The roles of individual differences and working memory in episodic memory

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A Dissertation

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The Roles of Individual Differences and Working Memory in Episodic Memory

by

Aparna A Sahu

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

Doctor of Philosophy Degree in Experimental Psychology

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May 2013
An Abstract of

The Roles of Individual Differences and Working Memory in Episodic Memory

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Past studies on strength of handedness, an individual difference variable, and working memory (WM) have shown their independent associations with episodic memory. The current study aimed to check for the associations between these three factors, in addition to assessing the role of strength of handedness in simple and complex WM tasks (measured by digit span and letter number sequencing tasks, respectively) and episodic memory (measured by verbal paired associates). Results revealed robust handedness differences in episodic memory echoing findings from a host of past studies, however, failed to show a significant association with WM. Further, a path model was attempted to check if handedness mediated via WM to influence episodic memory retrieval. Results revealed that the two were dissociated from one another and yet significantly affected episodic memory. The current findings are explained in the light of past evidence that support the roles of WM and handedness in encoding and retrieving episodic memories, respectively.
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List of Abbreviations

AMOS ......................... Analysis of Moment Structures
ANOVA ....................... Analysis of Variance
CFI .............................. Comparative Fit Index
C.R. ............................. Critical Ratio
CVLT-II ....................... California Verbal Learning Test – Second Edition
DS .............................. Digit Span
EHI .............................. Edinburgh Handedness Inventory
EEG .............................. Electroencephalogram
ERP ............................. Event Related Potential
HERA ............................ Hemispheric Encoding Retrieval Asymmetry
IBM .............................. International Business Machines Corp.
LNS .............................. Letter Number Sequencing
LTM .............................. Long Term Memory
MI .............................. Modification Indices/Index
MLE .............................. Maximum Likelihood Estimation
PA .............................. Path Analysis
PET .............................. Positron Emission Tomography
PFC .............................. Prefrontal Cortex
RMSEA .......................... Root Mean Square Error of Approximation
SAM .............................. Search for Associative Memory
SD .............................. Standard Deviation
SE .............................. Standard Error
SEM .............................. Structural Equation Modeling
STM .............................. Short Term Memory
TLI .............................. Tucker – Lewis Index
VPA .............................. Verbal Paired Associates
WAIS-IV ....................... Wechsler Adult Intelligence Scale – Fourth Edition
WM .............................. Working Memory
WMS ............................. Wechsler Memory Scale
WMS-III ....................... Wechsler Memory Scale – Third Edition
WMS-IV ....................... Wechsler Memory Scale – Fourth Edition
List of Symbols

$\beta$ ..........Beta weight (regression)
$F$ ..........Statistic for the ANOVA
$M$ ..........Mean score of a sample
$\eta^2_p$ ..........Partial Eta square
$N, n$ ..........Sample size
$p$ ..........Probability level
$R^2$ ..........Squared Multiple Correlation
$t$ ..........T test for two independent samples
$\chi^2$ ..........Chi Square
$z$ ..........Standard score
Chapter One

Episodic Memory

A) Introduction

Episodic memory refers to a long term memory system that is unique to an individual and is based on past happenings, specific in time and place (Tulving, 1972, 1993). It is a widely studied cognitive process assessed by tests of recall and recognition that makes reference to previously learned material (Friedman & Johnson, 2000). Behavioral studies have shown a direct relation between greater depth of processing of information at the encoding stage, and greater amounts of retrieval (Craik & Lockhart, 1972) with a greater frequency of “remember” responses than the “familiarity” feeling about responses (Tulving, 1985).

Studies have addressed the possible reasons for individual differences in episodic memory performances. In particular, two sets of studies that have provided evidence for these differences and are of interest to the dissertation, are, a) working memory (WM) capacity and, b) the roles of demographic variables such as age, gender and handedness.

The following literature review presents findings on the contributions of gender and handedness in both episodic memory and WM, and the role of WM in episodic memory. This helps further focus on untouched areas that need to be explored such as the role of strength of handedness in simple and complex WM in addition to proposing an extended hypothesis that addresses the combined effects of both strength of handedness (and gender; if gender differences are present in both memory processes) and WM in aiding episodic memory.
B) Individual Differences in Episodic Memory

*Gender/sex*: Behavioral studies have most often demonstrated a robust female advantage in verbal episodic memory (Geffen, Moar, O'Hanlon, Clark, & Geffen, 1990; Herlitz, Nilsson, & Backmann, 1997; Herlitz & Rehnman, 2008; Hultsch, Masson, & Small, 1991; Krueger & Salthouse, 2010). Interestingly, other variants of episodic memory, such as visuospatial episodic memory (Lewin, Wolgers, & Herlitz, 2001) and autobiographical memory recall (Rubin, Schulkind, & Rahhal, 1999) have not necessarily reported gender differences. However, Davis (1999) in his series of studies found greater autobiographical memory recall favoring females only when the memory was highly emotional in nature.

Studies that report gender differences suggest that females possess better acquisition abilities, encode information using contextual cues that links separate events to aide recollection (especially autobiographical), make use of more “generation” techniques such as paying attention to more attributes of items to be remembered (e.g., phonological cues – word rhymes, or associating more meaning to words) that facilitates better recall (Bertsch, Pesta, Wiscott, & McDaniel, 2007; Krueger & Salthouse, 2010).

The presence of sex differences in memory processes has been attributed to neurobiological factors. For instance, Mozley, Gur, Mozley, and Gur (2001) in their research showed that dopamine levels in the brain and its uptake in the caudate and putamen found in the subcortical regions was higher in females, which in turn was significantly correlated with performance on a verbal memory task. Some mammalian studies suggest the interplay between sex hormones, particularly estrogen and its production and uptake of certain neurotransmitters in the forebrain areas, and synapse
formation in the hippocampal regions, both areas that are strongly implicated in learning and memory (Kimura & Hampson, 1994; McCarthy, Auger, & Perrot-Sinal, 2002; McEwen, 1999).

In terms of neuroimaging evidence, females are reported to have greater gray matter volumes that may be useful in higher order cognitive processes such as memory (Gur, Turetsky, Matsui, Yan, Bilker, Hughett, & Gur, 1999). In another study, although gender differences in episodic retrieval were not present, there were significant differences in the activation levels of certain brain regions during retrieval. Significant differences were noticed in terms of selective increases in the anterior cingulate gyrus in females and in bilateral inferior frontal cortices in males during retrieval (Nyberg, Habib, & Herlitz, 2000). The same authors also found an interaction effect between inferior frontal area activation and memory testing. Females had a greater activation in this area at retrieval than at baseline however, males showed the opposite effect. This further supports the presence of differential functional neuroanatomical characteristics between the sexes.

