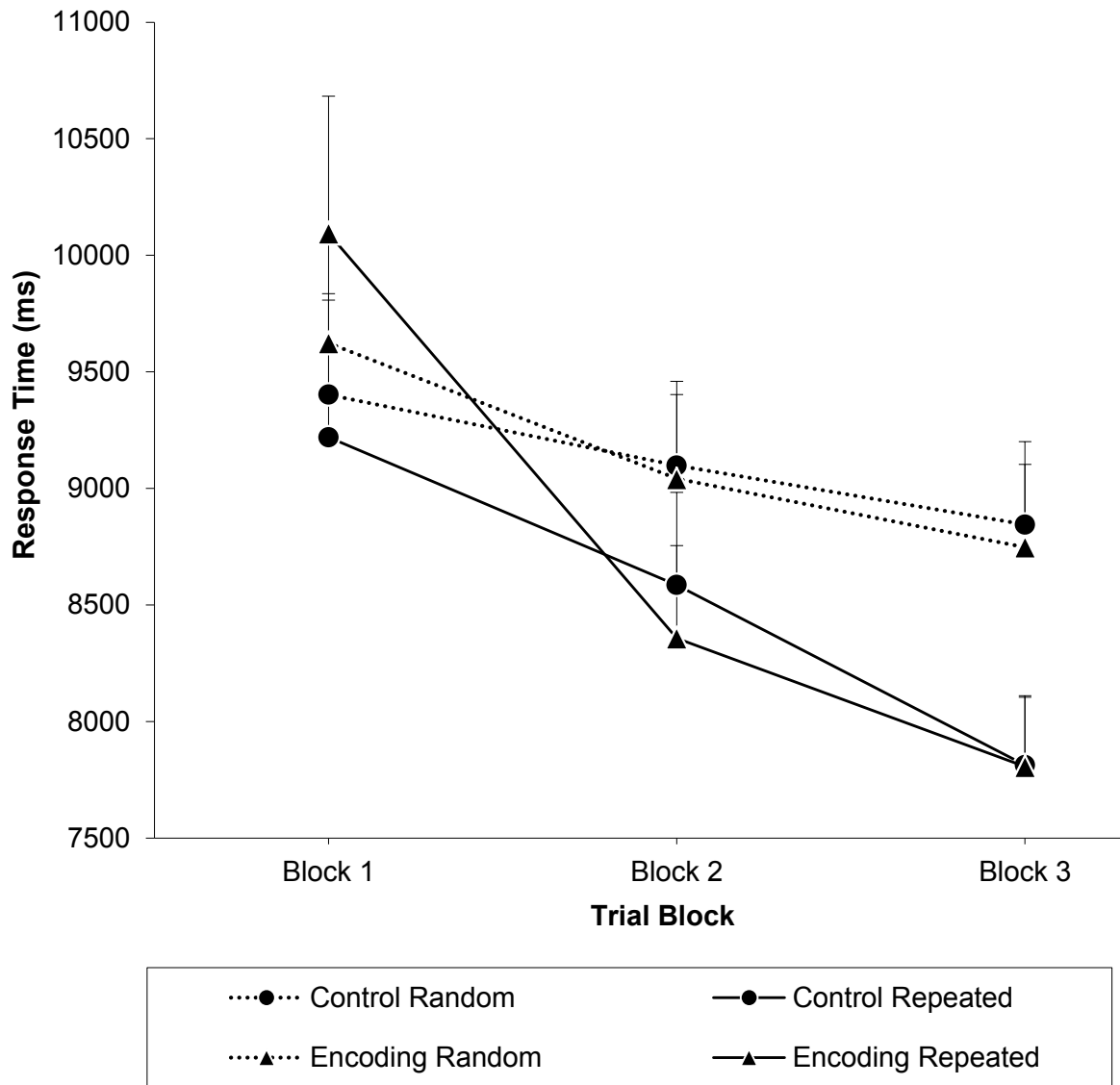


Figure 2. Response time performance (in milliseconds) required to recall the repeated and random sequences as a function of the block of trials for control participants and those tested under verbal dual-task conditions implemented at encoding in Experiment 1. Standard errors are represented in the figure by the error bars attached to each marker.

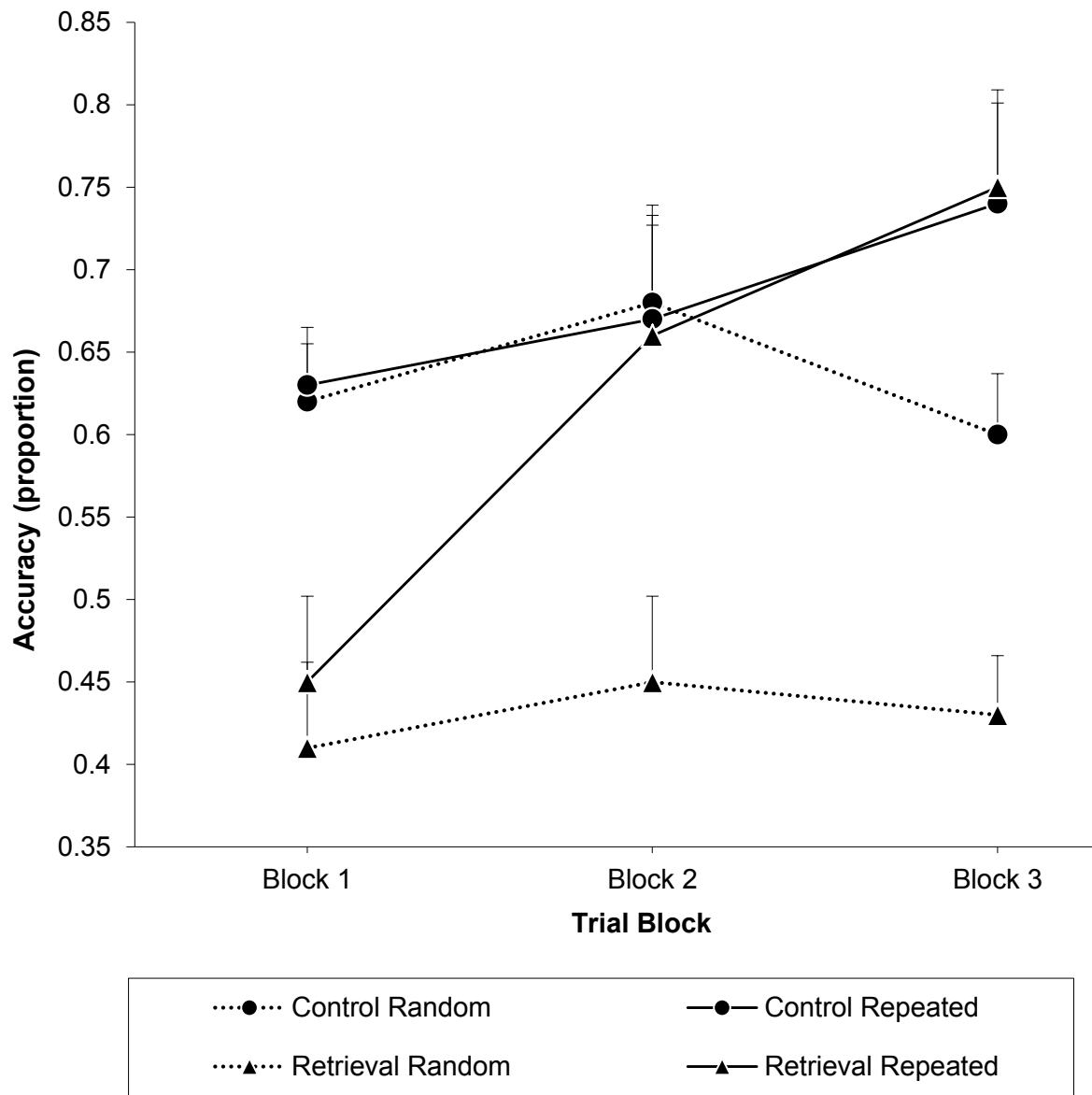


Figure 3. Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for control participants and those tested under verbal dual-task conditions implemented at retrieval in Experiment 2. Standard errors are represented in the figure by the error bars attached to each marker.

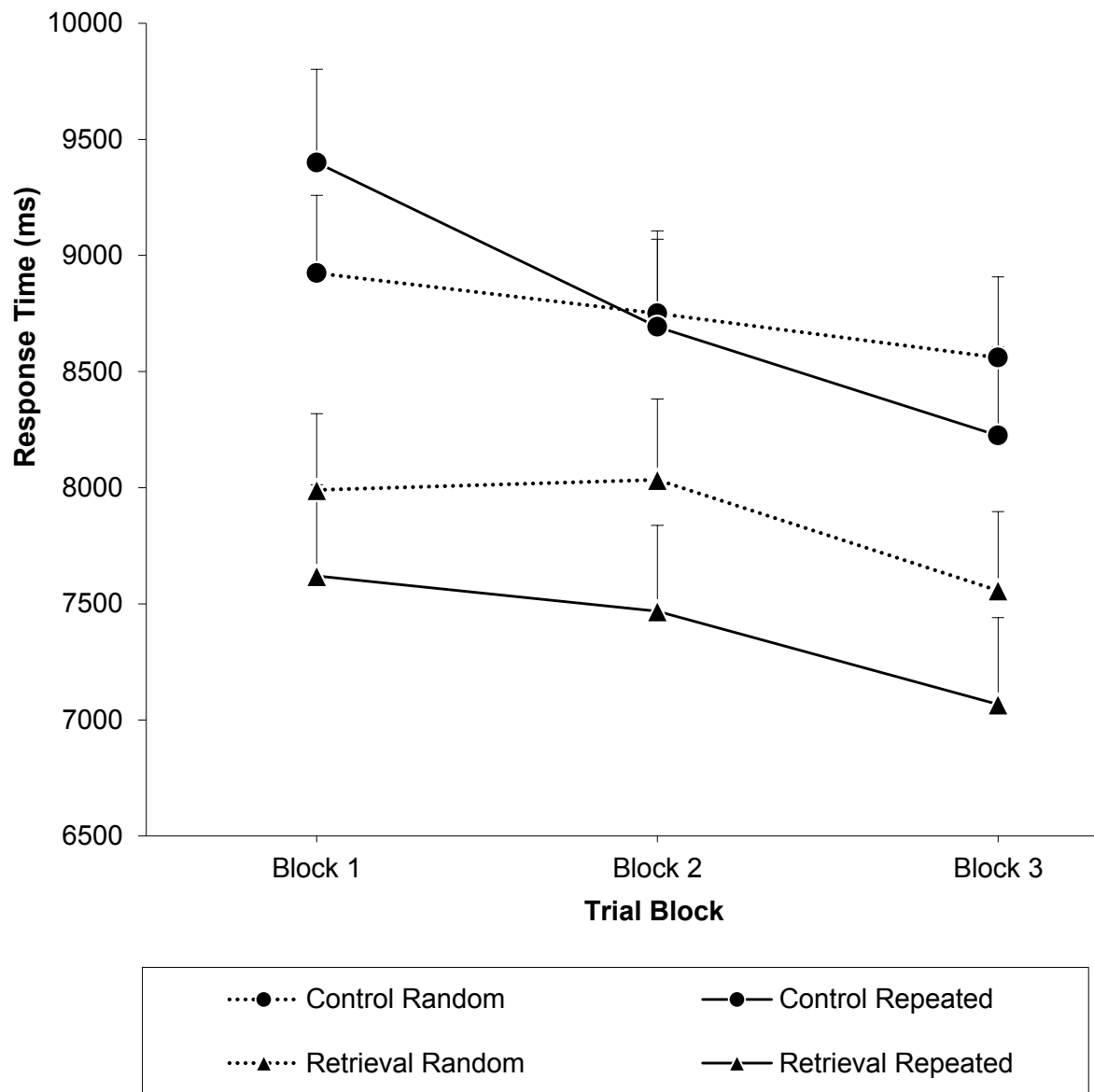


Figure 4. Response time performance (in milliseconds) required to recall the repeated and random sequences as a function of the block of trials for control participants and those tested under verbal dual-task conditions implemented at retrieval in Experiment 2. Standard errors are represented in the figure by the error bars attached to each marker.

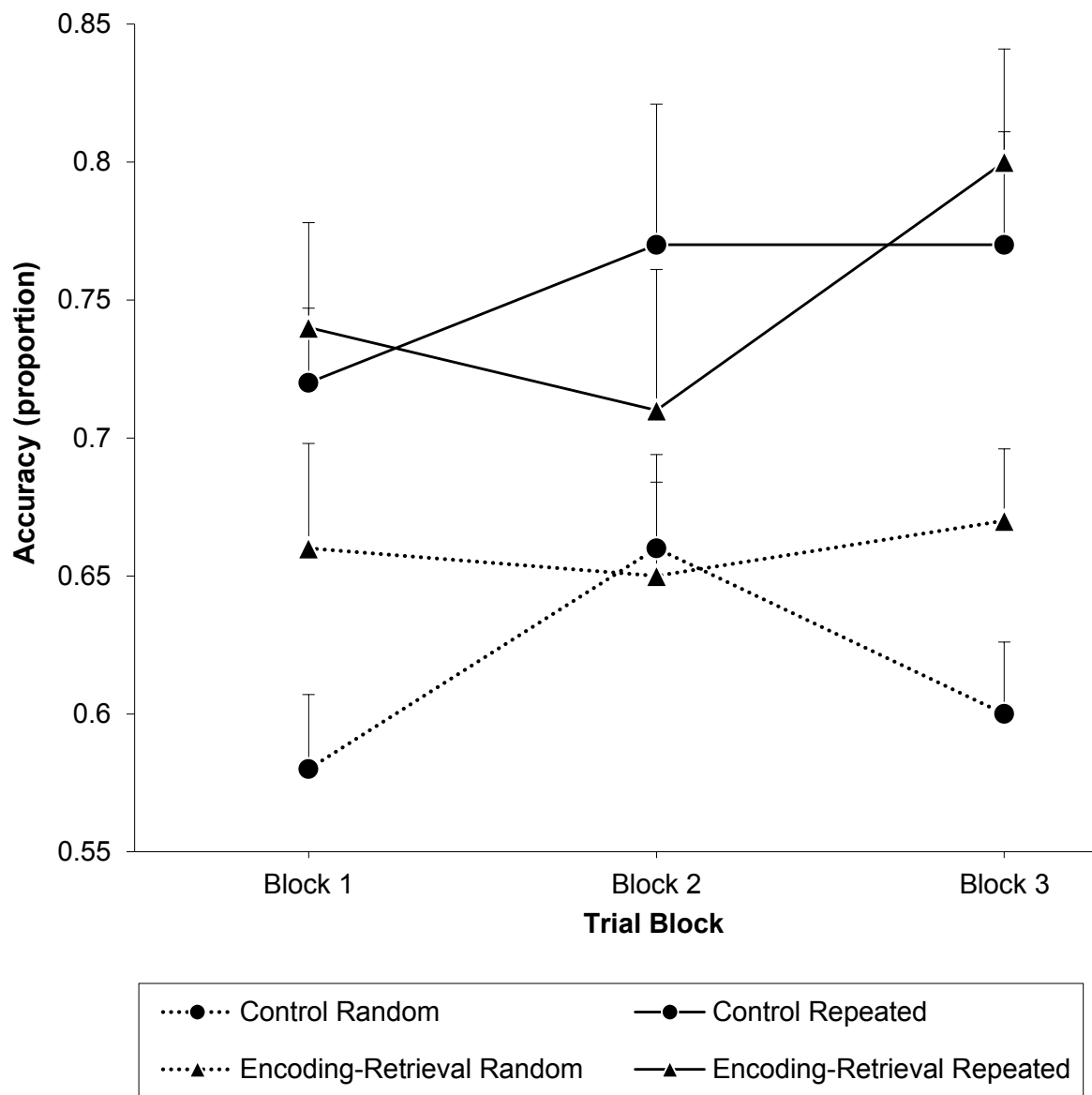


Figure 5. Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for those tested under verbal and touch screen dual-task conditions implemented at both encoding & retrieval in Experiment 3. Standard errors are represented in the figure by error bars attached to each marker.

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3. CHAPTER THREE: ARTICLE 2

**The effect of a modality specific dual-task on the retrieval of
visuospatial supra-span sequence learning:
An attempt at mimicking the age-related incidental learning deficit.**

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Abstract

Using the Hebb paradigm, we investigated whether specific attentional resources are necessary to demonstrate learning of sequence material that is visuospatial in nature. Through the implementation of a visuospatial dual-task, which overlapped extensively with the requirements of the visuospatial Hebb supra-span sequence learning task, we aimed to tax the individuals' attentional resources to a degree where learning of the repeated sequence would be impacted. Results indicated that carrying out a visuospatial dual-task at the retrieval stage of the Hebb learning task reduced learning in younger adults, to a similar extent to what has been observed among older adults who are known to demonstrate a deficit in learning this type of material (c.f. Turcotte, Gagnon, & Poirier, 2005). This confirmed that visuospatial Hebb supra-span sequence is reliant on attentional resources, with a particular emphasis on the attentional resources required to carry out responses within the Hebb task. Therefore, older adults may show a deficit in this form of learning because of limitations in their ability to donate the necessary attentional resources for response related processes.

Introduction

There is a growing interest in how aging effects sequencing ability, particularly since the capacity to learn sequential material is essential for carrying out virtually every form of behaviour (e.g. driving, playing an instrument etc.; Buchner & Frensch, 1997; Lashley, 1951; Schumacher & Schwarb, 2009; Soetens, Melis, & Noebaert, 2004; Whittlesea & Wright, 1997). The Hebb supra-span learning paradigm (1961), which measures long-term memory (LTM) trace formation, is amongst the main tasks used to examine sequence learning. In this task, participants perform immediate serial recall (ISR) of typically 24 supra-span sequences of material among which a repeated sequence is embedded. Learning of the repeated sequence is confirmed when recall performance of the repeated material, improves beyond a general practice effect (Turcotte, Gagnon & Poirier, 2005). This is demonstrated via an enhancement in recall performance of the repeated material that exceeds the improvement in recall performance of the random material, within a situation where the repetition is not explicitly made known.

Recent research has shown that while visuospatial sequence learning (e.g. learning required to operate a motor vehicle or instrument) unfolds normally in younger adult participants (c.f. Brasgold, Gagnon, Stinchcombe & Pershin, 2011; Couture & Tremblay, 2006; Couture, Lafond & Tremblay, 2008; Lafond, Tremblay, & Parmentier, 2010; Turcotte et al., 2005), it is disturbed by the aging process. Indeed, older adults demonstrate little to no learning of such material (c.f. Gagnon, Bedard, & Turcotte, 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte et al., 2005). Interestingly, using the Hebb supra-span task, it has been observed that older adults demonstrate a normal learning curve for verbal stimuli (digits, words, pseudo-words; c.f. Caird, 1964, 1966; Gagnon & Winocur, 1996; Heron &

Craik, 1964; Turcotte, 2002; Turcotte et al., 2005).

One suggestion we have put forth is that a limitation in attentional resources may be what is at the root of this observed age-related sequence learning deficit (see Brasgold et al., 2011). This proposal stems from several pieces of information. Firstly, there is the fact that the Hebb supra-span sequence learning task is conceived as a working memory task (Conway & Engle, 1996; Gagnon et al., 2005; Weitz, Oshea, Zook, & Needham, 2011). This is clearly indicated by the requirements of the task. The task necessitates that the individual perform ISR of information that is estimated to be beyond their capacity. This demands that on each trial, the participant must actively hold in memory, the previously presented stimuli, as well as the current stimulus being presented before recall ensues. Given that working memory is involved in storing, manipulating and maintaining information in an active state (Baddeley, 2000), it likely plays a fundamental role in the Hebb supra-span learning paradigm (for a similar proposal see Engle, Tuholski, Laughlin, & Conway, 1999).

The work of Baddeley, further implicates a role of working memory within the Hebb supra-span learning task. Baddeley (2000, 2001) has stipulated that within the working memory framework, the episodic buffer is responsible for bringing information from LTM into active focus, so that an individual can compare stored information with incoming information. Since it is likely that a demonstration of learning is dependent on if a representation in LTM is formed, as well as re-activated whenever the repeated sequence of material is presented, Baddeley's notion of the episodic buffer provides a mechanism by which learning may occur within the realm of the Hebb. This link with working memory directly implicates a role of attention. Indeed, in the majority of working memory frameworks there is the proposal of a master system that controls how processing is carried

out by directing attentional resources (c.f. Baddeley, 1986, 1996, 2000; Baddeley & Hitch, 1974; Coolidge & Wynn, 2005; Cowan, 1988, 1995; Engle, 2001; Engle et al., 1999; Kane & Engle, 2002; Shallice and Burgess, 1998). In Baddeley's framework, this is referred to as the central executive (Baddeley, 1986, 1996, 2000), or the attentional controller (Baddeley & Hitch, 1974). Additionally, according to some researchers, working memory and attention are even interchangeable terms for the same functions (see Milham et al., 2002 for a similar proposal). Findings from neuropsychological and neuroimaging studies clearly indicate that both functions appear to rely on similar neural substrates (c.f. Baddeley, 1986; Banich et al., 2000a, 2000b; Cohen & Servan-Schreiber, 1992; MacDonald, Cohen, Stenger, & Carter, 2000; Milham et al., 2002; Posner & Dehaene, 1994; Taylor, Kornblum, & Lauber, 1997; Wagner, 1999).