**Handedness**: Handedness is considered as an individual difference variable because it represents hemispheric asymmetries which influence cognitive processes (Hellige, 1993). There are two ways of approaching handedness to study cognitive processes: a) Direction of handedness (left versus right handed) and, b) strength of handedness (consistent/strong versus inconsistent/mixed).

Direction of handedness has been used as an indicator of hemispheric asymmetry and its relation to specific cognitive strength of individuals for verbal and
visuospatial/nonverbal abilities (e.g., Kim & Levine, 1991b). For instance, right handers are more often left hemisphere dominant for language (e.g., Knecht, Drager, Deppe, Bobe, Lohmann, Floel, Ringelstein, & Henningsen, 2000).

Strength of handedness on the other hand, is in focus because of a strong body of neurological and behavioral evidence that has vouched for its validity. It is considered as a behavioral proxy for interhemispheric communication based on the following set of studies.

Early studies suggested a strong association between increased corpus callosum sizes and inconsistent handedness (Habib, Gayraud, Oliva, Regis, Salamon, & Khalil, 1991; Witelson, 1985; 1989). Around the same time, the Hemispheric Encoding and Retrieval Asymmetry (HERA) model was proposed that showed lateralization differences in verbal episodic memory. Specifically, encoding of verbal episodic memories was associated with the left prefrontal cortex (PFC), and retrieval of the information was associated with the right and/or bilateral prefrontal cortices (Fletcher, Frith, Grasby, Shallice, Frackowiak & Dolan, 1995; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). The HERA model is additionally confirmed by an event related potential (ERP) study that assessed verbal long term memory (Friedman & Johnson, 2000) and an electroencephalogram (EEG) study that used visuo-spatial contents (Babiloni, Vecchio, Cappa, Pasqualetti, Rossi, Minuissi, & Rossini, 2006). A recent study showed strong associations between the encoding and retrieval asymmetry in episodic memory and the size of the anterior corpus callosum, further asserting the role of structural connectivity between hemispheres and episodic memory processes with frontal lobe involvement (Kompus, Kalpouzos, &
Westerhausen, 2011). Together, these findings provide evidence for the probable role of the corpus callosum in the interhemispheric exchange of information.

Given the set of observations between handedness, and the corpus callosum and their roles in episodic memory, behavioral studies were undertaken to explore the association between strength of handedness and episodic memory. These studies have used both non-clinical tests of recall not necessarily normed and are most often an adaptation from past experimental works (e.g., Christman & Butler, 2011; Christman, Propper, & Dion, 2004) as well as standardized memory tests used for the clinical population such as the paired associates from the Wechsler Memory Scale (WMS)-III and the California Verbal Learning test (CVLT)-II (Chu, Abeare, & Bondy, 2011; Lyle, McCabe, & Roediger, 2008). The following is an overview of all direct and indirect evidence that show the role of strength of handedness in episodic memory retrieval.

In the normal population, inconsistent handers have greater retrieval of explicit episodic information (Lyle, et al., 2008; Propper & Christman, 2004), fewer false alarms in memory recall (Christman, et al., 2004; Propper, Christman, & Phaneuf, 2005), better capacity for autobiographical memories (Christman, Propper, & Brown, 2006) with a higher recollection of autobiographical events in relation to sensory modalities of seeing, hearing and emotion based on a self report measure (Parker & Dagnell, 2010), and show deeper levels of processing during learning and better incidental learning (Alipour, Aerab-Sheybani, & Akhondy, 2012; Christman & Butler, 2011). These findings suggest that inconsistent handers possess greater access to information from the right hemisphere (using HERA model as the reference) during retrieval and therefore tend to have better
recall in episodic memory tasks. A significantly better episodic memory in inconsistent handers may be due to increased abilities to monitor source memory (Christman et al., 2004), and integrate information along with the content required to be remembered/recalled and the context during memorizing (Propper & Christman, 2004; Propper et al., 2005).

The behavioral findings, and the association of strength of handedness with the corpus callosum, together may imply that inconsistent handers are functionally less lateralized (that is, they may possess increased symmetry) and therefore have greater inter-hemispheric communication as represented by callosal volumes (Luders, Cherbuin, Thompson, Gutman, Antsey, Sachdev, & Toga, 2010).

Another set of findings further support the ideas on increased symmetry and inconsistent handedness. Studies on bilateral saccadic eye movements provide further evidence for the association between interhemispheric interaction and strength of handedness. Bilateral eye movements are known to induce bilateral activity in the frontal eye fields located in the precentral areas of the frontal cortex (Petit & Haxby, 1999; Rosano, Krisky, Welling, Eddy, Luna, Thulborn, & Sweeney, 2002). When individuals indulged in a short exercise (for about 30 seconds) of saccadic eye movements prior to item recognition, they were significantly better at discriminating between old and new stimuli words on the list (Christman, Garvey, Propper, & Phaneuf, 2003) and possessed associative recognition. The latter condition requires an individual to study pairs of words, and is later expected to correctly identify the list of paired words that they read during the initial exposure from word pairs that are incorrectly arranged (Parker, Relph,
& Dagnall, 2008). Other studies that followed the eye movement methodology, reported significantly lower incidence of false memories in the Deese-Roediger-McDermott paradigm (Christman, et al., 2006), greater delayed recall of episodic memories that were recorded by participants two weeks prior to the eye movement condition inducement (Christman, et al., 2003) and in the non-verbal episodic memory domain, greater recall for location and spatial memory (Brunyé, Mahoney, Augustyn, & Taylor, 2009). Additionally, eye movement conditions resulted in improved judgment in reporting memory for events such as staged crime scenes by corroborating more details that help discriminate between seen and unseen details about the scene. This finding thereby extends support for eye movement application in the real world of eyewitness testimony (Lyle & Jacobs, 2010). To further ascertain the effectiveness of the bilateral saccadic eye movement condition, other eye movement conditions such as smooth pursuits or vertical eye movements did not show such effects (Christman, et al., 2003; Parker et al., 2008).

Interestingly, when strength of handedness is factored in with saccadic eye movement in memory studies, it is noticed that consistent handers are benefited, such that their memory performance is similar to the inconsistent handers. Contrary to expectations, inconsistent handers do not show improvement in their performance in tests of recall but instead showed increased number of false alarms on recognition in the saccadic eye movement condition (Lyle, Logan, & Roediger, 2008).

These studies strongly imply that bilateral eye movements help in increasing interhemispheric interaction by activating the prefrontal cortices with perhaps greater integration of information specific to each hemisphere that aide in better episodic memory recall (Christman, et al., 2003, 2004). Since eye movements bring consistent
handeds to the level of inconsistent handers in terms of performance, could further imply that inconsistent handers may already possess a synchronous activity between hemispheres at the outset. The possibility of increased false alarms in inconsistent handers following eye movements could be a result of an overactive synchronicity between the hemispheres that could be causing excess retrieval of information that may be unrelated to the stimuli under study (Lyle, et al., 2008).

Handedness and white matter

Although already indicated in the previous subsection, this section is specifically dedicated to the implications of handedness research in cognitive processes as a function of white matter characteristics in the brain.

It is suggested that white matter in the frontal areas have extensive reciprocal connections to the other lobes and subcortical region (Filley, 1996). In addition, the ratio of white to grey matter is larger in the right frontal areas as compared to the left, and this has great relevance for cognitive processes that depend on these areas (Gur, Packer, Hungerbuhler, Reivich, Obrist, & Amarnek, 1980). Three types of white matter tracts that correspond to their pathways in the brain have extensively been studied. These are: Projection (sensory and motor functions), association (connect intrahemispheric gray matter structures) and commissural (corpus callosum - interhemispheric connections). Association and commissural fibers play an important role in cognitive and emotional processes (Filley, 2010). Cognitive functioning is a consequence of not only the information processing ability of the gray matter, but also the efficient transfer of
information by means of an expansive white matter network within and between brain hemispheres (Filley, 1998, 2010).

Initially, the finding between strength of handedness was restricted to the corpus callosum (Denenberg, Kertesz, & Cowell, 1991; Habib et al., 1991; Witelson, 1985, 1989) with the most recent study with a large sample echoing the negative association between strength rather than direction of handedness and the corpus callosum size (Luders, et al., 2010). However, more recent literature has explored white matter characteristics in other areas of the brain in relation to handedness. A study on language areas showed a significant asymmetry in the arcuate fasciculus (the white matter tract that connects the Broca’s and the Wernicke’s areas) of the two brain hemispheres in the consistent handed group. Although, the finding was not significant in the inconsistent handed group in combination with greater symmetries, it is still worth noting that this group did not show a marked asymmetry in the arcuate fasciculus (Propper, O’Donnell, Whalen, Tie, Norton, Suarez, Zollei, Radmanesh, & Golby, 2010).

A study by O’Donnell, Westin, Norton, Whalen, Rigolo, Propper, and Golby (2010) presented preliminary findings on overall symmetric white matter in the brain in the inconsistent handed group and an asymmetric pattern in the consistent handed. These findings are based on a small sample, however, there is room to consider these results as this provides evidence for the link between inconsistent handedness and advantages in some cognitive processes (such as memory processes).

Together these findings show promise for considering strength of handedness as a behavioral marker for white matter (a)symmetries in the brain hemispheres and possibly
an important area that needs to be considered to account for individual differences in cognitive processes.

**Summary**

Studies suggest that in addition to gender, degree of handedness is also an important individual difference factor for episodic memory processes. Modulatory effects of these variables can be assessed if these are considered independently or in combination with one another.

Strength of handedness has progressively made a mark in accounting for individual differences. As discussed above, it has been considered as a behavioral index for interhemispheric interaction that plays a vital role in episodic memory processes. However, it is also a well-known fact that long term memory (LTM) episodic in nature is dependent on short term memory (STM) or the WM. The following section of the literature review covers the roles of episodic memory in WM.
Chapter Two

Working Memory

A) Introduction

Baddeley and Hitch (1974) characterized the STM store further by proposing a dynamic system called the WM, in which the system temporarily integrates, coordinates, and manipulates several pieces of information. Based on normal behavioral studies, they hypothesized that WM consists of three components: the central executive that allocates attention and co-ordinates between the two supplementary buffer systems: a) the phonological loop that deals with auditory/verbal forms of information and b) the visuo-spatial sketchpad that deals with visual/ location and spatial specific type of information. Baddeley (2000) subsequently added the “Episodic Buffer” as an important component to explain the missing link between LTM and WM components. It is proposed that this buffer integrates episodes/scenes, which are held spatially and for a temporary period of time, with material in the LTM by using different codes (visual/verbal).

WM is measured by several tests- typically, cognitive batteries that are standardized for clinical populations include tests such as digit span, letter number sequencing (these tasks are discussed at length in the methods section), spatial span (such as the Corsi Block tapping test, that requires the participant to mimic the order in which the examiner taps a set of blocks that are spatially separated from one another) and experimental paradigms test for WM are measured using paradigms such as the operation span, letter span (these tasks involve verification task and memorizing letters, and participants are assessed on the accuracy of both), the N back task (a task that requires recognizing if a number was repeated after a gap of either one or two numbers in a
continuous series). Clinical and experimental tasks are moderately to highly correlated with each other, suggesting the presence of common WM characteristics (Shelton, Elliot, Hill, Calamia, & Gouvier, 2009). Additionally, neuroimaging studies that have used various WM tasks unanimously suggest the involvement of the fronto-parietal network that involves the dorsolateral PFC, the ventrolateral PFC, frontal poles, premotor cortices and posterior parietal cortex (Owen, McMillan, Laird, & Bullmore, 2005). The cooperative efforts of these brain areas have been taken to reflect the central executive and the involvement of the buffer systems in the WM paradigm (Li, Qin, Zhang, Jiang, & Yu, 2012).

Specific activations in PFC areas during a WM task performance correspond with WM characteristics. Temporary storage of information during a WM task is localized to the posterior regions, whereas active rehearsal of the information is anteriorly localized (Smith & Jonides, 1997). These include increased activity in the dorsal PFC areas during the manipulation of information- a task specific to the central executive system (D’Esposito, Postle, Ballard, & Lease, 1999); activation in the left supramarginal gyrus and the Broca’s area and the right PFC during sub vocal rehearsal and active maintenance of spatial information, respectively (Paulesu, Frith, & Frackowiak, 1993; Smith & Jonides, 1997).