Aside from these links with attention via working memory, attention is also necessary for accurate recall to occur within the Hebb task. For instance, individuals must inhibit previously encoded sequence material that is irrelevant, as well as actively maintain task relevant material on each trial. According to Milham and colleagues (2002), as well as Rabbit (1997), both of these are processes are heavily reliant on attentional resources (for a similar view c.f. Banich et al., 2000a, 2000b; Carter, Mintun, & Cohen, 1995; Posner & Dehaene, 1994; MacDonald et al., 2000). Further promoting this view is the *Processing resource account* of Hebb learning recently put forward by Weitz and colleagues (2011). This model contends that attentional resources are at the root of an individual's ability to successfully process incoming stimuli.

Tying working memory and attention together, as well as implicating the two constructs within Hebb supra-span learning, is crucial for explaining why attention might be

at the source of the observed age-related sequence learning deficit. This is largely motivated by the numerous investigations which have demonstrated that attention capacity (c.f. Castel & Craik, 2003; Craik, 1977a, 1982; Craik & Byrd, 1982; Hunt & Herzog, 1981; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991a), as well as working memory (Bopp & Verhaegen, 2005; Peterson & Peterson, 1959; Reuter-Lorenz et al., 1990; Salthouse, 1991b, 1994, 1996; Wingfield, Stine, Lahar & Aberdeen, 1988) declines with age. These findings suggest that older adults may demonstrate difficulty with processing supra-span sequence information because of a reduction in attentional resources, which would among other things, impact their ability to inhibit irrelevant material, maintain task relevant material in focus, retrieve and manipulate information stored in LTM, and carry out other essential functions associated with working memory. This works well with the findings of Turcotte and colleagues (2005) who found traces of spatial interference in the responses of their older participants. They noticed that their ISR of a given repeated sequence, contained errors that the participants had generated in the previously recalled repeated sequence.

Based on the above information, we initially carried out an investigation exploring whether attention plays a key role in visuospatial Hebb supra-span sequence learning. In a series of three experiments, younger adults completed the visuospatial Hebb supra-span sequence learning task, along with a verbal dual-task (DT), that was deployed in three different ways (at encoding; at retrieval; at both encoding and retrieval). DT procedures were used since they are commonly implemented to impact attentional resources on a variety of short and LTM tasks (Baddeley, 1996, 2001; Baddeley & Hitch, 1974; Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, 1982; Craik, Govani, Naveh-Benjamin, & Anderson,

1996; Fernandes & Moscovitch, 2000, 2002; Murdoch, 1965; Naveh-Benjamin, Vraik, Gavrilesco, & Anderson, 2000a; Naveh-Benjamin, Craik, Guez, & Dori, 1998; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000b; Nissen & Bullemer, 1987; Reinitz, Morrissey, & Demb, 1994; de Ribaupierre & Ludwig, 2003), as well as to mimic attentional deficits that are typically observed in older adults (Craik, 1977b, 1982, 1983; Craik & Byrd, 1982; Craik et al., 1996).

We selected a verbal DT based on the work of Nissen & Bullemer (1987), who showed that sequence learning performance was altered, when participants had to complete a tone-counting task alongside the Serial reaction time task (SRTT; another commonly used paradigm to explore sequence learning). Others have obtained comparable results using a similar strategy (c.f. Cheng, 1985; Cleeremans & Jiménez, 1998; Cohen, Ivry and Keele, 1990, Exp. 4; Curran & Keele, 1993; Frensch, Wenke & Rüniger, 1999; Hartley & Little, 1999; Howard & Howard, 1997; Howard, Howard, Japinske, DiYanni, Thompson, & Somberg, 2004; McDowall, Lustig, & Parkin, 1995; Shanks & Channon, 2002; Schmidtke & Heuer, 1997; Stadler, 1995; Styles, 1997). In our set of experiments, the verbal DT required that participants orally repeat individual letters that were presented via headphones, while performing the Hebb supra-span sequence learning task. The results indicated that regardless of whether the verbal DT was employed at encoding, retrieval or at both encoding and retrieval, learning of the repeated sequence was not significantly altered. However, overall accuracy was diminished when the DT had to be performed at retrieval, an indication that the retrieval stage of a visuospatial supra-span learning task necessitates greater attentional demand.

Our previous results also suggested that the type of DT implemented might not have been appropriate within the given context. It has been suggested that the impact of a DT on performance can only be attained when the DT and the main task have overlapping processing requirements, a situation that occurs when the perceptual features of both tasks are comparable (for a similar proposal regarding the SRTT with DT employment, see Schumacher & Schwarb, 2009; see also Maehara & Saito, 2007 for a general interpretation of memory processing overlap; see also Friedman, Polson, & Dafoe, 1988; Gopher & Sanders, 1984; Kinsbourne & Hicks, 1978; Wickens, 1984 for a similar view proposed within Multiple-resource models of attention). This effect has been demonstrated by various researchers using ISR as well as SRTTs (c.f. Baddeley & Hitch, 1974; Hartley & Little, 1999; Hartley, 2001). However, to our knowledge no such manipulation has been applied to the visuospatial Hebb supra-span sequence learning task.

To sum up, the above results suggest that that a visuospatial DT would have an impact on visuospatial Hebb supra-span sequence learning. Accordingly, in the present endeavour we wished to examine whether visuospatial supra-span sequence learning is substantially reliant on attentional resources, by subjecting younger participants to a visuospatial DT procedure alongside the visuospatial Hebb supra-span sequence learning task. We implemented the DT at the retrieval phase of the Hebb task, based on our earlier finding that greater attentional demands appear to be associated with the retrieval stage of the task (see Brasgold et al., 2011).

We hypothesized that the younger adults, who were required to complete the visuospatial sequence learning task along with the visuospatial DT, would show a learning deficit similar to that typically documented in older adults. This deficit would materialize

through recall accuracy performance, where recall performance between the random and the repeated sequences would not significantly differ.

Method

Participants

Forty University of Ottawa undergraduate English fluent students (29 women and 11 men), between the ages of 18 and 30 ($M = 20.85$; $SD = 3.01$), participated in this experiment. Each individual was randomly assigned to the control condition (17 women and 3 men) or experimental condition (12 women and 8 men). All participants were recruited either via the University of Ottawa's Integrated System of Participation in Research (ISPR) recruiting system or posters placed throughout the University of Ottawa campus. Those recruited through ISPR received course credit, while those recruited via the posters were compensated 10\$ for their involvement. All participants described themselves as healthy, with no history of major health concerns, vision or hearing issues, neurological conditions, psychoses, and alcoholism or drug abuse.

Materials

Each participant provided their consent and responded to a questionnaire regarding their health status, and education. All participants then completed a spatial span assessment task (SAT; Brooks & Watkins, 1990), as well as the Visuospatial Hebb supra-span sequence learning task (Hebb, 1961; Corsi, 1972). Those assigned to the experimental condition also completed a spatial reaction time DT alongside the SAT, as well as the visuospatial Hebb.

Stimuli and apparatus. E-builder was used to prepare the SAT, the visuospatial Hebb supra-span sequence learning task, and the spatial reaction time DT programs. Both the SAT and visuospatial Hebb supra-span sequence learning task were administered using a Intel Core 2 Duo Dell OptiPlex 755 CPU processor connected to a 17 inch Planar PT1701MU LCD touch screen (Computer A). A second Pentium (R) 4 IBM Think Centre CPU processor connected to a 17 inch NEC Accusync LCD72vx touch screen, was used to present the spatial reaction time DT (Computer B). Stimuli for the SAT and visuospatial Hebb tasks consisted of black squares measuring 2.54 cm² randomly positioned on a light grey computer display. A distance of approximately 3 cm was maintained between each square on the display. Presentation of a sequence was carried out by having each square light up in their appropriate temporal position, by changing from black to white (with black contour), and then back to black. Following the presentation of the last square within a sequence, a buzzer was heard, which indicated that recall should proceed. Stimuli for the spatial reaction time DT consisted of four sounds (car horn, dog bark, cat meow, and bird chirp). A touch screen which was sectioned into four coloured sections, represented each of the four sounds (red, green, yellow and blue respectively; see Figure 1 for an illustration). Each time a sound was heard, its associated screen section lit up, by changing from black to its assigned color. A cardboard box was used to cover this second screen during the main testing phase. Participants used the touch screen to re-produce the just seen sequence in the SAT and visuospatial Hebb, as well as to respond to each sound, within the spatial reaction time DT. Each computer was programmed to record accuracy and latency performance, for every task, trial by trial.

Span assessment task. A set of ten sequences of spatial locations was prepared for each sequence length (three-thirteen), for a total of 110 sequences. Permutation 1.0 software was used to generate each of these sequences, and it was ensured that no sequence generated, formed any recognizable pattern or shape. For each sequence length (three to thirteen), a standard visual display was created to present the stimuli. This meant that for each sequence length, the spatial locations of the squares were maintained throughout the task. Simply the order that each square lit up within the sequence changed from trial to trial. This also meant that only the number of squares required to form the sequence within a particular trial was displayed on the screen. This method differs from our previous research, where in the SAT, the number of squares on the screen remained at a standard of 13, with only those required for the sequence lighting-up. It was determined that assessing an individual's span using this method could result in an inaccurate estimate that would then allow the participant to easily notice a repetition, because their span was not being taxed sufficiently. However, results from previous research showed comparable estimates of average span, suggesting that either method would produce accurate results (c.f. Turcotte et al., 2005).

A different set of spatial sequences was generated for the visuospatial Hebb supra-span sequence learning task to ensure that none of the sequences for the SAT were the same as those later presented in the visuospatial Hebb. This was carried out in order to avoid learning effects from the SAT to Hebb. Random selection from the data set was also programmed so that no sequence could be presented more than once to the same participant. Within the SAT, on each trial, participant recall performance dictated the length of the next presented sequence. The length of the sequence could increase or decrease from trial to trial, and this was dependent on the individuals' performance. Please see the procedures section

for additional information on this method.

Visuospatial Hebb supra-span sequence learning task. Based on the SAT, which was set to evaluate span's that ranged from three to thirteen, sequences of spatial locations were prepared for each sequence length of five to thirteen for the Hebb task using Permutation 1.0 software. Again, it was ensured that no sequence generated formed a shape or pattern. The existence of 25 trials within the Hebb required that 18 sequences of spatial locations be generated for each sequence length, for a total of 167 sequences. From these 18 sequences, seventeen were used to form the random sequences, while the remaining 18th sequence created was presented on every third trial (3, 6, 9, 12, 15, 18, 21, and 24) as the repeated sequence. Two sets (set A and set B) of 167 spatial sequences were developed. Sets A and B were counterbalanced among the participants to ensure that performance results were not instigated by a potentially easier set of sequences (random or repeated). For this purpose, two different sets of spatial displays were also created: two for each sequence length (5 to 13). Unlike in the SAT, the number of squares presented from trial to trial was maintained, meaning that the spatial display remained the same throughout the task and contained the necessary squares that made up a sequence. The number of squares presented depended on the individuals' span, which was assessed using the SAT. To tax participants appropriately, an individual's span was increased by two (span +2).

Spatial reaction time dual-task. The secondary task involved presenting a 17 inch LCD touch screen sectioned into four coloured sections. Each subdivision was associated with one of four sounds, namely car horn with top left hand corner, dog bark with top right hand corner, cat meow with bottom left hand corner, and finally bird chirp with bottom right

hand corner. Through a three part training session, the participant was required to learn the associations between the sound and its location on the screen, without being able to see the screen (the screen was covered with a cardboard box). This was achieved by having participants use feedback regarding their performance. A correct response was followed by a bell sound, while a buzzer sound followed an incorrect response. Participants responded by pressing on the appropriate section of the touch screen in reaction to the auditory cue. The presentation of the spatial locations (and its associated sound) was randomized and three different response-stimulus intervals were used (250 milliseconds, 500 milliseconds, 700 milliseconds) to ensure that the participant could not anticipate when or which sound would occur next. Two versions of the DT were prepared: one containing 16 trials and another containing 25 trials that corresponded to the number of trials encountered in the SAT and the visuospatial Hebb supra-span sequence learning task respectively. A keyboard was used to control the start and end of the task. The DT task was only administered during the retrieval stage of each span or supra-span sequence. Both accuracy and reaction time performance were recorded.

Procedure

Each participant completed the 35 minute experiment on an individual basis. Experimental participants required an additional ten minutes of testing due to training on the DT. To begin, each participant was seated at a comfortable distance from the two computer screens (computer A and B). All participants then completed the SAT (Watkins, 1977) on computer A, in order to obtain an estimate of their span. This information was then used to carry out the visuospatial Hebb (1961) supra-span sequence learning task (Corsi, 1972) on

computer A as well. Those in the experimental group first learnt the “Spatial reaction time” DT procedure using computer B, which they then completed alongside the SAT, and the visuospatial Hebb supra-span sequence learning task. Instructions for the SAT and the visuospatial Hebb supra-span sequence learning task appeared on computer A, in black 40 point New York font displayed on a white background. Instructions for the spatial reaction time task (DT) were similarly presented on the display of computer B. In both cases, participants were given the opportunity to request clarification of the instructions from the experimenter. The experiment was supervised by the investigator who remained in the room throughout testing (see Appendix I for a copy of the investigators script; see Appendix J for a copy of the instructions displayed to participants).

Spatial reaction time dual-task. Before completing the SAT and visuospatial Hebb supra-span sequence learning task, experimental participants went through an extensive training session on the spatial reaction time task. In the first part of training, participants were presented with a touch screen that was divided into four sections. Each subdivision then proceeded to light up and its associated sound was played. The participant was required to touch the section of the screen that was associated with the particular sound immediately following its presentation. This first step was to familiarize the participants with the sounds and their associated locations. In the second phase of training, the screen sections no longer lit up. After learning the sound-location associations, a cardboard box was then used to cover the screen. This method ensured that the participant could identify the correct location using the sound without being able to see the screen. After hearing each sound, the participant had 1000 milliseconds to press on the appropriate section of the screen. If after this time no

response was obtained, the computer was programmed to present another sound to guarantee that participants were consistently required to respond to the DT. Training was complete once a participant responded to at least 60 sounds and no errors were recorded on the last 10 trials. If this was not achieved, the program continued to present sounds until the participant responded correctly to 10 sounds in a row. Following training, the participant completed the spatial reaction time task alongside the SAT, and then the visuospatial Hebb task.

Span assessment task. The SAT was used to obtain an estimate of span for each individual participant. The methods employed followed from the work of Watkins (1977; Brook & Watkins, 1990), who developed the staircase method, which entails using a participants performance to guide the future presentation of sequences. Basically, a correct response on a trial is followed by a trial which contains a sequence of stimuli that has increased by one square, while an error in recall, results in the presentation of a sequence that is shorter by one item on the subsequent trial. Instructions advised participants that they would be presented with a display containing squares, spatially dispersed throughout the screen. They were informed that each square would light up in succession by changing from black to white (with a black contour), and that following a buzzer, they would need to recreate the order the squares lit up in by pressing on the squares in the correct order. Participants were told that they could press on the space bar to leave a location blank, if they were unable to remember the position of a displayed square within the sequence presentation. However, they were encouraged to always guess before selecting this option. Instructions also warned participants that the number of squares composing a sequence could increase or decrease from trial to trial. They were not informed about why this would occur.

Experimental participants received slightly different instructions, informing them that they would be required to complete the spatial reaction time task (DT) procedure during the recall stage of the SAT and visuospatial Hebb supra-span sequence learning task.

Prior to completing the SAT, each participant went through a short training, in which they were presented with three trials of four item sequences. Successful completion of training was required in order to advance to the main testing phase of the SAT. Training was repeated if participant experienced any difficulty with recalling the material. In the main testing phase, each trial began with a screen presenting the word “Trial”, and the associated trial number in the center of the display for 1500 milliseconds. A light grey display containing black squares was then exhibited for another 1500 milliseconds, after which time each square then proceeded to light up one after the other by changing from black to white (with a grey contour), and then back to black to form the sequence. Each square lit up for 1250 milliseconds, followed by a delay of 250 milliseconds before the next lit up. These presentation rates were used following the work of Gagnon, Foster, Turcotte, and Jongelis (2004) which showed that these are adequate for processing the stimuli presented. A buzzer then sounded for 200 milliseconds, following a delay of 600 milliseconds, after the sequence presentation was complete. Participants were then given 30 milliseconds to recall the sequence that had just been presented. A number placed at the top of the recall screen informed participants of the number of squares that remained for them to select. The recall phase ended and the next trial automatically began, once the correct number of squares was selected. However, this did not rely on whether the correct order of the squares was chosen. All 16 trials of the SAT unfolded in the same manner. Once completed, the computer evaluated the individual’s span by calculating the mean performance score using the last 12

sequences that were carried out, as well as an estimation of performance on a 17th sequence had it been presented. This mean value was then rounded to the nearest whole number, and two was added to it in order to obtain a supra-span appraisal. This number was then used in the visuospatial Hebb supra-span sequence learning task.

Visuospatial Hebb supra-span learning task. The same methods outlined for the SAT, were used to carry out the visuospatial Hebb supra-span sequence learning task procedure. However, participants were not trained on the Hebb task and they were simply informed that they would be presented with 25, as opposed to 16 sequences of stimuli, which would contain a consistent number of squares from trial to trial. Participants were allowed 20 seconds for recall of the material in this case, and they were not informed that a repeated sequence of stimuli would be presented on every third trial of the task.

Scoring

To assess learning, data from the visuospatial supra-span Hebb learning task was separated into four blocks, following from the work of Fallon and Tehan (2001; see also Turcotte, et al., 2005; Turcotte, 2002). Within each block, a distinct block of data was created for the random and the repeated material, so that a comparison between recall performance for each of the types of material could be made. Blocking also allowed us to compare performance at several times throughout the task. Block 1, 2 and 3 for the repeated material, consisted of average recall performance on Trial 6, Trials 9, 12 and 15, and Trials 18, 21, and 24, respectively. Block 1, 2, and 3 for the random material, consisted of average recall performance on Trials 5 and 7, Trials 8, 10, 11, 13, 14, and 16, and Trials 17, 19, 20, 22, 23, and 25, respectively. Trials 2 through 4 were blocked together as baseline performance.

Although a repeated sequence appeared in this block, all sequences would be considered random since this was the first occurrence of the repetition.

In terms of scoring, an item-order analysis approach was undertaken. The program also recorded the response time in milliseconds that it took participants to complete recall of each sequence. Response time and accuracy were computed for each random and repeated sequence and averaged for each block of trials. Spatial reaction time dual-task performance was also recorded and scored. Average performance on the DT task (accuracy as well as response time) was used to discriminate low and high performers, and to determine whether performance on the DT influenced learning in the main task.

Results

Span Assessment Task

Results of an independent samples t-test assessing group differences on average span, indicated that span significantly differed between the two groups, with the experimental ($M = 5.19$, $SD = 0.68$) participants displaying a lower average span score than the control ($M = 6.20$, $SD = 0.62$) participants, $t(38) = 4.91$, $p < .001$. This confirmed that before the learning phase, the experimental participants expressed slightly lower short-term retention of spatial positions. Nevertheless, this finding was not a major concern, since for the main task sequence length was adjusted for each participant. However, this finding suggested that an analysis of response time performance data would be of limited value, given the greater number of stimuli that would need to be processed by the control participants. For that reason, response time data for the Hebb task was not considered when examining the learning differences between the groups.

Visuospatial Supra-span Hebb Learning Task

Baseline Performance. The independent t-test analysis indicated that at baseline, recall accuracy of the material by the control ($M = 0.55$, $SD = 0.09$) group was superior to that of the experimental group ($M = 0.43$, $SD = 0.13$), $t(38) = 3.64$, $p = .001$.

Learning of the repeated sequence preliminary inspection. The performance of the control and experimental groups on the repeated and random sequences in block 1, 2, and 3 is depicted in Fig. 2 for accuracy (presented as a proportion). Inspection of this figure, suggests that both the control and experimental groups' demonstrated superior recall of the repeated compared to the random sequence. The difference in recall between the repeated and random sequences appears to occur as early as the second block.

A mixed design group (control vs. experimental) x Sequence type (random vs. repeated) x Block of trials (block 1-3) ANOVA was conducted using accuracy performance. The between-subjects factor in the ANOVA was group, while both sequence type and trial block acted as within-subject factors.

Learning of the repeated sequence. The analysis of accuracy performance, indicated that the group effect was deemed not significant (control: $M = .54$, $SE = .03$; experimental: $M = .55$, $SE = .03$), $F(1, 38) = 0.08$, $p = .777$, partial eta-squared = .002, power = .059. Only one within-subjects factor, namely block (Table 1), was found to be significant, $F(1,38) = 15.36$, $p < .001$, partial eta-squared = .288, power = .968. This indicated that in general, both groups were more accurate in their recall performance across the average of the random and repeated sequences, as they progressed from block 1 to block 2 ($p = .001$), but even though more accurate from block 1 to block 2, as well as from block 2 to block 3, these

performance increases were found to be non-significant. The ANOVA analysis also yielded a significant Sequence x Block interaction, $F(1, 38) = 4.25$, $p = .046$, partial eta-squared = .101, power = .520 (Table 1), indicating that the effects of block on accuracy, depended on the sequence type being recalled. Follow-up analyses using pair-wise comparisons, confirmed this effect of block, showing that while on block 1 ($p = .250$) and block 2 ($p = .490$), recall was similar for the repeated and random sequence material, by block 3, recall of repeated material was significantly more accurate than that of the random material ($p = .034$).

The analysis also indicated, that while recall accuracy of the repeated sequence material did not improve from block 1 to block 2 ($p = .273$), there was significant improvement in accuracy performance noted from block 2 to block 3 ($p = .014$), as well as from block 1 to block 3 ($p = .003$), for the repeated sequence material. In terms of the random sequence material, no such significant improvement in recall accuracy was observed, at any of the three recorded moments (block 1, 2, and 3). In terms of the hypothesized three-way interaction between Sequence, Block, and Group, the analysis indicated that this did not reach significance, $F(1, 38) = 2.76$, $p = .105$, partial eta-squared = .068, power = .367 (see Figure 2). No other significant interactions were observed either. Nevertheless, given our apriori hypothesis that the visuospatial DT would impact performance in the experimental participants, we decided to look at the 3-way interaction more closely. We found that control participants demonstrated improvement in their recall of the repeated sequence material from block 2 to block 3 ($p = 0.020$), as well as from block 1 to block 3 ($p = 0.003$), accompanied by no significant improvement in their recall of the random material throughout the task. Conversely, for the younger adults exposed to the DT, there appeared to be no major improvement in their recall of either sequence type throughout the experiment. In fact, recall

of the random sequences remained superior to that of the repeated throughout (Table 1).

Spatial Reaction Time Dual-Task Performance

The first analysis examined whether there was trade-off between the spatial reaction DT and the supra-span learning task. A median split analysis grouping younger participants as either high (i.e. anyone who achieved an average of above 87.6% accuracy or below an average response speed of 2544.20 ms) or low (i.e. anyone who achieved below 87.6% accuracy or above 2544.20 ms in their average response speed) in terms of their performance on the DT was carried out. Two ANOVA's (one for RT and one for accuracy performance) using this grouping were executed. Results indicated that there was no effect of Group. Both younger "High" and "low" achieving participants performed similarly on the visuospatial supra-span sequence learning task.

Discussion

We proposed that older adults experience deficits in visuospatial Hebb supra-span sequence learning, as a result of their noted declines in attentional ability (c.f. Castel & Craik, 2003; Craik, 1977a, 1982; Craik & Byrd, 1982; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980). Accordingly, we hypothesized that implementation of a visuospatial DT alongside the Hebb visuospatial supra-span sequence learning task, would impact attention in a younger adult sample, resulting in a learning profile similar to that typically observed among older adults in this research area (c.f. Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005). Conversely, we also expected that this learning profile would contrast with that produced by the younger adults not subjected to the DT, who should display learning of the repeated sequence.

Our accuracy performance data support our hypotheses. Younger participant's, who were required to complete a visuospatial DT, showed no learning of the repeated sequence. In contrast, participants who were not exposed to the DT, expressed learning of the repeated sequence, as has been routinely found in research (c.f. Corsi, 1972; Couture & Tremblay, 2006; Gagnon et al., 2005; Gagnon & Winocur, 1996; Milner, 1971; Turcotte, 2002; Turcotte et al., 2005). We were able to show that learning was impaired in the DT group, by performing specific comparisons within each group that were based on a priori hypotheses. Admittedly, the three way interactions did not reach significance, and the overall pattern of results seemed to indicate that learning was evident in both the control and experimental groups; an effect that appeared to be generated by the steady learning pattern of the control participants. However, a close look at the performance profile of the DT participants also reinforces the hypothesis that learning was indeed impaired in the DT group. As indicated above, on each block of trials, the recall accuracy of the repeated sequence never surpassed that of the random sequences for the DT participants. Consequentially, this pattern of performance differs dramatically from what was observed amongst the control participants. This group showed a significant improvement in their recall of the repeated material, accompanied by only a slight, yet not significant improvement in their recall of the random sequence material. Our findings confirmed that we were able to reproduce in a younger population, the visuospatial Hebb supra-span learning deficit that is typically found in an older population (c.f. Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005). This supports our proposal that dividing-attention in a younger adult is an effective means of mimicking the effects of aging on attention (Craik, 1982, 1983), and that it should disrupt the performance on the main task, if the latter requires attention-based mechanisms.

In a previous study (Brasgold et al., 2011) investigating the effect of divided attention on visuospatial Hebb supra-span sequence learning in younger adults, we showed that a verbal DT was not sufficient in disrupting learning of the repeated sequence. In that study, participants subjected to the DT condition were asked to repeat words they heard, while encoding the sequences, while recalling the sequences, or while both encoding and recalling the sequences. Our results indicated that recalling the sequences was more demanding than encoding the sequences. This was demonstrated by lower accuracy on both random and repeated sequence material when participants were required to complete the verbal DT, as well as recall the sequences. However, the control and the DT participants displayed normal learning of the repeated material. The results of our previous investigation, together with the present findings, allow us to better understand the attentional requirements of the Hebb visuospatial supra-span sequence learning paradigm. In order to follow our line of reasoning the two main components of the Hebb task need to be considered. By all means, the Hebb supra-span learning task must be considered a working memory task (Conway & Engle, 1996; Gagnon et al., 2005; Weitz et al., 2011; for a similar proposal regarding sequence learning in general see Pascual-Leone et al., 1993). On any given trial, participants need to perform ISR of a sequence that is beyond their estimated capacity. Such a task necessarily involves working memory attention based mechanisms, such as the CE in Baddeley's (1986, 1996, 2000; Baddeley & Hitch, 1974) classic model. Our results fully support this interpretation. While recalling a spatial supra-span sequence, participants exposed to a verbal DT (Brasgold et al., 2011) or a spatial DT (as deployed in the present experiment), were significantly less accurate regardless of whether the sequence was composed of random or repeated sequence material. This finding is perfectly in line with the numerous studies that

noticed the disruptive effect of divided attention on a variety of memory tasks, including those reliant on working memory (c.f. Baddeley, 1996, 2001; Baddeley & Hitch; Baddeley et al., 1984; Craik, 1982; Craik et al., 1996; Fernandes & Moscovitch, 2000, 2002; Luo & Craik, 2009; Murdoch, 1965; Naveh-Benjamin et al., 2000a, 2000b; Reinitz et al., 1994).

The second and most important component of the Hebb spatial supra-span learning task concerns the cumulative learning of the repeated sequence as the task unfolds. In our previous study, we were unable to moderate this learning using a verbal DT and came to the conclusion that the learning process also largely depends on attention and space-based mechanisms. We carefully designed our spatial DT to target the space-based mechanisms and to eliminate its dependence on short-term memory mechanisms. The task can be conceived as a spatial reaction time task that is based on auditory cues. Participants went through extensive training to associate a location in space (four quadrants on a computer screen) with a given sound. They also learned to position their hand on the appropriate quadrant without looking at the computer screen. Once these two components were well learned and easily accomplished, participants were asked to complete the supra-span learning task. At that stage, the divided attention task required the participants to perform a manual response (touching the appropriate quadrant) in reaction to an auditory cue that was indicative of a location in space. Based on the mechanisms involved in the DT task, one could conclude that learning of the repeated sequence rests on the attention mechanisms that are necessary to process spatial information or to generate a manual response. We are unable to tease apart whether these mechanisms are mutually dependent or not, or whether one is more important than the other. However, we can definitely argue that the spatial processing or the response components are essential for learning the repeated sequence.

This finding fits nicely with the results of Turcotte and colleagues (2005). In their study, they observed that among the older adults, recall performance of the repeated sequence material contained some traces of interference that appeared to build up during the task. They concluded this after comparing the responses of the participants on the repeated sequences to those they produced for either the previous random sequence, or repeated sequence. They found that older adults appeared to have a greater tendency than their younger counterparts to reproduce some of the same errors when recalling the repeated sequence. The mechanisms responsible for this type of error are unknown, but they can be conceived as dependent on attention (e.g. inhibition of previous responses), and specific to spatial processing and response mechanisms.

Other interpretations to our findings are plausible. One could argue that the absence of learning observed here is simply caused by the difficulty of the DT and has nothing to do with spatial/response mechanisms. We recognize that the DT implemented in the present experiment is certainly more challenging than the one employed in our previous series of studies. Verbally repeating words heard through headphones is surely easier (Brasgold et al., 2011). It requires no prior training and accuracy was at ceiling. In our defense, we were able to train our participants on the spatial DT, so that they were able to reach an average accuracy that approached 90%, while performing the supra-span learning task. The response time was also very similar between studies, being slightly above eight seconds in both cases. Moreover, we made the demonstration that the level of performance attained on the DT did not influence learning on the Hebb supra-span learning task. To that end, we ran a median split ANOVA analysis, grouping the younger experimental participants as either “high” or “low” in terms of their performance on the DT. The analysis irrefutably showed that both

“high” and “low” achieving participants performed similarly on the visuospatial Hebb.

Our findings now allow us to reject a general attention deficit interpretation of the sequence learning impairment observed among older adults performing the supra-span Hebb. The research thus far has demonstrated that older adults show learning when the sequences are composed of verbal stimuli (digits, words, pseudo-words; c.f. Caird, 1964, 1966; Gagnon & Winocur, 1996; Heron & Craik, 1964; Turcotte, 2002; Turcotte et al., 2005), but have great difficulty expressing learning when the sequences consist of visuospatial locations (c.f. Gagnon et al., 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte et al., 2005). A general attention deficit does not seem the most plausible interpretation of our findings, as well as the findings pertaining to older adults.

Finally, we must also consider that mimicking in younger adults deficits that are typically observed in older adults, may not be the most appropriate route to take. Findings from a number of studies focused on investigating associative memory, suggest that dividing attention is not an effective means for imitating older adult behaviour (c.f. Castel & Craik, 2003; Naveh-Benjamin, Guez & Marom, 2003; Naveh-Benjamin, Guez & Shulman, 2004). These researchers contend that among younger adults, dividing attention simply has an impact on general memory performance, and does not simulate other aspects of processing that are associated with the aging process. Therefore, our findings cannot be seen a definite demonstration of the underlying cause of older adults’ sequence learning impairment. The behavioural pattern of older and younger adults subjected to a spatial DT may only be similar in appearance.

The next logical step consists of translating our interpretation into a paradigm that would facilitate learning in older adults. Two components of the task could be manipulated

in order to facilitate learning in older adults, and both would consist in decreasing interference. The first type of interference relates to spatial features, while the second relates to response interference. Couture and colleagues (2008) have proposed that learning on the Hebb supra-span learning task greatly depends on response production (see also Lafond, Tremblay, & Parmentier, 2010). Moreover, Harrington and Haaland (1992) have observed that when older adults are required to make complex hand movements while recalling material on the SRTT (another sequence learning task that is much less reliant on working memory than the Hebb), only marginal learning is observed, suggesting that this increase in motor requirements at retrieval, impacts response production. In the present research endeavour the DT employed also amplified the motor requirements of the task at the retrieval phase, which in-turn appears to have impacted learning in the younger adult participants.

In closing, our results suggest that visuospatial Hebb supra-span sequence learning is reliant on attentional resources, particularly with respect to the retrieval component of the task. The fact that older adults demonstrate difficulty with learning such material may reflect an underlying issue with contributing sufficient attentional resources when recalling the sequence material, strictly because of the method of recall imposed. This finding significantly adds to our understanding of the mechanisms involved in carrying out visuospatial sequence learning of the Hebb type. We suggest that future research examine whether learning on the Hebb supra-span learning task can be facilitated by decreasing the attentional requirements associated with the motor response component of the task. This could be achieved by asking the participants to recall the sequence of spatial positions using a different modality.

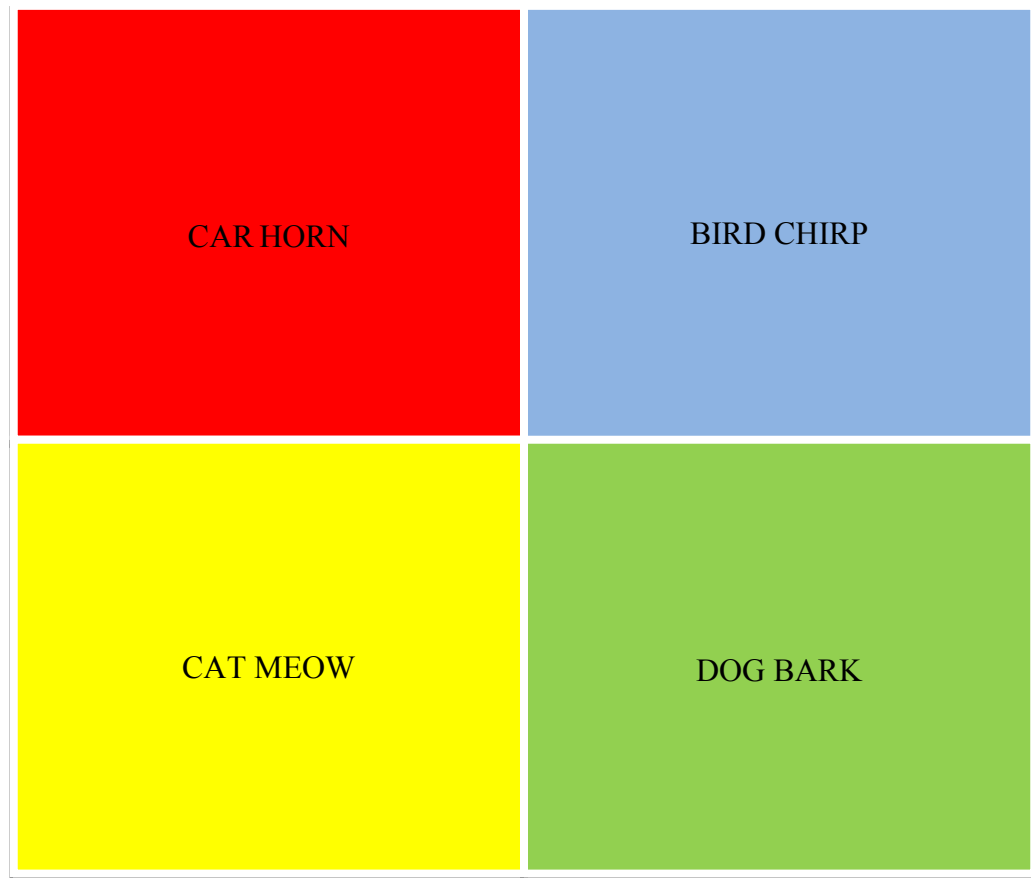


Figure 1. Illustration of the Spatial Reaction Time dual-task.

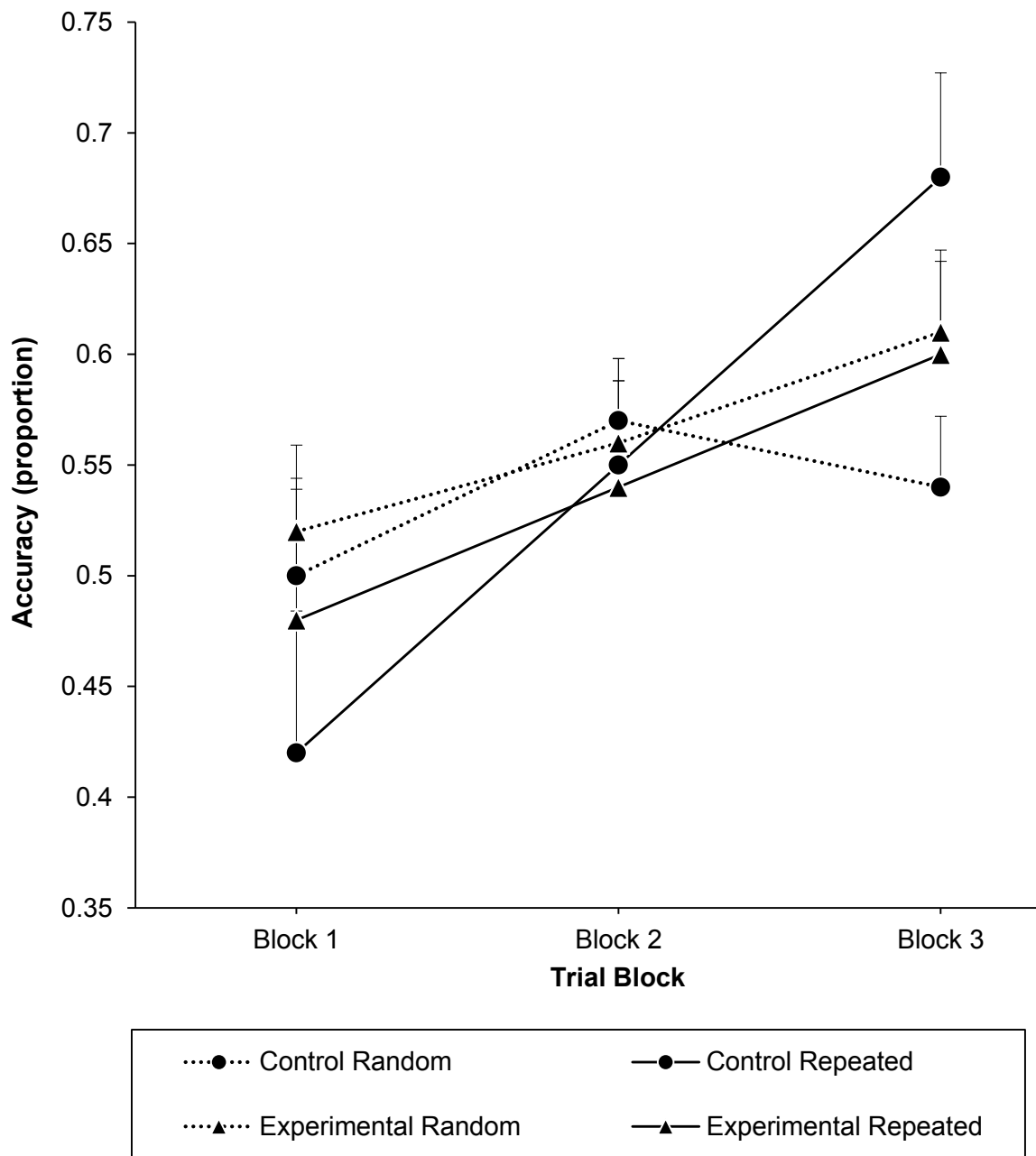


Figure 2. Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for control participants and experimental participants tested under the spatial DT implemented at retrieval. Standard errors are represented in the figure by the error bars attached to each marker.

Table 1

Mean Accuracy performance (as a proportion) on the Repeated and Random Sequences as a Function of the Block of trials for the Experimental and Control Groups Together and Apart (N = 40, 20 Control, 20 Experimental).

		Group				
		Experimental + Control		Control		Experimental
		Accuracy Performance		Accuracy Performance		Accuracy Performance
		(N = 40)		(n = 20)		(n = 20)
Condition	M	SE	M	SE	M	SE
Random						
Block 1	.51	.03	.50	.04	.52	.04
Block 2	.56	.02	.57	.03	.56	.03
Block 3	.58	.02	.54	.03	.61	.03
Repeated						
Block 1	.45	.04	.42	.06	.48	.06
Block 2	.54	.03	.55	.05	.54	.05
Block 3	.64	.03	.68	.05	.60	.05
Both						
Block 1	.48	.03	.46	.04	.50	.04
Block 2	.55	.02	.56	.03	.55	.03
Block 3	.61	.02	.61	.03	.61	.03

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4. CHAPTER FOUR: ARTICLE 3

**Investigating the role of response-based interference in
age-related visuospatial supra-span sequence learning deficits.**

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Abstract

In a previous experiment, we observed that attentional resources are particularly important at the retrieval phase of the visuospatial Hebb supra-span sequence learning paradigm for the establishment of learning (Brasgold, Gagnon, & Rodericks, 2011b). Given that older adults are known to have a deficit in demonstrating this form of learning (Gagnon, Bedard, & Turcotte, 2005; Turcotte, Gagnon, & Poirier, 2005), as well as noted issues with attention (Craig & Castel, 2003), we expected that learning ability for this material could be improved by reducing the attentional requirements associated with the retrieval aspect of the Hebb task. To achieve this, the traditional motor mode of recall (hand selection of the spatial locations) was replaced with a verbal mode of recall (verbal response), in which respondents used letters to recall the sequence of squares. A general improvement in performance was observed for the older adults exposed to the verbal response condition, while younger adults experienced no major benefit. Nevertheless, learning was not demonstrated by the older adults. Our findings suggest that attentional resources associated with the retrieval phase of the task, only partly explain the age-related deficits on this visuospatial sequence learning task.