Most often than not, activation sites in the frontal cortex during a WM task are task dependent. For example, verbal WM are left frontal lateralized whereas visual/spatial WM tasks are right frontal based. However, it is also noticed that at times verbal WM (for tasks such as the LNS or increasing length of letter strings) shows a bilateral PFC involvement. This has been attributed to the difficulty levels of the task that
may be leading to using additional strategies (e.g., visualization) to cope with the task (Haut, Kuwabara, Leach, & Arias, 2000; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999). Bor, Cumming, Scott, and Owen (2004) in their study also demonstrated that using strategies (structured sequencing) led to bilateral frontal involvement while remembering strings of digits than when not using such a strategy, further alluding to the efficiency of strategies for higher WM recall. Gerton, Brown, Meyer-Lindenberg, Kohn, Holt, Olsen, and Berman (2004) found occipital activation during both digit forward and backward learning, an activation which is normally found when an individual is vividly remembering stimuli (Wheeler, Petersen, & Buckner, 2000).

In summary, activated areas in the brain are a result of the nature of WM tasks that are performed- the need for attention, holding on to information online, task switching, and even strategy use and reorganization. Furthermore, all of these processes are necessary for successful memory processes.

B) Role of Working Memory in Episodic Memory

Theories such as the search for associative memory (SAM; Raaijmakers & Shiffrin, 1981) and the retrieval context framework (Kahana, Howard, & Polyn, 2008; Kahana, Howard, Zaromb, & Wingfield, 2002) strongly suggest that episodic retrieval is directed well when an individual also retrieves contextual cues that were utilized during the encoding phase in memory paradigms such as free recall and word pair associations. In other words, during encoding, associations between the context in which the learning happened and the item contents are formed which facilitate an episodic representation (Spillers & Unsworth, 2011). In doing so, the role of WM is strongly implicated. WM is
required to maintain new information in the presence of distractions, and in discriminating between relevant and irrelevant information by using contextual cues that were used during encoding and accordingly retrieving the information (Unsworth & Engle, 2007). Research suggests that low WM capacity individuals report fewer items at free recall, show more intrusions from previous trials during a list learning task, recall at a slow rate (Unsworth, 2007) and are disorganized in their approach while recalling (Spillers & Unsworth, 2011). In both, incidental and intentional learning conditions, high WM capacity individuals performed significantly better (Unsworth & Spillers, 2010) because of increased use of contextual cues and maintaining the use of same cues during both encoding and retrieval processes (Spillers & Unsworth, 2011; Unsworth, Brewer, & Spiller, 2011; Unsworth, & Spillers, 2010). This was tested by mismatching cues between encoding and retrieval conditions. Consequently, high WM capacity individuals’ performances were greatly compromised, and their performances resembled the low WM capacity individuals at retrieval. WM capacity has also been implicated in strategic retrieval of information as assessed by cluster size of a semantic fluency task (Rosen & Engle, 1997). The fluency task requires generation of words in a limited period of time, and therefore depends on semantic memory. Essentially, WM capacity seems to influence the type of strategy (active vs. associative and passive) adopted in searching for words in a fluency task and in selecting responses, both processes which are associated with PFC functioning.

Specifically, it is the central executive that seems to be playing the crucial role in dealing with the incoming stimuli for further processing. It not only performs the key roles of monitoring, processing and manipulating information but also allocates work to
the slave systems, and co-ordinates between them (if both are engaged for working on a laborious task).

Neuroimaging studies confirm the involvement of the same PFC areas for both WM and LTM tasks. Specifically, an overlap was found between WM and LTM in three areas of the PFC: the dorsolateral PFC, ventrolateral PFC and anterior PFC (Cabeza, Dolcos, Graham, & Nyberg, 2002; Ranganath, Johnson, & D’Esposito, 2003). Likewise, Nyberg, Marklun, Persson, Cabeza, Forstam, Petersson, and Ingvar (2003) found common activations in four areas of the PFC across WM, episodic memory and semantic memory. They suggested that these may signify underlying latent factors for all three types of memory processes, which include maintaining and updating information, performing effortful tasks, and monitoring and selecting responses. Taking all these findings together, it was speculated that the PFC is required in maintaining information in WM, which in turn is needed for LTM formation (Ranganath, Cohen, & Brozinsky, 2005).

C) Individual differences in Working Memory

Having discussed the role of WM in LTM, it is also important to know if individual differences play a role in WM as they have been in episodic memory. This section deals with gender, and handedness influences in the area of WM. In addition, this section needs mention because it will complete the goal of the study that seeks to understand the links between handedness and episodic memory.
**Gender/sex:** Some behavioral studies have shown gender differences in WM tasks however, there continues to be an influx of inconsistent results. While a recent study showed no gender difference either at the behavioral or neural level for an N back task (Schmidt, Jogia, Fast, Chirstodoulou, Haldene, Kumari, & Frangou, 2009), some past studies have shown that males outperform females in digit span (Lynn & Irwing, 2008), arithmetic and LNS (Sluie, Posthuma, Dolan, de Gaus, Colom, & Boomsma, 2006) and are quicker at tests of visospatial WM (Loring-Meier & Halpern, 1999). Neuroimaging studies provide evidence on gender asymmetries with females showing more extensive brain network activation than males, but interestingly no significant gender differences were noticed in the accuracy of performance (Goldstein, Jerram, Poldrack, Anagnoson, Breiter, Makris, Goodman, & Tsuang, 2005; Speck, Ernst, Braun, Koch, Miller, & Chang, 2000). The presence of gender asymmetries may therefore be reflective of the manner in which a WM task is performed with males taking a “problem solving” approach or may be reflective of gender asymmetries in the underlying neural organization (Speck, et al., 2000).

**Handedness:** The role of handedness in WM has been addressed by few studies in the recent past, however there are mixed results. While one recent study reported significantly better immediate memory span in the inconsistent handed young adult population (Sahu, 2010, unpublished thesis), other studies have not shown this significance although inconsistent handers had nominally higher scores than the consistent handers (Gunstad, Spitznagel, Luyster, Cohen, & Paul, 2007; Lyle, et al., 2008).
Past neuroimaging studies have illustrated a bilateral frontal involvement especially with demanding WM tasks such as LNS. There may be reasons to believe that handedness would have links with WM. WM tasks that are demanding in terms of load, and require manipulation of the data while maintaining it, may require interhemispheric interaction. In addition, if past studies have shown the links between handedness and episodic memory, it remains to understand if the association between WM and episodic memory is actually a function of handedness.