Introduction

On a daily basis, humans must display behaviours (e.g. language, navigation, problem solving) that rely extensively on one's capacity to remember the order of events (Buchner & Frensch, 1997; Conrad, 1964; Gathercole, 2001; Lashley, 1951; Melton, 1963; Remillard, 2003; Schumacher & Schwarb, 2009; Soetens, Melis, & Noebaert, 2004; Whittlesea & Wright, 1997; for a discussion see Mosse & Jarrold, 2008). Incidental long-term memory (LTM) for order information has been primarily investigated using the serial reaction time task (SRTT; Nissen & Bullemer, 1987) and the Hebb supra-span learning paradigm (Hebb, 1961). In the latter serial recall task, several sequences of items are recalled immediately after their presentation, among which one series of items is repeated every third trial. A marked improvement in recall performance of this repetition, beyond what would be expected with practice, is indicative of learning of the recurrent sequence; an aspect which is confirmed by comparing recall performance of the repeated versus the random sequence material. This demonstration of learning has been coined the Hebb repetition effect (c.f. Hebb, 1961).

Most research using the Hebb paradigm has explored the mechanisms of verbal sequence learning, concluding that learning unfolds normally in both younger and older adults (c.f. Caird, 1964, 1966; Gagnon & Winocur, 1996; Heron & Craik, 1964; Turcotte, 2002; Turcotte, Gagnon, & Poirier, 2005). More recently, investigators have become more attentive to understanding the processes involved in visuospatial sequence learning, primarily because this form of learning appears to be disturbed by the aging process. Indeed, a variety of researchers have observed that while younger adults are proficient at learning visuospatial sequences (c.f. Brasgold, Gagnon, Stinchcombe & Pershin, 2011a; Brasgold, Gagnon, &

Rodericks, 2011b; Couture & Tremblay, 2006; Couture, Lafond & Tremblay, 2008; Lafond, Tremblay, & Parmentier, 2010; Turcotte et al., 2005), older adults fail to exhibit a significant learning curve for such material (c.f. Gagnon, Bedard, & Turcotte, 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte et al., 2005).

It is known that attention is impacted by aging (c.f. Castel & Craik, 2003; Craik, 1977a, 1982; Craik & Byrd, 1982; Hunt & Herzog, 1981; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991). Accordingly, in a previous set of studies, we investigated whether a limitation in attentional resources could be responsible, if at least partly, for this age-related visuospatial sequence learning deficit (see Brasgold et al., 2011a, 2011b). The attentional requirements of the visuospatial Hebb (1961) supra-span sequence learning task were examined by employing a dual-task (DT) procedure that was intended to restrict the amount of attentional resources the individual could contribute to carry out the Hebb task, as well as to mimic the effect that old age has on attention in younger adults (Craik, 1977b, 1982, 1983; Craik & Byrd, 1982; Craik, Govani, Naveh-Benjamin, & Anderson, 1996).

In an initial investigation (see Brasgold et al., 2011a), we asked younger adults to complete the visuospatial Hebb supra-span sequence learning task along with a verbal DT (verbal repetition of orally presented individual alphabetical letters) that was implemented either while the sequences were studied, recalled, or at both moments. Results from this first investigation, indicated that learning of the repeated sequence was not significantly impacted by implementation of a verbal DT, in any of the three manners (at encoding; retrieval; encoding and retrieval). However, global immediate serial recall (ISR) performance was reduced when the DT was implemented at the retrieval stage. Based on DT research ranging

across various memory tasks (e.g. SRTT, Hebb sequence learning task, ISR tasks); we speculated that the methods used in this first investigation may have failed to appropriately tax the attention resources of the participant. It is likely that the DT did not rely on the same attention mechanisms as those of the Hebb task. The two tasks were structurally different and did not overlap from a perceptual perspective; two elements that appear fundamental in generating a DT effect (modality interpretation; c.f. ISR task and SRTT research of Baddeley & Hitch, 1974; Hartley, 2001; Hartley & Little, 1999; or structural similarity interpretation; c.f. Navon & Gopher, 1979; Wickens, 1984; for a similar proposal see Heuer & Schmidtke, 1996, p.131).

Based on the above arguments, we carefully devised a secondary task to consist of a high level of processing overlap with the visuospatial Hebb supra-span sequence learning task. The DT, which could be considered a spatial reaction time task, entailed training participants to associate four auditory cue sounds with four locations in space (a computer screen split into four). Upon hearing one of the four sounds, the participant was simply required to press on that sounds matching location, but without being able to look at the screen. After adequate training on the DT, younger adults randomly assigned to the experimental condition completed the spatial reaction time task along-side the visuospatial Hebb supra-span sequence learning task, while retrieving the supra-span sequences. Our findings clearly indicated that in contrast with younger adults from the control group who demonstrated better recall of the embedded repeated sequence than the random sequences, no such learning was observed in the experimental group. Therefore, using a DT that overlapped more extensively with the visuospatial Hebb, we were able to mimic the sequence learning behavior of older adults (c.f. Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005).

within a younger adult population. Our results strongly suggest that the response component of the visuospatial Hebb task plays a noteworthy role in whether learning occurs, and may explain why older adults are unable to express normal learning. The importance of the response mechanism has also been observed in SRTT research. Indeed, Harrington and Haaland (1992) observed that learning was reduced in older adults when they were required to respond by making complex hand movements as opposed to the standard button press reaction time paradigm.

The fact that the spatial DT increased the motor obligations at the retrieval stage of the Hebb task suggests not only that the motor response method of recall is especially reliant on attention, but that within this context, motor responding may be particularly important for the demonstration of learning. This finding works well with the dual-trace proposal of Estes (1991; see also Estes, 1972), which stipulates that within learning there are at least two types of memory traces that can form. One that is established based on the encoding of the stimuli (e.g. stimulus presentation), and the other being created based on response output (e.g. key presses, spoken responses, or response locations). Remillard (2003; see also Frendrich, Healy, & Bourne, 1991; O'Shea & Clegg, 2006) makes a similar proposal, claiming that learning can be perceptually-based (see also Parmentier, Mayberry, Huitson, & Jones, 2008), response-based (see also, Couture et al., 2008; Nattkemper & Prinz, 1997; Zingrbl & Koch, 2002) or even effector-based (e.g. which finger was used); while the generation effect (c.f. Hirshman & Bjork, 1988; Mulligan, 2002) stipulates that memory is better for items that are self-generated, than for items that are simply presented. Working from these theories, responding would appear to have a large influence on whether learning is achieved. Indeed, previous SRTT research has demonstrated that sequence learning fails to occur in younger

subjects who are prohibited from responding to the stimuli (c.f. Cohen & Johansson, 1967; Cunningham, Healy, & Williams, 1984; Howard, Mutter, & Howard, 1992).

The mechanisms responsible for response-based learning are unknown. Nevertheless, some guidance on this topic is provided by motor behavior research. Within this research there is a demonstration that repetitive actions (e.g. such as keystroke sequences or movement sequences) cause a set of movement instructions to form within the brain (i.e. a motor program), which inevitably appears to direct future execution of the motor sequence (c.f. Collard & Povel, 1982; Povel & Collard, 1982; Rosenbaum, Kenny, & Derr, 1983; Ziessler, 1995; Ziessler, Hänel & Hoffmann, 1988; Ziessler, Hänel & Sachse, 1990). Given that in both the SRT and the Visuospatial Hebb supra-span sequence learning task sequence of stimuli is regularly presented and participants repetitively perform a particular sequence of motor responses, it can be assumed that under these conditions, motor programs would form as well. Although Estes (1972; 1991), as well as Remillard (2003) propose that learning relies on both responses and stimuli encoding, Boyd, Vidoni, & Siengsukon (2008), as well as Hoffmann and Koch (1997) suggest that within sequence learning tasks, response control shifts from the stimuli to this developed internal motor program. This shift in control in-turn causes current responding to rely heavily on previously made motor responses, rather than the stimuli presentations. Importantly, according to this proposal, the motor program would only be in effect when a repeated sequence of material is recalled.

The role of response production within a verbal Hebb like supra-span sequence learning task has been investigated by Couture and colleagues (2008). In their research, younger adult participants heard 48 sequences composed of nine letters that were presented through headphones. Every fourth trial consisted of a nine letter repeated sequence of

material. Participants recalled the sequence of letters by using a computer display to manually click (using a mouse) on the nine letters in the order they had been presented orally. Results indicated that although all subjects demonstrated learning of the repeated sequence, their responses revealed that they consistently reproduced their previously elicited repeated sequence motor responses; a finding which supports the response-based proposal. In a similar investigation, Lafond and colleagues (2010) also concluded that future responding in the Hebb relies heavily on what previous responses were already made by the participant. They claim that the formed memory traces incorporate information from a participant's previous responses, which subsequently impacts recall of future sequence material.

The findings of Couture and colleagues (2008), as well as Lafond and colleagues (2010) provide some additional insight into the sequence learning process, which we believe may be helpful in explaining why older, but not younger adults show a deficit in learning visuospatial sequence material. Specifically, the authors not only found that participants repeated their previous responses, but that they did so regardless of whether their initial recall was accurate. A similar observation was made by Turcotte (2002; see also Turcotte et al., 2005) through an analysis of the error performance of both their younger and older adult participants, in which they compared the responses that were provided for the repeated and random material throughout the visuospatial Hebb task. They found empirical evidence of recurring transposition errors (where an item is recalled in the incorrect serial position) on subsequent repeated sequence trials; meaning that both their younger and older adult participants appeared to repeatedly commit the same errors that they had made on previous trials when recalling the repeated sequence of material. The authors claimed that this was evidence of interference coming from previously made responses. Following from this line

of thinking, McClelland (2001) has argued that within the Hebb, responding strengthens a response, even if the response given is inaccurate.

Couture and colleagues (2008), as well as Lafond and colleagues (2010) took their findings as evidence that there can be error learning, as well as correct learning of the sequence material. When error learning surpasses correct learning, there will be an abolishment of learning, if current standards are used to evaluate learning (i.e. increased recall performance of the repeated material compared to that of the random material). According to this perspective, learning in younger participants is preserved even when errors in recall are noted, because correct recall still exceeds error recall, resulting in a significant learning curve. Couture and colleagues do put forward the idea that error learning may outperform correct learning under certain conditions where more errors are likely to be made; a situation that might be incurred by older adults carrying out the visuospatial Hebb supra-span leaning task.

Our results (Brasgold et al, 2011b) concerning the role of attention within the response component of the visuospatial Hebb, suggest that attention may be the mediating factor in whether or not an individual will err when recalling the repeated sequence of material. Indeed, several researchers have suggested that attention is required to be able to inhibit irrelevant material, as well as to actively maintain task relevant material (i.e. attentional control; c.f. Banich et al., 2000a, 2000b; Carter, Mintun, & Cohen, 1995; MacDonald, Cohen, Stenger, & Carter, 2000; Milham et al., 2002; Posner & Dehaene, 1994; Rabbit, 1997). This includes among other things an ability to prevent irrelevant information from impeding on performance. Within the visuospatial Hebb supra-span learning task, inhibition, as well as active maintenance of material is clearly required in order to effectively

perform the task.

Koch and Hoffman (2000), as well as Bo and Seidler (2010) suggest that the impacts of attention are particular to the motor response method and that replacing this method of recall could alleviate the cognitive load experienced by older adults, resulting in a demonstration of sequence learning. The results of Bo and Seidler are of particular interest here. In their investigation, younger and older participants were required to respond verbally, rather than mechanically, to stimuli within a modified SRTT called the alternating serial reaction time task (ASRTT). In the typical ASRT task, random and repeated sequence material is interleaved together within blocks. Participants perform ISR of individual items that are presented in one of four locations on a screen by clicking on the location directly following presentation. An asterisk is typically used as the stimulus of presentation and it can appear in only one of the four locations at one time. Similar to the Hebb, an improvement in performance on the repeated material, that is beyond a practice benefit, is indicative of learning. In Bo and Seidler's task, four letters (i.e. A, B, C, D) were used in place of the asterisk. Each was associated with one of the four boxes presented on the computer screen. In one condition, participants responded in the traditional manner by using key presses, while in a comparison condition, participants responded verbally using the letters. Results indicated that older adult's performance appeared to benefit more when the verbal response method was employed, while the younger participants seem to suffer in this same situation.

Based on the above theoretical arguments and the empirical findings stemming from Hebb and SRTT literature, we make the prediction that replacing the motor response will facilitate visuospatial supra-span sequence learning in older individuals. In the present experiment, younger and older individuals were tested on the standard visuospatial Hebb

supra-span sequence learning task, as well as on a modified version of the task in which the sequence of spatial positions was recalled verbally instead of via a motor response. It was hypothesized that the verbal response, as opposed to traditional mechanical recall, would facilitate learning in older participants.

Method

Participants

Seventy-nine participants (42 Women, 37 Men) composed of thirty-nine younger adult English speaking participants between the ages of 18 and 29 ($M = 22.23$ years old) and forty older adult English speaking participants between the ages of 64 to 84 ($M = 72.50$ years old) partook in this study. Half of the participants from each age group were assigned to one of two conditions: verbal (experimental), or touch screen (control) response.

Posters placed throughout the University of Ottawa, and advertisements in two local Ottawa and Gatineau newspapers were used for recruitment. Several participants were also recruited through Ottawa's School of Psychology Integrated System of Participation in Research (ISPR). These individuals received course credit for their participation, while all other participants received 10\$.

In order to participate, a participant had to be healthy, with no history of neurological issues, psychiatric issues, and drug or alcohol abuse. In addition, all older adult participants recruited were required to be autonomous and living independently. These participants were also pre-screened for abnormal cognitive decline using the Mini-mental state examination (MMSE; Folstein, Folstein, & McHugh, 1975), as well as the Montreal cognitive assessment test (MOCA; Nasreddine, et al., 2005). None of the participants obtained scores that were

indicative of abnormal cognitive decline. All participants were also evaluated in terms of vocabulary using the Shipley institute of living scale (SILS; Shipley, 1991).

Materials

A consent form and general questionnaire assessing health, education, and career status was completed by each of the older and younger participants. In addition, the spatial span of each participant was assessed using the spatial span assessment task (SAT; Brooks & Watkins, 1990; Watkins, 1977). This was followed by the evaluation of visuospatial sequence learning ability using the Visuospatial Hebb supra-span sequence learning task (Hebb, 1961; Corsi, 1972). Two versions of the SAT and Visuospatial Hebb were employed: a verbal-based response version and a standard touch screen version. The verbal response version of the task is referred to as the experimental condition, while the standard version is referred to as the control condition in this paper.

Stimuli and apparatus. The general demographic questionnaire, cognitive and semantic tests were recorded and scored manually by the investigator. A 17 inch NEC Accusync LCD 72vx touch screen monitor attached to a Pentium(R) 4 IBM ThinkCentre computer was used to present the SAT and visuospatial Hebb supra-span sequence learning task. Both programs were prepared using E-builder programming software, which ensured that performance on the touch screen versions would be recorded and scored automatically for each trial. Performance in the verbal response versions of the SAT and visuospatial Hebb supra-span sequence learning tasks required manual scoring, since oral responses were provided by the participant. For both, the experimenter followed a scoring grid, and

responses were documented for verification using a tape recorder. The experimenter then used a keyboard to manually enter all scores into the computer program.

Span assessment task and visuospatial Hebb supra-span learning task. Except for the following accommodation, the same SAT (Watkins, 1977) and visuospatial Hebb (1961) supra-span sequence learning tasks generated by Brasgold and colleagues (2011b; Article 2) were employed here. Specifically, both tasks were adapted for the verbal response condition. This meant that while in the touch screen version of each task, recall of the sequence required tapping directly on the squares using the touch screen, in the verbal response version, each square was labelled with a different white uppercase letter (New York font, size 40) which participants could use to verbally recall the sequence. Different combinations of letters were used to label the squares within a display from trial to trial (no one combination was repeated), and the letters were only displayed during the retrieval phase of the task. This was carried out to avoid unintended learning of the letter sequences, as opposed to the spatial sequences. It was also ensured that none of the letters used within a sequence formed any recognizable words. As such, 110 permutations of letter sequences were obtained to label each of the 110 potential sequences that could be displayed in the SAT, while 324 permutations of letter sequences were created to label each of the 324 potential sequences that could be displayed in the Hebb sequence learning task. The letters were displayed in both the touch screen and verbal response versions of the SAT and visuospatial Hebb supra-span sequence learning task for consistency, but participants in the touch screen version were simply told to ignore the letters and use the touch screen to respond.

As was done in Brasgold and colleagues (2001b) research, stimuli for both tasks consisted of equidistant 2.54 cm² black squares randomly positioned on a computer display that was lightly grey coloured. To indicate their order within the sequence, a square would change from black to white (with a black contour) and then back to black. For both the SAT and Hebb task, only the number of required squares to form the sequence were presented on the display, and it was ensured that no sequence was presented more than once to the same participant. In the visuospatial Hebb supra-span sequence learning task, the length of the sequence remained the same from trial to trial, while in the SAT, the length of the sequence changed from trial to trial and was dependent on the participants' performance.

Procedure

The duration of the experiment was approximately 45 minutes for each of the younger participants and 60 minutes for each of the older participants (because of cognitive testing). All testing occurred over one session in the University of Ottawa's Cognitive Aging Lab. Each participant was tested on an individual basis and was randomly assigned to either the verbal response or touch screen condition. Half the participants from each age-group were asked to complete the touch screen version, while the other half were required to complete the verbal response version. After filling out the consent form and answering the general demographic questionnaire, each participant proceeded to complete the SILS vocabulary sub-test, on their own, within a 10 minute time frame. In addition, only the older adult participants completed the MMSE and the MoCA, both of which were administered by the investigator within a 15 minute time period. After being seated at a standard distance of 65 cm from the display, an assessment of spatial span for each participant was taken using

the SAT. Each participant was then evaluated on their ability to learn visuospatial sequences using the visuospatial Hebb supra-span sequence learning task.

For both the SAT and Hebb task, the assignment required that participants recall sequences of squares directly following their presentation. For the SAT this was carried out to obtain an assessment of spatial span, and so the number of squares composing a sequence changed from trial to trial. Correct recall of the sequence resulted in a longer sequence on the next trial, while incorrect recall of the sequence resulted in a shorter sequence on the subsequent trial. An average of the participant's performance across all 16 trials indicated their spatial span capacity. Conversely, in the visuospatial Hebb supra-span sequence learning task, which contained 25 as opposed to 16 trials, the number of squares composing a sequence remained constant from trial to trial. Instead, a repeated sequence of material was embedded among the random sequences. This repeated sequence appeared on every third trial of the task (3, 6, 9, 12, 15, 18, 21, and 24) and participants were not informed of its presence. In the touch screen version, both younger and older participants used the touch screen to recall the sequences of material following a buzzer, while in the verbal response version, letters were used by the participants to perform ISR (see Appendix K for a copy of the instructions displayed to participants in the control and experimental condition). This task modification required that the investigator manually score and enter each individual's performance into the computer. Accordingly, once recall was complete on a particular trial, the investigator pressed on the space bar of the keyboard and a screen then appeared allowing the experimenter to enter the participants' accuracy score. For the SAT, this required that the experimenter input either the letter U (for up) or D (for down), where U indicated that the participant was successful in their recall of the sequence, and D indicated

that they were not. Importantly, selecting U would inform the program that an additional square would need to be added to the next sequence presentation, while selecting D, would indicate that the next sequence presentation should contain one less square. Similarly, for the visuospatial Hebb supra-span sequence learning task, the experimenter input how many squares the participant recalled in their correct temporal position. This was achieved by entering the appropriate number using the keyboard. To record latency performance, in both the SAT and Hebb task, the investigator pressed on the space bar as soon as the participant completed their recall of the sequence. Aside from the change in recall and recording methods for the verbal response version, instructions and procedures followed those carried out by Brasgold and colleagues (2011b; Article 2). In all cases, the investigator remained in the room to ensure that all aspects of testing ran smoothly. This was also necessary for the verbal response condition, where manual scoring of performance was required.

Scoring

To examine if learning of the repeated sequence had occurred, recall of the repeated and random sequences was compared throughout the Hebb task. Whether or not recall improved for either sequence type, was also used as an indicator of learning. To achieve this, the data was grouped into four Blocks, where the first block was considered baseline (Baseline Block). Within each Block, the data for the repeated and random material was blocked separately. This technique would allow for a comparison between the sequence types to be made. These blocking methods followed those used by Brasgold and colleagues (2011b; see their methods for additional information). As is typical in the Hebb paradigm, an item-order analysis approach was undertaken, where rather than an entire sequence being

considered correct or incorrect, the number of correctly recalled squares in their appropriate temporal position was recorded. Response in milliseconds was also recorded for each trial.

Results

Education and Vocabulary

A Group (young vs. older adults) x Condition (verbal response vs. touch screen) ANOVA was carried on Education and Vocabulary (SILS) scores. With regards to level of Education, older adults were found to have slightly more years of education ($M = 15.87$, $SD = 2.01$) than the younger participants ($M = 14.87$, $SD = 2.84$), but the lack of a Group effect indicated that this difference was not significant, $F(1,75) = 3.46$, n.s., partial eta squared = .044, power = .451. A significant Condition effect indicated that that control participants had slightly more years of education ($M = 15.92$, $SD = 2.91$) than the Experimental participants ($M = 14.82$, $SD = 1.86$), $F(1,75) = 4.18$, $p = .044$, partial eta squared = .053, power = .523. The lack of a significant interaction between these two factors, $F(1,75) = 1.39$, n.s., partial eta squared = .018, power = .214, showed that Education level did not differ within the conditions by age.

In terms of Vocabulary, the analysis yielded a significant Group effect, with older adults demonstrating a higher level of vocabulary ($M = 36.15$, $SD = 2.67$) than the younger adult ($M = 31.80$, $SD = 3.58$) participants, $F(1,75) = 50.45$, $p < .001$, partial eta squared = .402, power = 1.00. No Condition effect, $F(1,75) = 1.07$, n.s., partial eta squared = .014, power = .175, or interaction between the two factors was observed, $F(1,75) = 27.31$, n.s., partial eta squared = .036, power = .381.

A preliminary analysis was run to explore if these differences in vocabulary and education influenced performance. Results of a Group (young vs. older adults) x Condition (verbal response vs. touch screen) x Sequence Type (random vs. repeated sequences) x Block of Trials (block 1 vs. 2 vs. 3), with Education level and SILS performance (Vocabulary level) as covariates, showed that both Education and Vocabulary levels did not influence performance in any way. Results were the same regardless of whether these two factors were incorporated into the main analysis or not. In order to ease the description of the remaining findings, only ANOVA's will be detailed and discussed.

Span Assessment Task

A Group (younger vs. older adults) x Condition (verbal response vs. touch screen) ANOVA was carried out on span scores. The analysis showed that the groups differed in terms of their span performance, $F(1,75) = 45.43, p < .001$, partial eta squared = .377, power = 1.00, with the younger adults demonstrating a significantly higher average spatial span ($M = 6.64, SD = 0.71$) than their older adult counterparts ($M = 5.61, SD = 0.65$). Neither the condition effect, nor the interaction between the two factors was found to be significant, $F(1,75) = .39, p = .533$, partial eta squared = .377, power = 1.00., and $F(1,75) = 1.49, p = .227$, partial eta squared = .019, power = .225 respectively. This confirmed that before the learning phase, the younger adults expressed superior short-term retention of spatial positions when compared to the older adults. This also indicated that within their respective age groups, participants expressed equivalent short-term retention of spatial positions in both conditions. The former finding, however, suggests that the younger participants were exposed to more stimuli, a requirement that would necessitate additional processing time,

when compared to the older adult participants. As such, the analysis on the response time data will not be reported here, as it would fail to accurately reflect any differences in performance.

Visuospatial Hebb Supra-Span Sequence Learning Task

Baseline performance. A Group (young vs. older adults) x Condition (verbal response vs. touch screen) ANOVA was carried out on baseline performance. The analysis showed no evidence of a significant group effect, condition effect, or interaction between these two factors. This indicated that at baseline, accuracy recall of the material did not vary by age-group, with younger adults demonstrating similar performance ($M = 0.54$, $SD = 0.18$) to their older adult counterparts ($M = 0.51$, $SD = 0.17$), $F(1,75) = .68$, $p = .412$ partial eta squared = .009, power = .129. Accuracy performance also did not differ between the conditions, with touch screen ($M = 0.49$, $SD = 0.17$) and verbal response ($M = 0.56$, $SD = 0.17$) participants performing similarly, $F(1,75) = 2.79$, $p = .099$, partial eta squared = .036, power = .379. Nor did it differ by age-group, either within or between conditions, with older and younger touch screen participants (Older: $M = 0.45$, $SD = 0.17$; Younger: $M = 0.54$, $SD = 0.16$) performing similarly to each other, and older and younger verbal response participants (Older: $M = 0.57$, $SD = 0.14$; Younger: $M = 0.54$, $SD = 0.21$) performing similarly to one another.

Learning of the repeated sequence. Accuracy performance (presented as a proportion) of the touch screen and verbal response participants, on the repeated and random sequences in Block 1, 2, and 3, is depicted in Figure 1 for the younger participants (touch

screen vs. verbal response) and Figure 2 for the older participants (touch screen vs. verbal response). A graphic representation of accuracy performance by condition (touch screen or verbal response), can also be found in Figure 3 for the control participants (old vs. young), and in Figure 4 for the experimental participants (old vs. young).

Learning of the repeated sequence through accuracy performance. A Group (young vs. older adults) x Condition (verbal response vs. touch screen) x Sequence Type (random vs. repeated Sequences) x Block of Trials (block 1 vs. 2 vs. 3) with repeated measures on the last two factors was carried out. The analysis yielded a significant Condition effect (touch screen: $M = .58$, $SE = .02$; verbal response: $M = .64$, $SE = .02$), $F(1,75) = 4.29$, $p = .042$, partial eta squared = .054, power = .533, but no Group effect (older: $M = .59$, $SE = .02$; younger: $M = .64$, $SE = .02$), $F(1, 75) = 2.52$, $p = .117$, partial eta-squared = .033, power = .351. A significant Group x Condition interaction was also found (older-touch screen: $M = .53$, $SE = .03$; older-verbal response: $M = .65$, $SE = .03$; younger-touch screen: $M = .64$, $SE = .03$; younger-verbal response: $M = .64$, $SE = .03$), $F(1, 75) = 4.62$, $p = .035$, partial eta squared = .058, power = .565. Follow-up analyses using pair-wise comparisons indicated that younger Touch screen participants outperform older Touch screen participants ($p = .010$), while no such difference in performance is observed between younger and older verbal response subjects. Additionally, the analysis demonstrated that while performance among the younger touch screen and verbal response participants could be considered equated, older verbal response participants significantly outperformed their touch screen counterparts ($p = .004$). Only one within-subjects factor, namely Block (block 1: $M = .53$, $SE = .02$; block 2: $M = .63$, $SE = .02$; block 3: $M = .68$, $SE = .02$), $F(1,75) = 58.55$, $p < .001$, partial eta-squared =

.438, power = 1.000) was found to be significant. In general, participants from all age groups and conditions were more accurate in their recall, as they progressed from block 1 to block 2 ($p < .001$), from block 2 to block 3 ($p = .001$), as well as from block 1 to block 3 ($p < .001$). The ANOVA analysis also yielded three significant interactions. A significant Block x Condition interaction, $F(1,75) = 5.66, p = .020$, partial eta-squared = .070, power = .652 (Table 1), indicated that the effects of block on accuracy depended on whether a touch screen or verbal response method of recall was employed. Follow-up analyses using pair-wise comparisons indicated that while on block 2 ($p = .006$) recall performance was superior for those in the verbal response condition, on block 2 and 3, there was no difference in performance between the two conditions.

The analysis also indicated that those who completed the touch screen version showed a significant improvement in recall performance throughout the entire experiment, from block 1 to 2 ($p < .001$), 2 to 3 ($p = .016$), and from block 1 to 3 ($p < .001$). Alternatively, those in the verbal response condition only showed significant improvement in recall accuracy performance from block 1 to 2 ($p = .041$), and from block 1 to 3 ($p = .001$). A Sequence x Block interaction, $F(1, 75) = 18.95, p < .001$, partial eta-squared = .202, power = .990 (Table 1), indicated that the effect of block on accuracy depended on the sequence type being recalled. Follow-up analyses using pair-wise comparisons confirmed that on block 1 ($p = .085$) and block 2 ($p = .803$) recall was similar for the repeated and random sequence material. However, by block 3, recall of the repeated sequence was significantly superior to that of the random material ($p < .001$). The analysis also indicated that recall accuracy of the repeated sequence material did improve from block 1 to block 2 ($p < .001$), block 2 to block 3 ($p = .001$), as well as from block 1 to block 3 ($p < .001$), while accuracy performance on

the random sequence material significantly differed between block 1 and block 2 ($p = .006$), block 1 and block 3 ($p = .010$), but not between block 2 and block 3 ($p = 1.00$).

Finally a three way interaction between Sequence, Block and Group was also found, $F(1,75) = 12.27$, $p = .001$, partial eta-squared = .141, power = .933 (Table 1). Recall accuracy varied according to the age of the participants, the type of sequence, and the block of trials. Follow-up analyses indicated that the younger adults recalled random material more accurately than the repeated on block 1 ($p = .003$), while this trend reversed by block 3, with recall of the repeated outperforming that of the random material ($p < .001$). Conversely, for the older adults, no significant difference in recall between the repeated and random material was noted. An additional follow-up test revealed that while the younger adult participants' recall of the repeated material improved significantly from block 1 to 2 ($p = .001$), 1 to 3 ($p < .001$), and 2 to 3 ($p = .002$), recall of the random material did not. Interestingly, the older adult participants' recall of the repeated and random material showed significant improvement from block 1 to block 3 ($p = .002$ and $.009$ respectively), suggesting the observance of a strong overall practice effect.

In terms of the hypothesized four-way interaction between Group, Sequence, Block, and Condition, the analysis indicated that this did not reach significance, $F(1,75) = .233$, $p = .631$, partial eta-squared = .003, power = .076 (see Figure 2; Table 2).

Discussion

We proposed that the motor recall method imposed within the visuospatial Hebb paradigm results in the formation of a motor memory trace that may interfere with the memory of the just seen sequence, when an individual is performing ISR. This interpretation

was motivated by the work of Turcotte (2002; see also Turcotte et al., 2005) who observed that older adults committed more errors than their younger counterparts when recalling the repeated sequence on the visuospatial Hebb supra-span sequence learning task. It was hypothesized that replacing the motor recall requirements of the task would eliminate the effect of past motor responses, thus causing older adults ISR to rely more heavily on the just seen sequence, rather than on their previous responses. As such, learning of the repeated sequence was expected among older adults who were asked to perform ISR using a verbal mode of response, as opposed to the standard motor response.

Several noteworthy findings were obtained that offer support to our predictions. For instance, in terms of recall performance, the presence of a condition effect indicates that those who completed the verbal response version were more accurate than those who completed the touch screen version. This suggests that a reduction in the mechanical requirements of the task benefits performance. Most importantly, the implementation of a verbal response procedure facilitates performance among the older adult participants. Older adults' performance in the verbal response condition was significantly superior to their performance in the touch screen response condition; a finding that is perfectly in line with our interpretation. This clearly makes the demonstration that for older individuals, motor retrieval of a visuospatial sequence impedes learning. Most impressively, older adults' retrieval performance equated the performance of the younger participants tested under the same retrieval procedure. In sum, using a verbal response mode, the age-related reduced ISR of visuospatial sequences that is recurrently found in previous research, was partially eliminated here (.f. Gagnon et al., 2005; Gagnon & Winocur, 1996; Turcotte, 2002; Turcotte et al., 2005). With regards to the standard recall procedure, our findings also offer a

replication of the performance observed in previous studies (c.f. Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005). Younger adults outperformed the older participants in this condition. Their ISR was found to be superior.

The main prediction of this endeavor was that the age-related learning deficit for the repeated sequence would be alleviated in the verbal response condition. As is classically found in the Hebb supra-span sequence learning literature, younger adults demonstrated better learning of the repeated sequence over the random sequences in both touch screen (see Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005 for comparable results using the standard recall paradigm) and verbal response conditions. This was clearly demonstrated by both a Sequence x Block effect, as well as a Sequence x Block x Group effect.

Unfortunately, the latter analysis did not confirm better learning of the repeated sequence in the group of older adults tested under the verbal response condition. Nevertheless, a very interesting finding was obtained. Older adults tested in the verbal response condition were better at recalling the repeated compared to the random sequences, across all three blocks of trials. In contrast, among the older adults tested in the touch screen condition, recall of the repeated sequence was comparable to their recall of the random sequences in the first two blocks, and only slightly superior in the very last block. The lack of an interaction effect is probably explained by the overall improvement in ISR that was observed across all the blocks amongst the older adults tested in the verbal response condition. Moreover, older adults showed impressive recall performance of both the repeated and the random sequences on the first block of trials. In contrast, within the first block of trials, younger adults showed a lower level of performance on the repeated sequence, which then improved across the two remaining blocks. One should also note that in both conditions (touch screen and verbal

response), performance recall of the random sequences flattened in the group of younger adults, while older adults' recall improved throughout the task, for both types of sequences, in the verbal response condition.

The benefit of using a verbal response mode was clearly demonstrated in this paper. Older adults' ISR performance was dramatically improved. Moreover, the performance pattern of the older adults showed signs of improved learning of the repeated sequence, when compared to their performance on the random sequences. The present findings are in line with the results of a previous study, in which we used younger adults as a model of old age (see Brasgold et al., 2011b). This was achieved by having younger adults complete a DT that required the processing of spatial information, as well as the production of a motor response. We demonstrated that learning of the repeated sequence was abolished when younger participants were requested to complete the Hebb visuospatial supra-span sequence learning task while completing a spatial DT that was implemented at the retrieval stage (see Brasgold et al., 2011b). Based on that study, we concluded the following: 1) within the visuospatial Hebb supra-span sequence paradigm, learning of the repeated sequence relies strongly on attention mechanisms; 2) the attention mechanisms are specific to the processing of spatial information and the production of a related motor response; and 3) the age-related effect probably occurs at the retrieval stage.

We had two goals in mind when designing the present research. One consisted in reversing the learning deficit in older adults, by decreasing the attention load associated with the retrieval task. The second was to demonstrate that the age-related effect was best explained by a motor interference interpretation. We anticipated that a reduction in the motor requirements of the task might reduce the cognitive demands of the task, allowing for an

improvement in performance to be observed among older adult participants. As expected, older control (touch screen) participants do not demonstrate learning of the repeated sequence material (see Turcotte et al., 2005, for similar results), while those in the verbal response condition appear to show an improvement in their general learning of the material, and even better recall of the repeated sequence. The above findings definitely suggest that removal of the mechanical response does lead to a reduction in interference, allowing older adults to learn the material more effectively.

The results are also in line with those of Couture and colleagues (2008) who found that learning within a verbal Hebb paradigm, where a visuospatial response was required, relies extensively on responding; a concept also supported by SRTT investigations that have revealed an absence of learning when responding is prohibited (c.f. Cohen & Johansson, 1967; Cunningham et al., 1984; Howard et al., 1992). In their study, Couture and colleagues observed that participants repeatedly reproduced their previously elicited motor responses (see also Lafond et al., 2010; as well as Turcotte, 2002 and Turcotte et al., 2005). They concluded that, within the context of the Hebb, individuals learn their motor responses (for additional work regarding response-based learning see Nattkemper & Prinz, 1997; Zingrbl & Koch, 2002). This is an aspect that is supported by motor behavior research, which stipulates that a motor program, which guides future behavior, is formed whenever repetitive movements are performed (c.f. Collard & Povel, 1982; Povel & Collard, 1982; Rosenbaum et al., 1983; Ziessler, 1995; Ziessler et al., 1988, 1990). The fact that learning was still evident in their participants may simply be an indication that younger adults are capable of learning from their mistakes. Indeed, Couture and colleagues demonstrated that there is correct sequence learning, as well as error sequence learning among younger adult

participants, and that correct learning in these individuals exceeds that of error learning.

According to Estes (1972, 1991), learning is not only response-based, but stimulus-based as well (for a similar proposal see Frenndrich et al., 1991; O'Shea & Clegg, 2006; Remillard, 2003). Taken together with Couture and colleagues contentions, this could explain why the younger adult participants were able to demonstrate learning. They learned from the stimulus presentation and adapted their motor programs accordingly.

Applying the same line of thinking to our previous study, in which a learning deficit was observed among younger adults when a spatial response-based DT was implemented at retrieval (Article 2; Brasgold et al., 2011b), one could conclude that younger participants who were exposed to the spatial DT had difficulty processing the stimulus representations, and relied to a larger extent on their response representations. We contend that this resulted because of the motor requirements associated with the spatial DT, which restricted the attentional resources that could be contributed to carrying out the visuospatial Hebb task. One could speculate that the increase in motor requirements hindered their ability to appropriately inhibit automatic responding that is guided by the developed motor programs. Although this interpretation could only be confirmed through a detailed error analysis, it does fit well with the knowledge that older adults are known to experience difficulty with inhibiting no longer relevant information (c.f. Burke, 1997; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; May, Zacks, Hasher & Multhaup, 1999; McDowd, 1997; McDowd, Oseas-Kreger, & Fillion, 1995; and Zacks & Hasher, 1994). Accordingly, this could potentially explain why younger adults exposed to a spatial DT, as well as older adults tested on the standard mechanical response-based Hebb visuospatial supra-span learning task, show reduced learning.

In the current research endeavour the replacement of the motor method of recall with a verbal mode improved performance among our older adult participants. This finding also conforms to the framework just outlined. Indeed, it can be conceived that implementation of a verbal method of recall reduced the attentional requirements of the visuospatial Hebb supra-span task. Thus, older adults were able to focus on both stimuli and response representations when carrying out the visuospatial Hebb task. This in-turn improved their recall of both the random and repeated sequence material. The fact that under these conditions learning was still not fully observed among the older adults can be interpreted in several ways. For one, it is possible that the verbal mode of recall was still too attentionally demanding. Letters labeling the squares were used to perform recall and this required that the participant translate the spatial location into a letter response. The letters were also only displayed during the recall stage. It is therefore possible that this technique interfered to some degree with their memory trace.

In conclusion, changing the retrieval requirements of the visuospatial Hebb supra-span sequence learning task had a significant effect on both younger and older adults' recall accuracy. Both groups showed better ISR of the sequences when using a verbal retrieval procedure. Improved learning of the repeated sequence was fully demonstrated in younger adults and partly observed in older individuals. We conclude that old age does not influence Hebb's supra-span learning of visuospatial sequences per se, but that the processes underlying successful retrieval of the sequences under high attentional demand (mechanical response) are less efficient with old age.

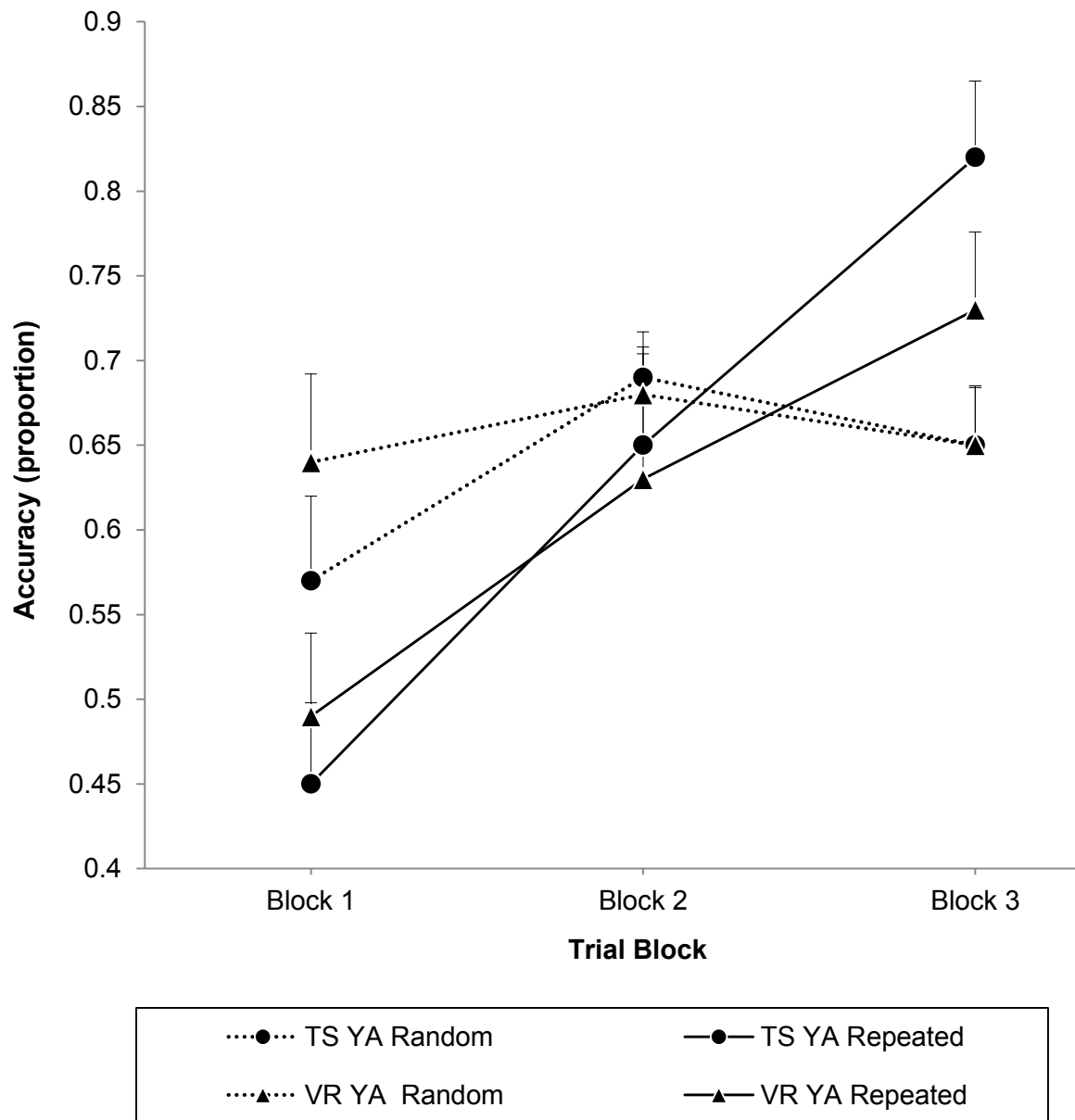


Figure 1: Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for younger adult participants tested under the verbal (VR) and motor (Touch screen; TS) recall methods. Standard errors are represented in the figure by the error bars attached to each marker.