**Summary**

Literature acknowledges the roles of WM especially during the initial learning of episodic memory information. Similarities between the two constructs exist in terms of the brain regions recruited for their roles. However, if both WM and LTM episodic memory are evaluated together, it would clarify how individual difference variables (e.g., gender asymmetries) differentially affect both the memory processes. In terms of handedness, although there are limited findings on its effects in WM, there seems to be a convergence of evidence on an inconsistent hand advantage in both WM and episodic memory. This therefore has been the driving force behind the current study. In keeping with the scope of the current study, handedness (and gender if there are significant differences) as individual difference variable(s) will be considered along with simple and complex working memory processes to check for their individual and/or combined contributions on episodic memory retrieval.
Chapter Three

Rationale for the Study

Review of literature has covered three independent yet related ideas. First, individual differences have an important role to play in cognitive processes. Second, an association between strength of handedness and retrieval of episodic memories is demonstrated by several studies. Handedness is shown to be associated with the white matter in the brain and therefore is deemed as a behavioral representation of interhemispheric interaction (and based on the more recent findings, perhaps a behavioral proxy for white matter (a)symmetry in the brain) and greater access to information from the right hemisphere during retrieval. Third, studies have shown a direct relationship between WM capacity, and the number of individual entities that can be encoded, and the retrieval of information at immediate and delayed intervals that depends on the LTM.

Handedness and episodic memory are shown to be associated with one another; however, the role of WM in this association has largely remained unexplored. In keeping with the evidence in the existing framework of memory processes, the following were goals were proposed in the study.

a) Primarily, the study is an extension of past studies that have shown independent roles of handedness and WM in episodic memory. The study aimed to clarify the route of the association between handedness, WM and episodic memory. If handedness is linked to episodic memory, then WM will be a part of the association because of its integral role in memory processes. In other words, WM would mediate between handedness and episodic memory. If this association is present, it could also be proposed that handedness may have a role to play in encoding processes in the memory paradigm.
However, it could also be possible that both handedness and WM are dissociated from one another in the retrieval of episodic memory. If such is the case, then it can be proposed that WM is a cognitive process that plays a role during encoding (or temporarily holding on to information for a short period of time while its being remembered, rehearsed and entered into the LTM) of the to be learned information. Handedness, on the other hand, would be exclusively related to episodic memory process because of a greater access to right hemisphere during retrieval of episodic memories, as has been proposed previously based on experimental evidence.

Regardless of the direction/path the model takes, this study would furnish potentially missing information to the existing knowledge on the role of handedness in memory processes. While most studies have concentrated on retrieval processes, very few have addressed the role of handedness in encoding processes. By means of a path model, which incorporates WM that has shown its crucial role in memory, this issue can be thus addressed.

b) Along way, the study aimed to check for handedness differences in WM and episodic memory tasks respectively. Specifically, it aimed to seek a clarification on whether handedness differences are present for simple immediate WM storage capacity and/ or complex WM tasks that entail both maintaining information (storage) and indulging in simultaneous secondary processing of tasks. In terms of episodic memory, the current study aimed to replicate findings from past studies that have repeatedly shown the association between this process and handedness. Although a couple of studies in the past have used standardized tasks such as the CVLT, and WMS-III, the current study used the latest episodic memory task from the 4th edition of the WMS battery.
Chapter Four

Hypotheses

1) Inconsistent handers will significantly score better on both WM tasks than consistent handers.

This hypothesis is based on past studies that have shown an advantage for inconsistent handers in immediate memory span (Sahu, 2010; unpublished thesis). In addition, Kempe, Brooks, and Christman (2009) in their study have shown an inconsistent handedness advantage in foreign language acquisition, alluding to the involvement of the WM in learning and recalling words.

2) There will be no gender differences in WM and episodic memory task performances.

As mentioned in the literature review, past studies on gender asymmetries in WM and episodic memory performances have shown mixed results. As far as WM is concerned, a past study that used digit span showed a male advantage (Lynn & Irwing, 2008) however, a recent study failed to replicate those results (Sahu, 2010, unpublished thesis). Studies on handedness and episodic memory have also not shown gender differences (e.g., Christman, et al., 2004; Lyle, et al., 2008) however, a few studies have reported a female advantage in verbal episodic memory (e.g., Geffen, et al., 1990; Herlitz, et al., 1997). This analysis will therefore be performed to check if gender is modulating the handedness effects in WM and episodic memory processes. If gender differences are absent, final statistical analyses will not incorporate this variable.
3) Handedness and WM will show strong associations with immediate and delayed episodic memory recall. In addition, the association between handedness and episodic memory will be mediated by WM.

Past research has shown a robust connection between episodic memory and handedness, with inconsistent handers showing a significantly greater recall than consistent handers (e.g., Lyle, et al., 2008; Propper, et al., 2004) and a promising association between handedness and WM (Gunstad, et al., 2007; Kempe, et al., 2009). In considering all three variables, this hypothesis will be tested using structural equation model to check for the dynamics of the associations, by examining direct and indirect relations between independent variables – handedness, immediate memory capacity, and complex WM on the outcome variable- episodic memory. The path analysis will consider the WM tasks as the mediators (indirect effect) between handedness and episodic memory as well as specify direct links between handedness and WM to episodic memory, respectively.
Chapter Five

Methods

Sample

Data were collected from undergraduate participants who belonged to the Principles of Psychology course. They received research credit (or in some cases extra research credit) towards their course. The study was open to all students who were above the age of 18 years. A total of 210 psychology students participated in the study.

Materials

Handedness Inventory

The Edinburgh Handedness Inventory (EHI; Oldfield, 1971) was administered in order to obtain the strength of handedness score. The handedness questionnaire asks about one’s hand preference for performing everyday activities such as - writing, throwing, drawing, brushing teeth, etc. Each activity has a frequency scale (and their corresponding valence) as follows: Always right (+10), usually right (+5), no preference (0), usually left (-5) and always left (-10).

As has been practiced in past studies, handedness groups were determined based on a cut-off score using the median split method. Christman, et al. (2004) defined inconsistent handers as those scoring below the cut-off score whereas those who score above the cut-off are categorized as consistent handers.
Working Memory Tasks

1) Digit Span (DS) Task

The digit span is part of the Wechsler Adult Intelligence Scale – IV (WAIS-IV) battery that measures storage capacity of the WM. The test consists of forward and backward immediate recall of numbers. Each number was read out from the list at a pace of 1 digit per second. Two trials were presented for each string of numbers. The maximum possible raw score on the forward is 9 whereas on the backward span is 8 (minimum = 2 for both spans). A combined score for both forward and backward spans comprised the total score.

2) Letter Number Sequencing (LNS) Task

This test belongs to the WAIS-IV battery and measures complex WM task. It requires a participant to reorder an unordered set of letters and numbers and report all numbers in order, starting with the lowest followed by the letters in an alphabetical order. E.g., the participant was read the series- 1-C-4-F-7-Z-2, and was expected to report in the following sequence 1, 2, 4, 7, C, F, Z (Per the standardized version, recalling the letters first and then the numbers, was also accepted and scored accordingly). In this task, one needs to hold on to information and manipulate it to present them in the required order. Each series of letters and numbers have three trials. The maximum number of letter number sequence trials that can be achieve is 30 (minimum = 3).

(Note: A couple of trials in the LNS task contain the letter ‘V’. During the pilot testing sessions, the letter was heard as ‘B’ by a few participants that led to an interrupted
performance; therefore, ‘V’ was duly replaced by the letter ‘Z’ to avoid phonetic confusion.

Memory Task

Verbal Paired Associates (VPA)

The VPA is a verbal memory test from the Wechsler Memory Scale- IV (WMS-IV) that consists of fourteen word pairs of which ten pairs are unrelated and therefore are not necessarily easy to remember instantly (e.g., day-box), whereas the rest are related and therefore easy to remember (e.g., sky-cloud). After reading out the list, the participant was read the first word of each pair, and he/she was required to respond with the corresponding word of that pair. Per the standardized protocol for this test, if the participant gave an incorrect response or did not give an answer within five seconds, the correct response was provided. The list was read four times and the same feedback format was maintained for all four trials. Total scores across all four trials were considered as immediate recall or the learning curve on this task. Delayed recall was obtained 12-16 minutes after the administration of the test. A recognition task was also administered after the delayed recall.

Procedure

Participants were tested individually. After signing the informed consent form for the study, the participant’s demographic details (age, gender) were recorded. Following this, the test battery was administered. The immediate recall of the VPA task was administered first. The delayed recall was recorded about 12-16 minutes after the last trial
of the immediate recall, which was towards the end of the study. The WM tasks and the
handedness questionnaire were administered during the gap between the fourth trial and
the delayed recall of the VPA. After completing the study, the participant was also asked
about strategies they may have adopted for the WM tasks. They were then debriefed and
escorted out of the testing laboratory.
Chapter Six

Statistical Analyses

Primary Analyses

- Descriptive Statistics

All data were screened for missing data, outliers and membership to the specified age group (18 years to 30 years) for the study. Descriptive statistics that include the mean, standard deviation (SD), and skewness and kurtosis values were calculated for the WM tasks, the total immediate VPA recall scores and delayed scores.

- Parametric Analyses

- WM analyses
  a) A 2 x 2 x 2 mixed Analysis of Variance (ANOVA) was conducted with handedness and gender as the between subjects variables and digit span – forward and backward raw scores as the within subject variable.

  b) A 2 x 2 between subjects ANOVA was performed with handedness and gender as the between subjects variables and the total raw score on the LNS as the dependent variable.

- Episodic memory analyses
  a) A 2 x 2 x 2 mixed ANOVA was performed with handedness and gender as the between subjects variables and the total raw score on the immediate recall across four trials and the delayed recall of the VPA as the within subject variable.
b) A 2 x 2 x 2 mixed ANOVA was performed with handedness and gender as the between subjects variables and the first trial and the delayed recall of the VPA as the within subject variable.

- SEM analysis

One of the primary goals of SEM analysis is to check for how the proposed theory based on constructs explains the data and to understand the dynamics between variables on the whole in addition to also assessing single paths drawn between variables. SEM was therefore attempted in view of the robust independent associations between handedness and WM in episodic memory.

SEM analysis involves six steps.

a) Specifying a model (based on prior theory and past research)

b) Determining whether the model is identified (for the software to estimate model parameters)

c) Selecting measures for variables represented in the model and collecting data

d) Analyzing the model

e) Evaluating the model (how reflective is the model of the data; if the model does not fit the data, the next step is performed)

f) Re-specifying the model after evaluating the model fit criteria and re-running the model on the same data

There are several methods for estimation employed in SEM analyses. One of the most commonly used and a default estimation procedure is the Maximum Likelihood Estimation (MLE). This method simultaneously estimates paths in the model. It makes every attempt to pick estimates that are reflective of the observed covariance
(unstandardized form of correlation) in the data. In other words, it identifies parameter values to achieve model fit (Hair, Black, Babin, Anderson, & Tatham, 2010).

The proposed model has one latent variable (episodic memory) with three indicator variables (trial one, total scores across four trials and delayed recall of the VPA task). One of them was fixed with the assignment of the value of 1.0 by convention. The fixed parameter is used as a constant for estimating other variables (Kline, 2005). In addition to fixing one indicator variable, error terms are also fixed. Fixing parameters is closely related to the concept of model identification—deriving unique estimates for parameters if the model is theoretically justified (Kline, 2005). In other words, the concept of identification is based on whether adequate amount of information is present to seek a solution for a set of equations that define a model (Hair, et al., 2010).

As part of the SEM analysis, standardized path coefficients (parameters in the model) are provided. Each path coefficient/parameter has its own standard error (SE), and dividing the parameter by its SE, results in a $z$ test value. If the parameter’s value is above 1.96, then it is considered statistically significant (Byrne, 2009).

SEM analyses also provide fit indices. These help in evaluating the validity and acceptability of the model. It is recommended that a group of fit indices be considered for model evaluation. This is because, at times fit indices are sensitive to and therefore do not account for factors such as sample size, degrees of freedom, the number of indicators and even the type of outcome variables in the model (continuous vs. categorical). This could therefore lead to the rejection of a hypothesized model that may actually be a true reflection of the real world. Evaluating a group of fit indices therefore helps in making some educated decisions about the model.
There are several fit indices available to evaluate the model, and the ones that are most frequently referred to, were used in the current study. They are as follows:

a) **Chi-square Goodness of fit index**: measures the difference between the observed and estimated correlation matrix. A smaller difference value is desired as it implies that the observed correlations are not significantly different from the estimated ones. However, this index has certain drawbacks, because, it is not interpreted in a standardized form and is sensitive to sample size.

b) **Root Mean Square error of approximation (RMSEA)**: This index indicates whether a model can fit the hypothetical population covariance system. Acceptable values are considered to be between 0.00 and 0.08 (with a 95% confidence interval). Smaller values (closer to 0) indicate a good fit.

c) **Comparative Fit index (CFI)**: This index helps in deciding whether the model that is being tested is better than a null model (model with no specified relationships). CFI values can range from 0 to 1, and a value of 0.95 and greater suggests a good model fit.

d) **Tucker Lewis Index (TLI)**: This index considers model complexity and compares the estimated model to the null model. TLI values range from 0 to 1 and those values that are closer to 1 demonstrate a good model fit.