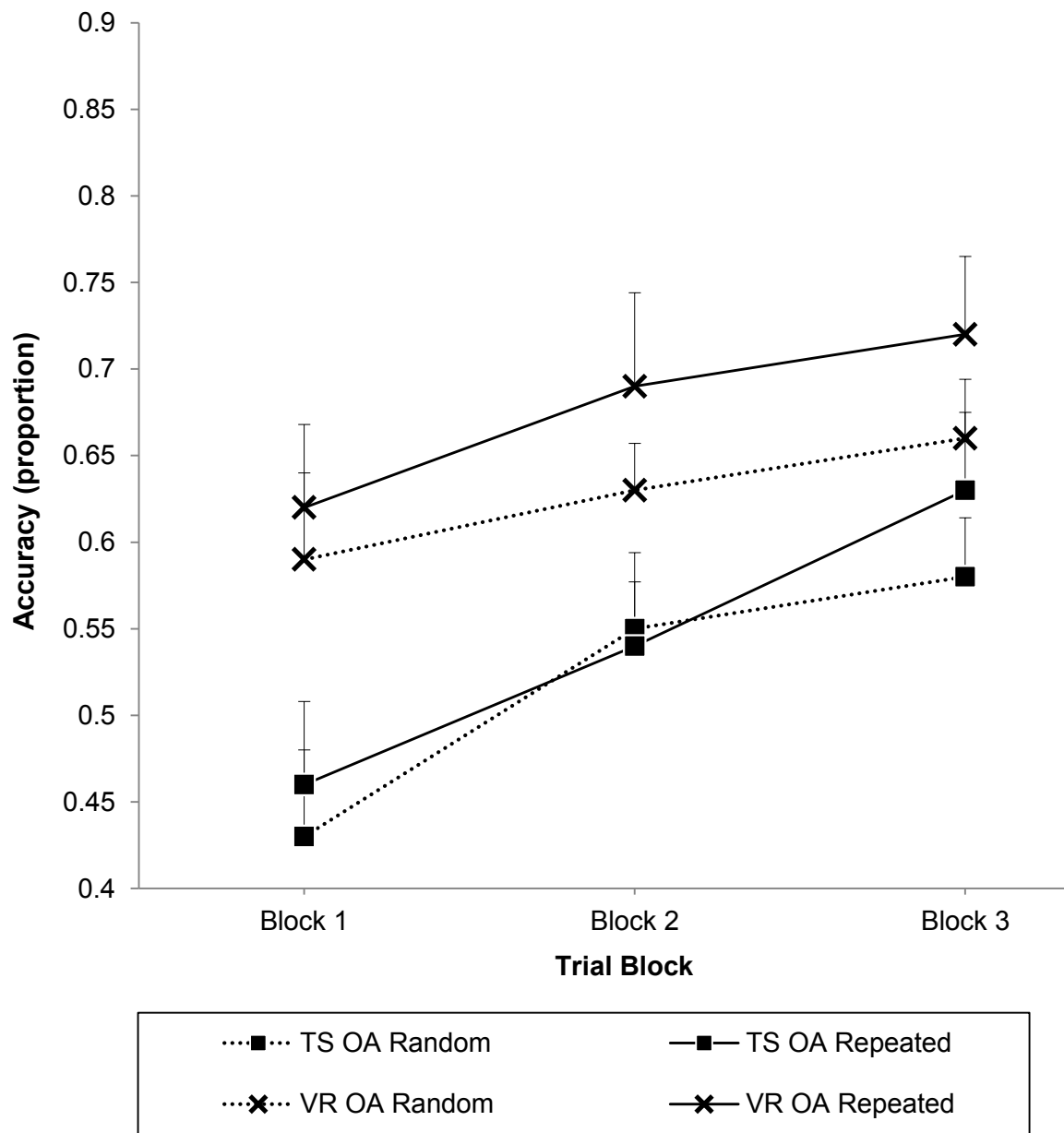


Figure 2: Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for older adult participants tested under the verbal (VR) and motor (Touch screen; TS) recall methods. Standard errors are represented in the figure by the error bars attached to each marker.

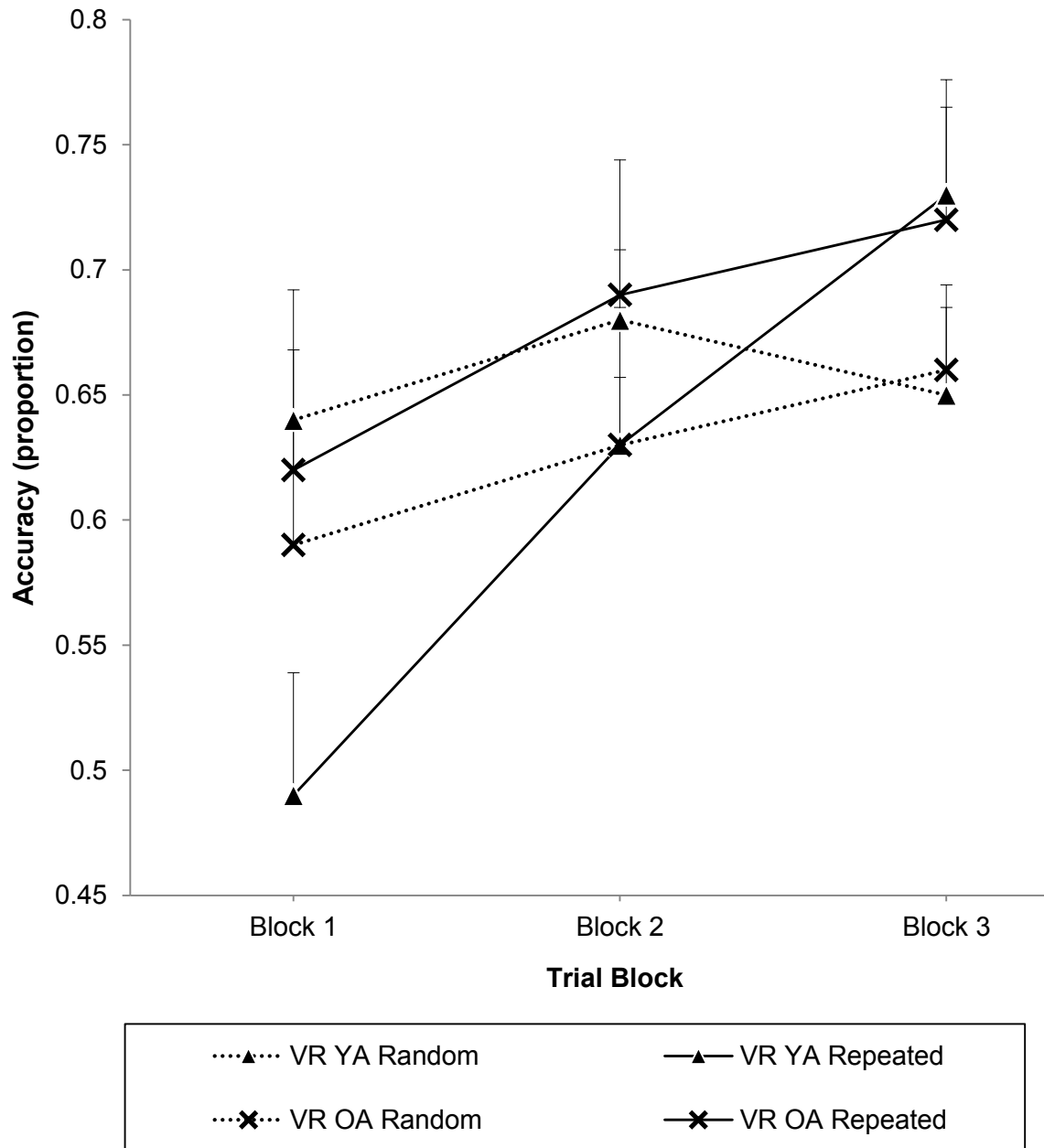


Figure 3: Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for younger and older adult participants tested under the verbal response (VR) recall method. Standard errors are represented in the figure by the error bars attached to each marker.

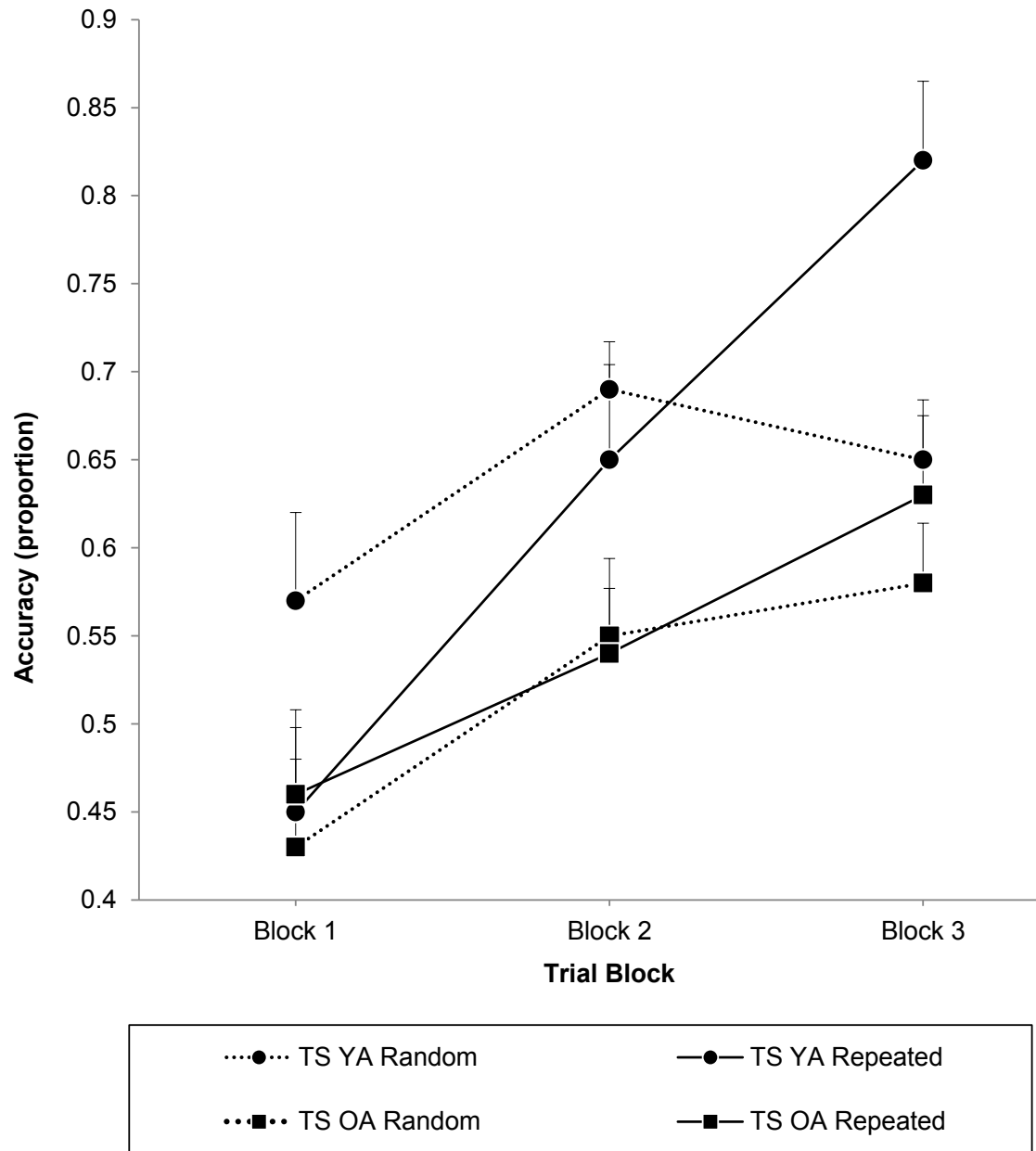


Figure 4: Accuracy performance (as a proportion) as assessed through recall of the repeated and random sequences as a function of the block of trials for younger and older participants tested under the motor recall (Touch screen; TS) method. Standard errors are represented in the figure by the error bars attached to each marker.

Table 1

Mean Accuracy Performance (as a proportion) on the Repeated and Random Sequences as a Function of the Block of Trials for All Participants Together as Well as by Age-Group and Condition (N = 79, 39 Younger Adults, 40 Older Adults, 39 Control, 40 Experimental).

Group										
Condition	All Participants		Younger Adults		Older Adults		TS		VR	
	Accuracy		Accuracy		Accuracy		Accuracy		Accuracy	
	Performance		Performance		Performance		Performance		Performance	
	(N = 79)		(n = 40)		(n = 40)		(n = 39)		(n = 40)	
	M	SE	M	SE	M	SE	M	SE	M	SE
Random										
Block 1	.56	.02	.60	.04	.51	.04	.50	.04	.62	.04
Block 2	.64	.01	.69	.02	.59	.02	.62	.02	.65	.02
Block 3	.63	.02	.65	.02	.62	.02	.61	.02	.65	.02
Repeated										
Block 1	.51	.02	.47	.03	.54	.03	.45	.03	.56	.03
Block 2	.63	.03	.64	.04	.52	.04	.60	.04	.66	.04
Block 3	.72	.02	.77	.03	.67	.03	.73	.03	.72	.03
Both										
Block 1	.53	.02	.54	.03	.53	.03	.48	.03	.59	.03
Block 2	.63	.02	.67	.02	.60	.02	.61	.02	.66	.02
Block 3	.68	.02	.71	.02	.65	.02	.67	.02	.69	.02

Table 2

Mean Accuracy Performance (as a proportion) on the Repeated and Random Sequences as a Function of the Block of Trials for All Participants by Age Group According to the Assigned Condition (N = 79, 39 Younger Adults, 40 Older Adults).

	Group							
	TS Younger Adults		VR Younger Adults		TS Older Adults		VR Older Adults	
	Accuracy Performance		Accuracy Performance		Accuracy Performance		Accuracy Performance	
	(n = 20)		(n = 20)		(n = 19)		(n = 20)	
Condition	M	SE	M	SE	M	SE	M	SE
Random								
Block 1	.57	.05	.64	.05	.43	.05	.59	.05
Block 2	.69	.03	.68	.03	.55	.03	.63	.03
Block 3	.65	.03	.65	.03	.58	.03	.66	.03
Repeated								
Block 1	.45	.05	.49	.05	.46	.05	.63	.05
Block 2	.65	.05	.63	.05	.54	.05	.69	.05
Block 3	.82	.04	.73	.05	.63	.04	.72	.04
Both								
Block 1	.51	.04	.56	.04	.45	.04	.61	.04
Block 2	.67	.03	.66	.03	.54	.03	.66	.03
Block 3	.73	.03	.69	.04	.60	.03	.69	.03

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5. CHAPTER FIVE

5.1. General Discussion

5.1.1. Revisiting the Principal Objectives of the Thesis

The goal of the present research endeavour was to investigate the conditions under which attention manipulations disrupt visuospatial sequence learning and to determine whether there is a manner in which visuospatial sequence learning ability can be restored in older adults. We suggested that attention might play a role within this observed age-related learning deficit because of several reasons. Firstly, attention is known to be impacted by the aging process (c.f. Castel & Craik, 2003; Craik, 1977a; 1982; Craik & Byrd, 1982; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991a). Secondly, the visuospatial Hebb supra-span learning task is reliant on working memory (c.f. Conway and Engle, 1996; Gagnon et al., 2005; Weitz et al., 2011; for a similar proposal regarding all sequence learning in general see Pascual-Leone et al., 1993), a process within which attention has been consistently implicated (c.f. Baddeley, 1986, 1996, 2000; Baddeley & Hitch, 1974; Coolidge & Wynn, 2005; Cowan, 1988, 1995; Engle, 2001; Engle et al., 1999a; Kane & Engle, 2002; Shallice and Burgess, 1998).

5.1.2. Revisiting the Investigations

In the introduction of the thesis, we examined the Hebb supra-span learning task within the context of working memory and we highlighted that the executive requirements of the Hebb task are essential for the demonstration of learning. Most importantly, we justified the importance of fully operating attention mechanisms. On the basis of an age-related

attention decrease (Castel & Craik, 2003; Craik, 1977a; 1982; Craik & Byrd, 1982; Hunt & Herzog, 1981; Parasuraman & Giambra, 1991; Parkin & Walter, 1991; Puglisi, 1980; Salthouse, 1991a), we anticipated that using a verbal DT alongside the visuospatial Hebb supra-span learning task would impact learning performance among a younger adult population in a similar manner to that routinely reported among older adults in this area of research (c.f. Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005). As such, we carried out a series of four studies, in which we used DT procedures in an attempt to mimic the impacts of the aging process on attention (Article 1 and 2; Brasgold, Gagnon, Stinchcombe & Pershin, 2011a; Brasgold, Gagnon, & Rodericks, 2011b). Specifically, in each of the studies, younger adults were tested under DT conditions to examine the contributions of attention within visuospatial sequence learning. Following from the work of Nissen and Bullemer (1987), a verbal DT procedure was implemented in the first set of studies in three different manners (Experiment 1: DT at Encoding; Experiment 2: DT at retrieval; Experiment 3: DT at encoding and retrieval; Brasgold et al., 2011a). This method was selected since we felt that it was a wiser scenario to first test whether a general decline in attention could explain older adults' deficits on visuospatial supra-span sequence learning.

Our accuracy performance data from this first investigation (see Brasgold et al., 2011a; Article 1) showed that learning of the repeated sequence unfolded normally among the younger participants subjected to the verbal DT, as well as for those who carried out the visuospatial Hebb supra-span learning task alone. Participants exposed to either of these conditions showed enhanced recall of the repeated material, which surpassed that of the random, beyond what would be considered a general practice effect. Our results provide further evidence that visuospatial sequence learning of the Hebb type unfolds normally in

younger adults (c.f. Corsi, 1972; Couture & Tremblay, 2006; Gagnon et al., 2005; Gagnon & Winocur, 1996; Milner, 1971; Tremblay et al., 2005; Turcotte, 2002; Turcotte et al., 2005).

Our response time performance data from Experiment 1, where the verbal DT was implemented only at encoding, provided comparable results to those obtained using accuracy performance. This suggested that RT (latency) could also be used as an effective indicator of incidental learning. To our knowledge, this is the first investigation where response time has been explored as a reliable indicator of incidental learning within the context of the Hebb paradigm.

The response time results yielded a different pattern of results when the DT was administered at retrieval (Brasgold et al., 2011a, Experiment 2; Article 1). Interestingly, it was found that the DT speeded participants' retrieval of the sequences. There are two implications of this finding. Firstly, response time data are not always a reliable indicator. Secondly, faster responding on the Hebb task while completing the DT is an indicator that the attentional challenge was increased under dual-task requirements, and that retrieval of supra-span sequences requires the allocation of the necessary attention. The previous interpretation is also supported by the effect of a DT at retrieval on recall accuracy. We noted that in Experiment 3 of this investigation, participants who were tested under dual-task requirements had average span scores that were significantly lower than participants who were not tested under the DT procedure. However, we were only able to show that the DT has some effect on general accuracy, but failed to counteract incidental learning of the repeated sequence. From this, we concluded that the type of DT implemented might simply have been unsuitable to generate a learning deficit in younger participants. We put forth the idea that disturbing learning of the repeated sequence could be achieved by using a DT that

more effectively impacts the attention mediated processes that are particular to the visuospatial Hebb supra-span sequence learning paradigm.

We grounded this interpretation of our findings in the state of the research in the field, as well as on a review of DT research showing that an overlap in sensory modality between a main and secondary task could be required if an impact on resources is to be observed (c.f. Hartley & Little, 1999; Hartley, 2001; Baddeley & Hitch, 1974; for a similar proposal implicating structural similarity see Heuer & Schmidtke, 1996, p.131; Navon & Gopher, 1979; Wickens, 1984). For instance, Baddeley's conception of working memory (Baddeley, 1986, 1992, 1996; 1997, 2000; 2001; See also Baddeley & Hitch, 1974) along with the multiple-resource theory, suggest that we may have at least two separate types of attentional resources for the processing of phonological and visuospatial material (c.f. Friedman, Polson, & Dafoe, 1988; Gopher & Sanders, 1984; Kinsbourne & Hicks, 1978; Wickens, 1984). The cognitive load approach also suggests that modality overlap among tasks is more effective in taxing attentional resources (Chandler & Sweller, 1991; Sweller, 1993; 1994; Sweller, Chandler, Tierney, & Cooper, 1990). This interpretation is further motivated by two findings. Firstly, that older adults are found to express normal incidental learning when tested with verbal sequences of stimuli, but not when tested with spatial sequences of stimuli (c.f. Caird, 1964, 1966; Gagnon & Winocur, 1996; Heron & Craik, 1964; Turcotte, 2002; Turcotte et al., 2005). Secondly, that traces of interference in the ISR of older adults responses tested on the spatial Hebb task have been observed (Couture et al., 2008; Lafond et al., 2010; Turcotte, 2002; Turcotte et al., 2005).