Models in SEM can be respecified if model indices are inadequate and do not match with the benchmarks mentioned above. At times, model fit could be present
however there may be some error in the model that may not have been accounted for apriori (for example, accounting for the covariance between measurement errors between certain variables). In this case, it becomes necessary to check for modification indices (MI). These point out to the presence of multicollinearity or high correlations in the error terms between variables. Large MI values are of concern; however these also make way for adding a path in the model for improved fit of the model (Kline, 2005). MI can be considered if and only if they are theoretically justified. The aforementioned fit indices are strongly recommended when the model is modified (Schrieber, Nora, Stage, Barlow & King, 2006).

Tests that were employed to assess WM and episodic memory in the current study are reported to have robust psychometric characteristics. The LNS task has an overall split half reliability coefficients of 0.88 (Wechsler, 2008a). Digit span forward and backward have a split half reliability of 0.81 and 0.82 respectively. Criterion-related validity between the previous version of the WMS (WMS-III) and WAIS-IV digit span is 0.57 (Wechsler, 2009). The VPA test-rest reliability (averaged across age groups from 16-69 years) coefficients for immediate and delayed recalls are 0.94 and 0.85 respectively (Wechsler, 2009). Concurrent validity between VPA total words at immediate recall across four trials and CVLT-II total words at immediate recall across five trials is reported to be 0.54. A correlation of 0.51 is reported between CVLT-II delayed and VPA- delayed recalls (Wechsler, 2009).
Secondary (Exploratory) Analyses for WM

Although these secondary analyses were not proposed at the outset of conducting the study, qualitative data was collected as part of the study and these are being incorporated to corroborate the primary analyses on WM.

Prior to debriefing, participants were asked about the possible strategies they may have used while performing the simple and complex WM tasks. First, they were asked an open ended question about how they remembered the stimuli in the forward and backward conditions of the digit span and the LNS task. If they could not verbalize the strategy used, the following was asked:

a) For the digit span task, participants were asked if they were grouping the series of numbers into units of 2’s, 3’s, or 4’s (similar to a telephone number).

b) For the LNS task, participants were asked if they were arranging the string of letters and numbers while listening to the series or if they waited for the entire string of letters and numbers to be read out before arranging them in the expected order.

Responses to the above questions were coded dichotomously as they were considered as independent variables and were subjected to a between subjects’ ANOVA method.

a) A 2 (handedness) x 2 (grouping strategy) ANOVA was conducted separately for forward and backward digit spans.

b) For the LNS task, a 2 (handedness) x 2 (arranging the letter, number string strategy) ANOVA was conducted.
Chapter Seven

Results

Descriptive Statistics

Data screening

Three participants were excluded from the analyses, as they did not belong to the proposed age group of 18-30 years, thus the sample size was reduced to 207. There were no missing data. Data screening techniques were adopted to screen for univariate and multivariate outliers in keeping with the proposed analyses.

Univariate outliers

Descriptive statistics data for the entire sample on the outcome variables that include digit span forward, backward, total scores on the letter number sequencing, scores on the first trial of the VPA, total VPA scores and delayed recall scores on the VPA are presented in table 1.

Although the skew and kurtosis values of the outcome variables are within limits (except for the delayed recall of the VPA), z scores for all were calculated to check for values above three SDs from the mean ($z = 3.29$). One participant had a $z$ score of -3.77 in the total scores on VPA; and two participants had a $z$ score of -3.61 in the delayed recall of VPA.
Table 1: Descriptive statistic data of the measured variables (N = 207)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
<th>Skew</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS - Forward</td>
<td>6.88</td>
<td>1.10</td>
<td>0.10</td>
<td>-0.52</td>
</tr>
<tr>
<td>DS - Backward</td>
<td>5.31</td>
<td>1.04</td>
<td>0.48</td>
<td>-0.08</td>
</tr>
<tr>
<td>DS - Total</td>
<td>12.20</td>
<td>1.79</td>
<td>0.40</td>
<td>0.03</td>
</tr>
<tr>
<td>Total LNS</td>
<td>21.62</td>
<td>2.47</td>
<td>0.30</td>
<td>-0.04</td>
</tr>
<tr>
<td>First trial of VPA</td>
<td>6.43</td>
<td>2.52</td>
<td>0.22</td>
<td>-0.07</td>
</tr>
<tr>
<td>Total VPA</td>
<td>42.02</td>
<td>7.43</td>
<td>-0.73</td>
<td>0.30</td>
</tr>
<tr>
<td>VPA - Delayed recall</td>
<td>12.95</td>
<td>1.65</td>
<td>-1.62</td>
<td>1.80</td>
</tr>
<tr>
<td>Total VPA (with replaced</td>
<td>42.05</td>
<td>7.33</td>
<td>-0.63</td>
<td>-0.17</td>
</tr>
<tr>
<td>univariate outlier score)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VPA - Delayed recall (with</td>
<td>12.96</td>
<td>1.61</td>
<td>-1.54</td>
<td>1.28</td>
</tr>
<tr>
<td>replaced univariate outlier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>scores)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: VPA = verbal paired associates; DS = digit span; LNS = letter number sequencing; SD = standard deviation

Despite their outlier status, these scores were retained for the main analyses. The following were the justifications for their inclusion:

1) Significant issues in univariate and multivariate analyses occur when skew values of 2 and above, and kurtosis values of 7 and above are present (Curran, West & Finch, 1996). This is not the case in the current study, as the skew and kurtosis values for total VPA scores are below the proposed benchmarks.
2) Case by case evaluation of the outlying values:

a) The participant with the lowest learning scores on the VPA: If the participant had a poor recall during delayed recall such that the score was below a z score of -3.29, then there would be reason to believe that there was a problem in the consolidation of information during learning and the data point truly belongs to a different population. However, this was not the case, as this participant recalled 10 out of the 14 word pairs correctly (within 2 SDs) during the delayed recall phase.

b) The two participants who obtained a z score of -3.61 (raw score of 7) were the lowest on delayed recall. The negative skew is in fact reflective of a ceiling effect (i.e. correctly recalled all the 14 word pairs) obtained by a majority (60%) in the sample. Relatively speaking therefore, the low score is poorly projected. In addition, the distribution would continue to remain skewed regardless of whether these scores are discarded or retained.