In order to investigate this modality proposal, we carried out a second investigation (Article 2; Brasgold et al., 2011b). This involved developing a DT that overlapped more

explicitly with the processing requirements inherent to the visuospatial Hebb supra-span sequence learning paradigm. Younger adults completed the Hebb task along with this spatial DT which was implemented at the retrieval phase. Implementing the DT at retrieval was motivated by the findings of our first set of studies, in which we observed that a decrease in general attention at retrieval impacts overall performance, as well as influences how the main task is accomplished (faster completion time; see Brasgold et al., 2011a; Article 1). The DT (Spatial reaction time task) that we designed to interfere with the visuospatial Hebb supra-span learning task had the following features: 1) it required the processing of spatial locations (up, down, right and left); 2) it required a manual response; 3) the memory load was negligible; 4) the task did not rely on the visual processing of stimuli. Under this manipulation we obtained one of the two main achievements of this thesis. In agreement with our predictions, younger participants showed a learning profile that was comparable to that consistently reported for older adults tested under standard testing conditions (c.f. Gagnon et al., 2005; Turcotte, 2002; Turcotte et al., 2005). Specifically, the younger participants who performed the spatial DT failed to show adequate improvement in their recall accuracy of the repeated sequence. In fact, their recall accuracy of the repeated sequence never surpassed that for the random sequences. Conversely, the younger participants not subjected to the spatial DT showed improvement in their recall accuracy of the repeated sequence, and one, which prominently exceeded their recall accuracy for the random material (i.e. the Hebb effect).

Findings from this second investigation support Craik's (1982, 1983) contention that dividing attention in a younger adult appears to be an effective means of mimicking the effects of aging on attention, within a situation where the main task relies on attention-based

mechanisms. More importantly the results clearly support the contribution of reduced attention in the age-related visuospatial sequence learning deficit. The fact that an impact on learning was not observed in our previous investigations (Article 1; Brasgold et al., 2011a) where a verbal DT was implemented, suggested that the sequence learning deficit results from a reduction in a specific form of attentional resources that are linked to carrying out processing at the response stage of the visuospatial Hebb task. Taking into consideration the attributes of the spatial DT, we maintained that the DT either impacted attentional resources associated with the processing of spatial information or the attention mechanisms necessary to generate a manual response; the former of which is in accordance with both the Multiple resource and Cognitive load theory (c.f. Multiple-resource theory literature of Friedman et al., 1988; Gopher & Sanders, 1984; Kinsbourne & Hicks, 1978; Wickens, 1984; as well as Cognitive load theory proposals provided by Chandler & Sweller, 1991; Sweller, 1993; 1994; Sweller et al., 1990). Our results also promote an interpretation that highlights the importance of the response component of the visuospatial Hebb supra-span learning task. Proposing that learning within the Hebb paradigm is reliant on responding fits well with Estes's (1991; see also Estes, 1972) dual-trace proposal. His suggestion is that memory traces are formed based on the studied stimuli, as well as the responses to these stimuli (for a similar proposal see Frendrich, Healy, & Bourne, 1991; O'Shea & Clegg, 2006; Remillard, 2003). Our interpretation is also in agreement with the numerous researchers who recommend that learning is response-based (c.f. Couture et al., 2008; Nattkemper & Prinz, 1997; Zingrbl & Koch, 2002); a fact supported by SRTT investigations showing a failure in learning when responding is prohibited (c.f. Cohen & Johansson, 1967; Cunningham et al., 1984; Howard, Mutter, & Howard, 1992).

A look at motor behavior research (c.f. Collard & Povel, 1982; Povel & Collard, 1982; Rosenbaum, Kenny, & Derr, 1983; Ziessler, 1995; Ziessler, Hänel & Hoffmann, 1988; Ziesler, Hänel & Sachse, 1990) led us to speculate that this response-based reliance of learning stems from the creation of motor programs in the brain (i.e. a set of movement instructions that form as a result of repetitive actions), which are then used to direct future response behavior (for a proposal of this as it pertains to sequence learning please see Hoffmann & Koch, 1997; Koch & Hoffmann, 2000). Within the context of the visuospatial Hebb supra-span sequence learning paradigm, one can appreciate how this could be beneficial for the demonstration of learning. Each time the repeated sequence of material appears, the motor program runs, causing each subsequent response to replicate the material that is found within the developed motor program. Indeed, a number of investigations have found that on subsequent trials where the repetition is presented, participants tend to duplicate the errors they committed on previous trials of the repeated material (i.e. transposition errors; c.f. Couture et al., 2008; Lafond et al., 2010; Turcotte, 2002; Turcotte et al., 2005). Turcotte (2002), Turcotte and colleagues (2005), Couture and colleagues (2008), as well as Lafond and colleagues (2010) also found that their older adult participants showed a greater tendency than their younger counterparts to commit these repetitive errors. Based on this contention, we proposed that older adults may demonstrate a difficulty with learning visuospatial sequences because of either a higher likelihood to commit errors right from the start and/or an issue with inhibiting previously formed faulty motor programs; both of which we argue are reliant on attentional resources (for support c.f. Banich et al., 2000a, 2000b; Carter et al., 1995; MacDonald et al., 2000; Milham et al., 2002; Posner & Dehaene, 1994; Rabbitt, 1997). The proposal that older adults are known to have difficulty with inhibiting no

longer relevant information in several cognitive domains (c.f. Burke, 1997; Hasher et al., 1991, 1999; Hasher & Zacks, 1988; May et al., 1999; McDowd, 1997; McDowd et al., 1995; and Zacks & Hasher, 1994), certainly advocates for some form of a response-based interpretative framework.

To tackle this interpretation, in a first investigation (Article 3; Brasgold & Gagnon, 2011) we chose to eliminate the learning deficit of older adults on this task by decreasing the amount of mechanical output that had to be generated by the participant at retrieval. We hypothesized that eliminating the manual response component of the task would reduce the attentional requirements needed to deal with the interference from previous manual responses. This would in-turn leave older participants with sufficient attentional resources to carry out the ISR task. Accordingly, both older and younger participants completed either the standard visuospatial Hebb supra-span learning task, or a modified version of the task that consisted of a verbal response recall method, rather than a manual response method.

Results from this last study are eloquent. Our findings indicate that the replacement of the motor response with a verbal response eased recall performance in a dramatic manner. Participants who carried out verbal response recall were significantly more accurate than those who responded using the traditional motor response. This was especially evident among the older adult participants whom appeared to benefit substantially more than the younger adults did from the implementation of a verbal response mode of recall. For the very first time in this field, our data strongly advocate for learning of the Hebb visuospatial sequences in older adults. Across all blocks of trials, average accuracy scores were consistently superior for the repeated sequence than the random sequences. This finding perfectly matches our results from our second investigation (Article 2; Brasgold et al.,

2011b), in which we observed a general reduction in learning performance among younger participants when the motor requirements associated with carrying out the task were increased. In one case, we successfully used younger adults and a DT procedure as a model of old age learning deficits of the Hebb type, while in the other case we were partially successful at reversing the learning deficit in older adults.

The findings from these five studies significantly add to our understanding of the mechanisms involved in carrying out visuospatial supra-span sequence learning of the Hebb type. As we claimed in the introduction, the effect of old age on the incidental learning of supra-span visual sequences is best understood if casted within a working memory framework. The supra-span nature of the task definitely implies that executive processing needs to take place in order to recall challenging strings of stimuli (Conway & Engle, 1996; Gagnon et al., 2005; Weitz et al., 2011). We also exploited another working memory concept, namely the executive buffer, in order to explain the inherent relationship between working memory and LTM in Hebb supra-span learning task. We finally claimed that attention-based mechanisms could be at the root of the deficits faced by older adults on this task. Our results provide evidence that enhanced recall of the repeated sequence depends at least partly on an individual's ability to donate the appropriate attentional resources at the retrieval stage of the task. We clearly showed that these attention-based processes are highly specific (spatial, but most likely motor based), and are fundamental to retrieve of the just seen sequence and for allowing the Hebb learning effect to occur.

5.1.3. Limitations

The experiments that we conducted are not without limitations and certainly

alternative interpretations of our results can be proposed. The first limitations are methodological and have to do with our assessment of span. In our first set of studies (Article 1; Brasgold et al., 2011a), we mentioned that during the span assessment task 13 squares always appeared on the screen, even though only some of them would actually be used to form a sequence. The presence of these extraneous squares may have in fact led to an inaccurate evaluation of span, since having more options to choose from would surely elevate the difficulty level of the task. An inadequate evaluation of span would likely translate into a greater ease in carrying out the subsequent Hebb task, where the squares presented on each trial was then restricted to the number of squares composing a sequence. Therefore, although the verbal DT appeared to impact accuracy performance in a general manner, as well as response time performance (i.e. speeding of responses in Experiment 2), the easiness of the visuospatial Hebb supra-span sequence learning task may have allowed participants to demonstrate learning, even under what appeared to be challenging DT conditions. We eliminated this confound in the second investigation (see Brasgold et al., 2011b; Article 2) by adjusting the number of squares in the span assessment task to reflect the number of required squares to compose the sequence. However, the use of a different DT procedure (spatial reaction time task) prohibits us from making any informative statements regarding the results of the first investigation.

One could also claim that when younger adults were exposed to a spatial and response based DT, the learning deficit that was observed could be explained by a difficulty interpretation. At first glance, the spatial-response DT appears more challenging, as opposed to more attentionally demanding, than the verbal repetition task that was employed in the first set of experiments. However, all participants were trained on the DT task prior to their

assessment on the Hebb task, and it was ensured that they achieved high accuracy scores before being allowed to complete the Hebb. Moreover, the obtained span scores were similar between DT and control participants, suggesting that DT was not merely just more challenging. As such, our results appear to go against such an interpretation of the results.

Another limitation to interpreting our results stems from the use of younger adults as a model of old age. Within the first four studies (Article 1 and Article 2), we investigated the impact of DT procedures on younger adults completing the visuospatial Hebb. Based on the work of Craik (1982, 1983) we employed this method as a means of mimicking the behaviour of older adults within a younger adult population. However, there is some evidence that within this context, performance of younger adults is only similar in appearance to that of older adults, being the result of a general decline in memory performance, rather than specific processing issues (c.f. Castel & Craik, 2003; Naveh-Benjamin, Guez & Marom, 2003; Naveh-Benjamin, Guez & Shulman, 2004). This may explain why we observed only general impacts on performance in the first three experiments. However, the results of the second investigation were quite revealing, but had to be confirmed through a paradigm that could be applied to older adults. We carried out the third investigation (Article 3) with the goal of translating our findings from the previous studies into a demonstration of learning in older adults. Our somewhat successful attempt strongly indicates that our approach to this issue was quite appropriate. The results suggest that splitting of attention among two tasks does mimic general performance behaviour of older adults (Craik, 1977b, 1982, 1983; Craik & Byrd, 1982; Craik et al., 1996). The results are also in contrast to those of Castel and Craik (2003), as well as Naveh-Benjamin and colleagues (2003, 2004) who argue that dividing attention will impact general memory

performance, but not mimic specific aspects of processing that are associated with the aging process.

Before concluding, we must address one other potential drawback to our results. Data gained from our span assessment in our third investigation (Brasgold & Gagnon, 2011; Article 3) suggests that the verbal response method we implemented may have failed to allow us to accurately evaluate the impacts of reducing the attentional requirements of the Hebb task on visuospatial supra-span sequence learning among older adult participants. Our results showed that span remained significantly higher for the younger compared to the older participants regardless of the response method employed. It was also observed that implementation of the verbal response method of recall did not impact span capacity, with both older and younger participants demonstrating spans that were equivalent to those exhibited in the touch screen conditions. Fortunately, these results can be interpreted differently and seen as a validation of our predictions. Our manipulation did not have an impact on span itself, but instead on the processes involved in performing a highly demanding working memory task that necessitates the discrimination between memory traces of stimuli and responses. This is another indication that manipulating the type of response played a substantial role in our capacity to boost supra-span sequence learning in older adults.

5.1.4. Other Interpretations and Recommendations for Future Investigations

Aside from the limitations outlined, there are also alternative interpretations which can be put forth to explain why it is that older adults have difficulty with learning visuospatial sequence material presented using the Hebb paradigm. Essential to our attention

proposal, we demonstrated that performance on the visuospatial Hebb supra-span sequence learning task must be reliant on working memory, a stance that has been assumed by several other researchers (c.f. Conway & Engle, 1996; Gagnon et al., 2005; Weitz et al., 2011). Given the rather complex nature of working memory, it is possible that rather than attention, other aspects of processing associated with working memory are responsible for the observed deficits.

According to Baddeley's (2000, 2001) description of working memory, the episodic buffer is responsible for transferring information from LTM into an active state in working memory so that it can be used to carry out the requirements of a memory task. If the conception of the episodic buffer is valid, then visuospatial Hebb supra-span sequence learning would depend on proper functioning of this element, since a comparison between current stimuli presentations and previously encoded material would be essential.

Importantly, Baddeley (2006) has equated the episodic buffer to consciousness, stating that an individual becomes aware of LTM information through the episodic buffer, which allows them to process incoming information more efficiently. Earlier we reviewed research exploring the relationship between awareness of the repetition and the demonstration of learning within the confines of the Hebb paradigm (c.f. Caird, 1964; Charness & Campbell, 1988; Couture & Tremblay, 2006; Drachman & Arbit, 1966; Gagnon, et al., 2004, 2005; McKelvie, 1987; Milberg et al., 1988; Milner, 1971; Rausch & Ary, 1990; Turcotte, 2002; Turcotte et al., 2005). We concluded that sequence learning does not appear to be dependent on whether awareness of the repetition occurs. However, several researchers have demonstrated that awareness of the repetition (being placed in the intentional condition) improved learning performance among younger, but not older adult participants (c.f. Gagnon

et al., 2005). This finding suggests that although awareness of the repetition is not required to establish learning, it is an aspect that improves learning; a finding that supports Baddeley's notion of the episodic buffer. The fact that older adults did not benefit from being in the intentional condition of Gagnon and colleagues (2005) study may also indicate an issue with processing associated with the episodic buffer. In our investigation, we decided to concentrate on the manipulation of attention and to leave apart the awareness debate. Future studies should examine whether within the Hebb paradigm, awareness of the repetition is reduced among younger participants submitted to a spatial DT, or whether it improves when a verbal mode of response is used, as was done in our last study.

Research conducted by Mayr (1996) who observed that participants were able to simultaneously learn a sequence of spatial locations and a sequence of four different objects, (non-spatial sequence) suggests that the learning of spatial and non-spatial sequences relies on independent learning systems. Qualifying this finding, Mayr (1996), as well as Willingham and colleagues (1998) reported that non-spatial sequence learning appears to result in more explicit knowledge than spatial sequence learning. Given that learning of both types of sequence material is observed among younger adults, this suggests that awareness of the repetition may not play a large role in the learning process. In either case, this would not invalidate the involvement of the episodic buffer. This aspect could be essential to discriminate just seen sequences from sequence recall performed in the past in a similar way to that proposed by Estes (1972, 1991).

5.1.5. Implications

The contributions of this research are clear. Our results show that the visuospatial

Hebb supra-span sequence learning task is reliant on attention and in particular the availability of specific attentional resources that are associated with carrying out motor based recall of the material. We supported this interpretation through a DT model of aging and by partially reversing the lack of learning in older adults. We conclude that the deficit observed likely stems from a combination of processing issues associated with working memory, among which we have identified a role of attention and motor ability. Our findings allow us to provide a response to the age-related dissociation on Hebb supra-span learning. Older adults are able to show learning of an embedded repeated sequence when sequences are made of verbal and non-verbal stimuli. This learning phenomenon is more likely to occur in situations where the attentional demands at retrieval are reduced.

5.2. Introduction and General Discussion References

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6. CHAPTER 6

6.1. APPENDICES

Appendix A

Recruiting Advertisements for all Investigations

Newspaper and flyer advertisements

AVIS DE RECHERCHE

Le laboratoire de vieillissement cognitif de l'École de psychologie de l'Université d'Ottawa est à la recherche d'hommes et femmes âgés(es) de 65 à 80 ans, ainsi que d'hommes et femmes âgés(es) de 18 à 35 ans désirant participer sur une base volontaire, à une étude sur la psychologie du vieillissement. Plus précisément, nous recherchons des gens en bonne santé qui désirent compléter une étude sur « la mémoire et le traitement de l'information lors du vieillissement normal ». Cette étude vise à mieux comprendre comment les adultes et les personnes âgées diffèrent dans leur étude du matériel d'ordre.

Dr. Gagnon et son équipe prévoient seulement une rencontre, d'une durée maximale d'une heure pour les participants jeunes et de deux heures pour les participants âgées. Tous les participants seront payés \$5 pour chaque demi-heure de participation. En plus, les frais de transport, qui compris des billets d'autobus ou les frais de stationnement seront couverts. Si participation dure plus qu'une expérience, des casse-croûte seront fournis entre les sessions. Nous vous remercions à l'avance de votre précieuse collaboration.

RESEARCH NOTICE

The Cognitive Aging Laboratory at the University of Ottawa's School of Psychology is currently recruiting participants. We are searching for people who are willing to participate on a volunteer basis in a study concerning the psychology of aging. In particular, we are looking for men and women who are between the ages of 65 and 80 years old, as well as men and women who fall within the age range of 18 and 35 years old. In general, we are looking for healthy participants who are interested in helping to complete a psychological study, its purpose being to better understand how younger and older adults differ in their learning of sequence material. Dr. Gagnon and his research team require only one appointment not lasting more than 1 hour for younger adult participants and 2 hours for older adult participants. All participants will be compensated 5\$ for each half hour of their time. Transportation, including either bus tickets or parking fees will also be paid for. If participating in more than one Experiment, a snack will be provided between the testing sessions. We thank you in advance for your cooperation.

University of Ottawa ISPR System posting

Title: Spatial Memory I (for Experiment 1)¹

Description

The Cognitive Aging Laboratory at the University of Ottawa's School of Psychology is currently looking for men and women between the ages of 18 and 35 years old, who would like to participate in a study on visual memory. In general, we are looking for healthy participants (without neuropsychological, psychiatric, alcoholism or drug abuse antecedents). Your task will consist in completing a computerized task, which will not last longer than 35 minutes. Your memory will be tested in this study. This study is part of a larger investigation on memory and information processing in young and older adults. With this study, we hope to better understand how older adults differ from younger adults in terms of their way of organizing and processing new information. As an Intro to Experimental Psychology student, you will receive 1 point for your participation. This study has been approved by the University of Ottawa's Social Sciences and Humanities ethics board.

Eligibility Requirements

Male & Female between the ages of 18-35; English fluency (1st or 2nd language); Normal or corrected vision and/or hearing.

Sign-Up Restrictions

Must NOT have signed up or completed ANY of these studies: **Spatial Memory I** (Inactive)

Prescreen Restrictions: YES

Duration: 35 minutes

Points: 1 Point

¹ The same information was posted for all five experiments on ISPR. The only difference was in the title, sign-up restrictions and duration for each posting. In Experiment 2, and #3 (Investigation #1), Investigation #2, and Investigation #3 the titles were Spatial Memory II, III, I, IV and V respectively. Sign-up restrictions for each study entailed that the individual could not have participated in any of the previous Spatial Memory studies. Duration for Investigation #2 and #3 was 45 minutes and 60 minutes respectively.

Appendix B

Telephone Recruitment Script for all Investigations

Hello, Can I speak with _____.

If they are NOT THERE. Say the following:

Would you mind taking a message? Thank you. Can you please tell _____ that Melissa Called from the University of Ottawa and that I would appreciate if she/he called me back at their convenience.

If they ARE THERE, say the following: *Good day, _____ my name is Melissa Brasgold and I am calling from the laboratory of cognitive aging located at the University of Ottawa. Is this a bad time?*

If YES, continue with the following: *When would be a good time to call you back or would you like to call me when it is more convenient for you?*

If NOT, continue with the following:

I am calling as a follow up to your response to one of our recruiting advertisements. Do you recall this advertisement?

If YES, continue with the following:

Good, currently, we are conducting an experiment in the lab regarding visuo-spatial memory, which is a type of memory used when navigating while walking or driving.

Are you still interested in participating at this time?

If NOT interested, continue with the following:

No problem, can I ask if you are simply not interested in participating in this particular study or in any studies at this time, but you would be interested in being contacted to participate in future studies. Make a note on their file regarding if they wish to be contacted in future or not.

If YES, continue with the following:

Great! I'd just like to do a quick review to make sure that nothing concerning your health may prohibit you from being able to participate in the study.

Questions to ask:

- 1. How is your vision? Have you had any eye surgery? Do you wear glasses?***
- 2. How is your hearing? Do you wear a hearing aid?***
- 3. Have you ever lost consciousness, experienced a head injury or been in a coma?***
- 4. Do you experience any issues major with memory, attention or concentration?***

Once information is checked.....**Continue with the following:**

Great, now that we've confirmed that you are eligible to participate let me give you some more information on the study. The study will require approximately 35 minutes (45minutes for Investigation 2 and 60 minutes for Investigation 3) of your time and you will be compensated 5\$ for each half hour of your time. Can we go ahead and schedule you in for a testing slot?²

If yes, schedule participant.

Make sure to provide the following:

- Contact information for the lab (address, phone number, email, name).
- Time & date of appointment.
- Inform them to contact you at least 24 hours in advance if they wish to cancel or re-schedule.
- That they must bring their glasses with them or contacts and contact case as they will need to remove their contacts.
- Also let them know that they are free to withdraw at any point and that their information will be kept strictly confidential.

² For Investigation #2 and #3 participants were informed that the study would require approximately 45-60 minutes of their time and that they would be compensated \$10.

Appendix C

General Participant Questionnaire

ID #: _____

General Participant Questionnaire

Date: _____ / _____ /200 Time: _____ Investigation #: _____ Exp. _____

Name: _____ ID: _____

Age: _____ Sex: M F

Place of birth: _____ Year of Immigration: _____

Mother Tongue: _____ Birth date: _____ / _____ /

Number of Years of Education, please circle highest grade attained.

QC: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Elementary Secondary CEGEP Undergrad Graduate-professional

ON: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26

Vision Problems (Near-sighted, Far-sighted, glaucoma, cataracts, color-blindness, etc.):

Glasses: Yes No

Hearing Problems: _____

History of Problems with Attention, Concentration or Memory; Head injury: Yes No

Are there other matters concerning your health which you think are important and relevant, which I have not asked you? _____

Would you like to participate in future research: Yes No

Span: _____ Span +2: _____

Group: Experimental or Control (circle one)

Aware: Yes or No (circle one)

Investigation 2/3 Testing Version: A or B (circle one)

Any issues with Testing (Interruptions – Noise, program freezes, program errors, participant issues):

Appendix D

Consent Form for all Investigations

CONSENT TO PARTICIPATE IN VISUAL MEMORY RESEARCH PROJECT

ID # _____

A. PURPOSE

I have been informed that the purpose of this study is to gain further insight into how visual memory works.

B. PROCEDURES

With respect to the study, I understand that:

It involves completing a general questionnaire regarding myself and two memory tasks that assess cognitive processes, including those related to visual memory and attention.

The entire study requires approximately 35 minutes of my time and in appreciation of my participation, I will receive \$5 for my time.³

C. CONDITIONS OF PARTICIPATION

With respect to my participation in the study, I understand that:

I am free to withdraw my consent and discontinue at any time without negative consequences.

My participation is confidential (i.e., the researcher will know, but will not disclose my identity)

The data from this study may be published.

The purpose of this study has not been concealed & there is nothing of which I have not been informed.

I will not experience any physical pain, and there are no known risks associated with my participation.

Since the task is of a cognitive nature, there is a possibility that I might experience fatigue. At all times, my state will be continuously monitored to insure my well-being. If at any time I am uncomfortable or too tired to proceed, I may withdraw myself from the study.

If I wish I will receive a summary of the findings of the study when they become available.

I HAVE CAREFULLY READ THE ABOVE AND UNDERSTAND THIS AGREEMENT. I, _____, freely consent to participate in a study on memory. This study is being conducted by a graduate and undergraduate student. I understand that they are under the supervision of Dr. Gagnon from the Cognitive Aging Laboratory of the School of Psychology at the University of Ottawa.

NAME (please print) _____ SIGNATURE _____

WITNESS SIGNATURE _____ DATE _____

³ For younger participants recruited via ISPR, this reads “I will receive 1 point course credit for my time”. For all participants in Investigation #2 and #3 this reads “The entire study requires approximately 45/60 minutes of my time and in appreciation of my participation, I will receive \$10.”

Appendix E

Investigators Script for Investigation 1 and 3

Materials:

- Computer
- Erasable Pen
- Answer Sheet
- Consent Form
- Tape Recorder
- Wireless Keyboard⁴

So first off, I'd like to thank you for coming in. As we discussed briefly on the phone you will be completing two tasks. The first task is a visuospatial sequence memory task, which is a form of memory used when we navigate, drive, and play piano for example. The memory task, will involve you verbally recalling sequences of squares that are presented on a computer screen. All the directions for the task will be presented on the screen prior to starting the task, but if you should have any questions at any point during the instruction presentation screens or the practice trials, feel free to ask. If you require glasses to read, then you should put them on now. Before beginning, I would like you to read over the following consent form. If you agree with the statements, simply provide a dated signature. Ok, now that you have signed the consent form, I am going to start the program. Remember, if at any point you do not feel well or you need to stop, please don't hesitate to let me know.

Run span assessment. After span assessment: Ok, now that you have completed the first part of this task, we can continue with the second part. Once again, all the directions will appear on the screen. There will be no practice trial this time, so should you have any questions regarding the instructions, please do not hesitate to ask. Remember, once again, if at any time you do not feel well or you wish to stop, simply let me know.

Run Supra-span task. After Supra Span Assessment: Thank, debrief, pay participant and make sure to fill out two copies of a receipt, one for our records and a second for the participant.

⁴ For Investigation #3, a timer, performance recording grids, as well as a copy of the MMSE, MOCA and Shipley were also necessary.

Appendix F

Debriefing Script for all Investigations

The researcher will **read** the following script once both sessions are complete.

“ Firstly, thank you very much for your participation in this cognitive experiment. This investigation you participated in was very straightforward in terms of us assessing your memory. The purpose was to measure your ability to learn sequential material that is spatial in nature, so that we can gain knowledge regarding how this type of learning unfolds in older and younger adults.

Do you have any questions?

At this point, you answer any other questions the participant has. If any emotional or mental discomfort arises at this point, or any other point, do refer the participant to Dr. Gagnon himself.

Appendix G

Instructions Presented for the Span Assessment Task in Investigation 1

- On the following screen you will be presented with a series of squares.
- Each square will “light up” by changing from black to white.
- The order that they light up will indicate their order in the sequence.
- Each square will only light up once in a sequence.
- Once the entire sequence is presented, a buzzer will sound.
- You will have 30 seconds to recall the sequence of squares in the original order they had been presented by using the mouse to click on the squares.
- If you are unsure of which square came next in a sequence, you are encouraged to take your best guess or you may press the space bar to leave a blank.
- A number counter on the top of the screen will indicate how many squares you have left to click on in the sequence.
- Once the sequence has been recalled, the next trial will begin.
- You will be presented with a number of sequences, and the number of squares in each sequence may increase or decrease from one trial to the next.
- A series of single letters will be orally presented through headphones while the sequence of squares are lighting up (In Experiment 1).⁵
- You must verbally repeat each letter you hear directly after it is presented.
- Each new trial will be signalled by a “trial loading” screen.
- As a practice, we will start with three warm-up trials.
- The task will get more complicated after the warm-up trials as more squares will be displayed.

Do you have any questions at this stage? If not, click any location on the screen.

⁵ In Experiment 2, this read “A series of single letters will be orally presented through headphones while you are recalling the order in which the squares lit up. You will need to verbally repeat each letter directly after it is presented. In Experiment 3, this read “A series of single letters will be orally presented through headphones throughout the experiment. You will need to verbally repeat each letter directly after it is presented.

Appendix H

Instructions Presented for the Visuospatial Hebb Supra-span Sequence Learning Task in Investigation 1

- Like before, you will be presented with a series of squares.
- Each square will “light up” by changing from black to white.
- The order they light up will indicate their order in the sequence.
- Each square will only light up once in a sequence.
- Once the entire sequence is presented, a buzzer will sound.
- You will have 20 seconds to recall the sequence of squares in the original order they had been presented by using the mouse to click on each square.
- If you are unsure of which square came next in a sequence, you are encouraged to take your best guess or click on the space bar to leave a blank.
- Once you have recalled a sequence, the next trial will automatically begin.
- Each new trial will be signalled by a “Trail #” screen.
- You will be presented with a total of 25 sequences (Trials).
- Unlike before, the number of squares presented within a sequence will remain constant from trial to trial.
- A series of single letters will be orally presented through headphones while the sequence of squares are lighting up (In Experiment 1).⁶
- You must verbally repeat each letter you hear directly after it is presented.
- It is normal to find this task challenging. Please try your best.

If you do not have any questions, click any location on the screen to continue.

⁶ In Experiment 2, this read “A series of single letters will be orally presented through headphones while you are recalling the order in which the squares lit up. You will need to verbally repeat each letter directly after it is presented. In Experiment 3, this read “A series of single letters will be orally presented through headphones throughout the experiment. You will need to verbally repeat each letter directly after it is presented

Appendix I

Investigators Script for Investigation 2

Script for Experimental Participants

Materials:

- 2 Computers
- 2 Wireless Keyboards
- 2 Mouses
- 2 Chairs
- Demographic Questionnaire
- Consent Form
- Pen
- Clipboard

Preparation before participant arrives:

On Demographic Questionnaire Fill in:

- Participant #
- Date
- Time of appointment
- Participants name and/or ID number if available
- Testing Version
- Group – Experimental or Control
- Any other available info: Age, Sex.

On Consent Form, fill in participants ID # after I, _____...

Set up Simon Says Task #1 on Left Computer.

Set up Visual Span Task #3b on Right Computer.

Have consent form and demographic questionnaire on a clipboard with working pen!

When participant arrives seat them in the testing room in front of the left computer and say the following:

So first off, I'd like to thank you for coming in. As we discussed briefly on the phone you will be completing two sets of tasks, both of which are quite similar.

Both sets of tasks explore visual-spatial sequence memory, which is a form of memory used when we navigate, drive, and play piano for example.

In each set of tasks there will be two tasks that need to be completed simultaneously. One of the tasks will involve you recalling sequences of squares that are presented on a computer screen. The other task which you will complete at the same time will involve pressing on a particular section of a computer screen in response to a specific sound.

You will be using touch screens for both tasks, so all responses will be made directly by pressing on the screen. All the directions for each task will be presented on the computer monitor prior to starting, but if you should have any questions at any point during the instruction presentation screens or the practice trials, please feel free to ask.

For each of the tasks there is a training session during which you will be guided if necessary. If you require glasses to read, then you should put them on now. Before beginning the first task, I would like you to read over the following consent form. If you agree with the statements, simply fill in your name and provide a dated signature at the bottom.

Let them sign the consent form. Then say:

Ok, now that you have signed the consent form, I am going to start the program. Remember, if at any point you do not feel well or you need to stop, please don't hesitate to let me know.

Task #1:

Run Simon Says Part 1 on left Computer and say:

Please read the directions on the following screen. Once you have finished, press on the screen to see the continuation of the directions.

Once they have finished reading say the following:

Basically you will hear a sound and a section of the screen corresponding to that sound will light up. You will need to press on that section of the screen.

Ensure that they understand and then have them click ahead.

Task #2:

Once they have completed task #1, set up Simon Says Task #2 on the left computer and say:

“ Ok now you will complete the same task again, except now there will be no colours lighting up. This means you will need to learn what sound corresponds to which of the 4 sections on the screen. You will receive feedback after each response in the form of a bell if you are correct or a buzzer if you are not. This will allow you to learn from your mistakes. I will now start the task, you may read the instructions and if you do not have any questions, you can simply press ahead to start the task.”

After they have completed Task #2, say the following:

I just want to make sure that you have learnt which sound matches with each of the 4 sections on the screen.

Can you tell me what sound corresponds to the top left hand section? (Horn)

The top right hand section? (Dog Bark)

The bottom left hand section? (Cat meow)

The bottom right hand section? (Whistle / chirp)

If the participant is unable to learn the associations, please thank them for their time and debrief them. Do not mention that they failed to meet the requirements for completing the task. Simply make it seem as though they have completed the task.

Task #3

Prep Task 3A (Simon says) on the left computer

Prep Task 3B (Span assessment) on the Right computer

Now say the following:

“Ok, you will now learn the second task which as I mentioned earlier will involve memorizing the order in which a series of clocks light up. Please read the instructions on the following two screens.”

Once they have finished, say the following: *“Do you understand what you need to do?”*

If yes, say *“ Ok please make sure to tap directly on each block when you are recalling the sequence they lit up in. There is a counter on the top that will let you know how many blocks you have left to click on to complete the sequence. Do you have any questions? If not, then please simply press on the screen to start the practice phase.”*

If no, say. *“Ok, basically you will be shown some blocks on the screen. Each block will light up once in a sequence.*

Your task is to try and recall what order the blocks lit up in. After hearing the bell, you will need to press on each block in the order you remember it lighting up in.

Please make sure that you tap directly on each block when are recalling the sequence they lit up in.

There is a counter on the top that will let you know how many blocks you have left to click on to complete the sequence.

Do you have any questions? If not, then please simply press on the screen to start the practice phase.”

Make sure they understand and then start the practice trials. Watch them and help them along if necessary. If they need to re-do the practice, you will need to re-run the program completely, so make sure they are clear on what they need to do before running the practice.

If you do need to re-run the program, press Alt + Esc and the program will close. Simply re-open it and under Subject # type the individual’s subject # again. This will write over the original file.

Once they have completed task, check the results file for the participant on task 3B (Span) on the right computer. On the Demographic Sheet record their span (round up if .6+, down if less) and span + 2 score.

Task #4

Prep Task 3A (Simon says) again on the left computer - Make sure Subject # has an “a” after it.

Prep Task 4 (Hebb Supraspan) on the Right computer – Use the correct Version and span + 2 score

Say the following:

“Ok, now that you have completed the first set of tasks, we can continue with the second set. Once again, you will complete both tasks simultaneously, except in this case the first task, will be slightly different.

Unlike before where the number of blocks on the screen changed from trial to trial, here the number of blocks shown will remain constant. Also, you will now have 20 seconds to recall the sequence of blocks, whereas before you had 30 seconds.

Other than these two changes all aspects of the task are the same. Again, all the directions will appear on the screen. There will be no practice trial this time, so should you have any questions regarding the instructions, please do not hesitate to ask. Remember, once again, if at any time you do not feel well or you wish to stop, simply let me know”.

Have the participant read the instructions and then click ahead if they have no questions.

If ISPR:

Once they have finished debrief them using the debriefing script. Then thank them for their time and let them know that their credit will be updated within a few days.

If Paid.....

Once they have finished debrief them, pay them and make sure to fill out two copies of each type of receipt (participation, transportation) , one for our records and one for the schools records.

Appendix J

Instructions Displayed in Investigation 2

Instructions for the Experimental group

Spatial Dual-task Instructions

- During this experiment you will be completing two tasks simultaneously.
- This is Task #1.
- In this task you will be presented with a screen that is divided in 4.
- Each of the 4 sections is associated with a particular sound and when a particular section lights up, the corresponding sound will also be heard.
- Your task is to learn which sound corresponds to which section on the screen and then to be able to press on the corresponding location each time its particular sound is heard.
- You will need to memorize which sound corresponds to which location, because you will need to press on the corresponding location without being able to see the section that lights up.
- You will go through a training phase in which you will learn the 4 sounds and to which particular location on the screen they correspond.
- You will then be placed behind a cardboard wall so that you cannot see the screen. One at a time the sections will light up, with their corresponding sound and you will be required to blindly press on the corresponding screen location.
- Once you achieve 20 correct responses, the learning phase will be completed.
- You will then learn about task #2.

Span Assessment Instructions

Screen 1

- This is Task #2.
- On the following screen you will be presented with a series of squares.
- Each square will “light up” by changing from black to white.
- The order that they light up will indicate their order in the sequence.
- Each square will only light up once in a sequence.
- Once the entire sequence is presented, a buzzer will sound.
- You will have 30 seconds to recall the sequence of squares in the original order they had been presented by pressing on the squares on the screen.
- If you are unsure of which square came next in a sequence, you are encouraged to take your best guess, or you may press on the space bar to leave that position blank.

Screen 2

While recalling the sequence of squares you will complete task #1 simultaneously.

In task #1, you will hear one sound at a time and you will need to press on the corresponding location as quickly and accurately as possible.

You will perform task #1 during each recall phase only.

It will start once the buzzer sound for task #2 is heard indicating that the recall phase has begun and will end once you have finished pressing on all the squares that lit up in the sequence.

In task #2 you will be presented with a number of sequences, and the number of squares in each sequence may increase or decrease from one trial to the next.

Each new trial will be signaled by a “trial loading” screen.

As a practice, we will start with three warm-up trials.

The task will get more complicated after the warm-up trials as more squares will be displayed.

Do you have any question at this stage?

Visuospatial Supra-Span Sequence Learning Assessment Instructions

Screen 1

- Like before, on the following screen you will be presented with a series of squares.
- Each square will “light up” by changing from black to white.
- The order that they light up will indicate their order in the sequence.
- Each square will only light up once in a sequence.
- Once the entire sequence is presented, a buzzer will sound.
- You will have 20 seconds to recall the sequence of squares in the original order they had been presented by pressing on the squares on the screen.
- If you are unsure of which square came next in a sequence, you are encouraged to take your best guess, or you may press on the space bar to leave that position blank.

Screen 2

Like before you will also complete task #1 simultaneously.

In task #1, you will hear one sound at a time and you will need to press on the corresponding location as quickly and accurately as possible.

You will perform task #1 during each recall phase only.

It will start once the buzzer sound for task #2 is heard indicating that the recall phase has begun and will end once you have finished pressing on all the squares that lit up in the sequence.

In task #2 you will be presented with a total of 25 sequences (Trials).

Unlike before, the number of squares presented within the sequence, will remain constant from trial to trial.

Each new trial will be signaled by a “Trial #” screen.

It is normal to find this task difficult. Please, try your best.

Do you have any question at this stage?

Instructions for Control Group

Span Assessment Instructions

Screen 1

On the following screen you will be presented with a series of squares.

Each square will “light up” by changing from black to white.

The order that they light up will indicate their order in the sequence.

Each square will only light up once in a sequence.

Once the entire sequence is presented, a buzzer will sound.

You will have 30 seconds to recall the sequence of squares in the original order they had been presented by pressing on the squares on the screen.

If you are unsure of which square came next in a sequence, you are encouraged to take your best guess, or you may press on the space bar to leave that position blank.

Screen 2

- While recalling the sequence of squares you will hear several buzzing noises. Simply pay no attention to them.
- You will be presented with a number of sequences, and the number of squares in each sequence may increase or decrease from one trial to the next.
- Each new trial will be signaled by a “trial loading” screen.
- As a practice, we will start with three warm-up trials.
- The task will get more complicated after the warm-up trials as more squares will be displayed on the screen.

Do you have any question at this stage?

Visuospatial Supra-Span Sequence Learning Assessment Instructions**Screen 1**

Like before, on the following screen you will be presented with a series of squares.

Each square will “light up” by changing from black to white.

The order that they light up will indicate their order in the sequence.

Each square will only light up once in a sequence.

Once the entire sequence is presented, a buzzer will sound.

You will have 20 seconds to recall the sequence of squares in the original order they had been presented by pressing on the squares on the screen.

If you are unsure of which square came next in a sequence, you are encouraged to take your best guess, or you may press on the space bar to leave that position blank

Screen 2

You will be presented with a total of 25 sequences (Trials).

Unlike before, the number of squares presented within the sequence, will remain constant from trial to trial.

Each new trial will be signaled by a “Trial #” screen.

It is normal to find this task difficult. Please, try your best.

Do you have any question at this stage?

Appendix K

Instructions Displayed in Investigation 3

Span Assessment Task

On the following screen you will be presented with a series of squares.

Each square will “light up” by changing from black to white.

The order that they light up will indicate their order in the sequence.

Each square will only light up once in a sequence.

Once the entire sequence is presented, a buzzer will sound.

You will have 30 seconds to verbally recall the sequence of squares in the original order they had been presented by using the letters that have been provided to label each square.⁷

If you are unsure of which square came next in a sequence, you are encouraged to take your best guess.⁸

A number counter on the top of the screen will indicate how many squares you have left to click on in the sequence.

- Once you are done, press the space bar and wait for the administrator to load the next trial.⁹
- You will be presented with a number of sequences, and the number of squares in each sequence may increase or decrease from one trial to the next.
- Each new trial will be signalled by a “trial loading” screen.
- As a practice, we will start with three warm-up trials.
- The task will get more complicated after the warm-up trials as more squares will be displayed on the screen.

Do you have any questions at this stage? If not, click any location on the screen.

⁷ The touch screen version reads “to recall by touching directly on the squares”.

⁸ The touch screen version reads “If you are unsure of which square came next in a sequence, you are encouraged to take your best guess. You may press the space bar to leave a blank.

⁹ The touch screen version reads “Once the sequence has been recalled, the next trial will automatically begin”.

Visuospatial Hebb supra-span sequence learning task

Like before, you will be presented with a series of squares.

Each square will “light up” by changing from black to white.

The order they light up will indicate their order in the sequence.

Each square will only light up once in a sequence.

Once the entire sequence is presented, a buzzer will sound.

You will have 20 seconds to verbally recall the sequence of squares in the original order they had been presented by using the letters labelling each.¹⁰

If you are unsure of which square came next in a sequence, you are encouraged to take your best guess.¹¹

Once you are done, press the space bar and then wait for the administrator to load the next trial.¹²

You will be presented with a total of 25 sequences (Trials).

Unlike before, the number of squares presented within a sequence will remain constant from trial to trial.

Each new trial will be signalled by a “Trail #” screen.

It is normal to find this task challenging. Please try your best.

If you do not have any questions, click any location on the screen to continue.

¹⁰ The touch screen version reads “to recall by touching directly on the squares”.

¹¹ The touch screen version reads “If you are unsure of which square came next in a sequence, you are encouraged to take your best guess. You may press the space bar to leave a blank.

¹² The touch screen version reads “Once the sequence has been recalled, the next trial will automatically begin”.