In view of the decision of retaining these relatively few (1.4%) outliers for the analysis, one of the ways that was chosen to deal with them was by replacing their current values into new values that were exactly three SDs away from the outcome variables’ respective means (Kline, 1998).

**Multivariate Outliers**

Mahalanobis distance $D^2$ statistic was calculated to check for multivariate outliers. This statistic helps in detecting whether a participant is responding differently compared to the rest of the group on different dimensions, and these show up as extreme scores on two or more variables (Tabachnick & Fidell, 2000). Handedness absolute
scores, digit span total scores and letter number sequencing scores were used as the three predictors (as these were considered in the SEM analyses) on a dummy variable as the outcome variable. Mahalanobis distance $D^2$ values were evaluated using $\chi^2 (3, N = 207) = 16.27$, $p = 0.001$. No value was found at or above this threshold.

The final analyses was performed on a sample of 207 participants ($\text{Mean age} = 19.18$, $\text{SD} = 1.364$; $\text{males} = 88$). The median split method on the absolute scores of the EHI produced a median score of 80, which was treated as the cut-off point for dividing the group into consistent ($n = 122$) and inconsistent handers ($n = 85$; EHI absolute score $< 80$).

Parametric Analyses

The following are the parametric analyses results for WM and episodic memory.

**WM analyses**

a) A $2 \times 2 \times 2$ mixed ANOVA was conducted to assess the roles of handedness and gender on simple WM ability as assessed by the digit span forward and backward tasks from the WAIS-IV battery. There was a significant main effect for digit span, $F (1,203) = 347.34$, $p = 0.001$, $\eta^2_p = 0.64$, with digit span forward performance ($M = 6.90$) being significantly better than backward performance ($M = 5.31$). Interaction effects between digit span and gender, digit span and handedness, digit span, gender and handedness, and gender and handedness, were not significant ($F < 1$). Main effects for gender, and
handedness, were also not significant ($F < 1$), suggesting that both gender and handedness groups performed similarly on this task.

![Figure 1: Gender differences on mean scores of complex WM as measured by the Letter number sequencing (LNS) task](chart.png)

Figure 1: Gender differences on mean scores of complex WM as measured by the Letter number sequencing (LNS) task

b) A $2 \times 2$ between subjects ANOVA was conducted to assess the roles of handedness and gender on complex WM as measured by the LNS task. As presented in figure 1, there was a main effect of gender, $F(1,203) = 8.50, p = 0.004, \eta^2_p = 0.04$, with males ($M = 22.14$) outperforming females ($M = 21.18$) in complex working memory. Main effects of handedness, and interaction effect between handedness and gender, were absent ($F < 1$).
Table 2: Mean (SD) of the outcome variables used in the study factored by handedness groups (N = 207)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Inconsistent Handed</th>
<th>Consistent Handed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.80 (1.09)</td>
<td>6.94 (1.12)</td>
</tr>
<tr>
<td>DS- Forward</td>
<td>5.25 (1.08)</td>
<td>5.36 (1.01)</td>
</tr>
<tr>
<td>DS- Backward</td>
<td>12.05 (1.83)</td>
<td>12.30 (1.77)</td>
</tr>
<tr>
<td>Total score on the LNS</td>
<td>21.55 (2.47)</td>
<td>21.67 (2.48)</td>
</tr>
<tr>
<td>Trial 1 VPA</td>
<td>6.92 (2.37)</td>
<td>6.10 (2.57)</td>
</tr>
<tr>
<td>Trial 2 VPA</td>
<td>10.89 (2.25)</td>
<td>9.96 (2.70)</td>
</tr>
<tr>
<td>Trial 3 VPA</td>
<td>12.27 (2.05)</td>
<td>12.08 (2.18)</td>
</tr>
<tr>
<td>Trial 4 VPA</td>
<td>13.25 (1.23)</td>
<td>12.98 (1.71)</td>
</tr>
<tr>
<td>Total VPA scores</td>
<td>43.33 (6.66)</td>
<td>41.16 (7.66)</td>
</tr>
<tr>
<td>VPA-Delayed recall</td>
<td>13.13 (1.54)</td>
<td>12.84 (1.71)</td>
</tr>
</tbody>
</table>

Note: **VPA = verbal paired associates; DS = digit span; LNS = letter number sequencing; SD = standard deviation

Episodic memory analyses

A 2 x 2 x 2 mixed ANOVA was proposed to assess the roles of handedness and gender on episodic memory as measured by the total raw scores on the immediate recall across four trials and the delayed recall of the VPA. The choice of the two parameters for episodic memory was decided as such because they were considered as an adequate representation of episodic memory as a function of time (immediate recall followed by a delayed recall condition after a gap of 10-16 minutes).
However, prior to running the ANOVA, a correlation was attempted on the three variables that comprise episodic memory (first trial of VPA, total scores of VPA and the delayed recall) to check for the presence of multicollinearity. As seen in table 3, scores on total scores correlated highly with the first trial and delayed recall with coefficients of 0.79 and 0.77 respectively. In order to avoid the multicollinearity issue, the first trial on the VPA and the delayed recall scores were considered for this mixed ANOVA.

Figure 2: Mean scores across the immediate (T1 to T4) and delayed recalls for the Verbal paired associated (VPA) task between handedness groups

A main effect of episodic memory was present, $F(1, 203) = 1503.17, p = 0.0001, \eta^2_p = 0.881$, with performance on delayed recall being better ($M = 12.96$) than the first trial on the VPA ($M = 6.43$). A main effect of handedness was present, $F(1,203) = 4.49, p = 0.035, \eta^2_p = 0.02$, with inconsistent handers outperforming consistent handers significantly in the recall of word pairs. Specifically, test of simple main effects showed
that recall on Trial 1 on the VPA by inconsistent handers \((M = 6.92)\) was significantly better than consistent handers \((M = 6.10)\), \(F(1,205) = 5.41, p = 0.02\). However, test of simple main effects for delayed recall was not significant, \(F(1,205) = 1.57, p = 0.21\). A graphical presentation of these scores are seen in figure 2 that shows an inconsistent handed advantage in the initial trials of learning.

Main effect of gender \((F < 1)\), interaction effects of gender and handedness \((F < 1)\), episodic memory and gender, \(F(1,203) = 1.622, p = 0.20, \eta^2_p = 0.008\), episodic memory and handedness, \(F(1,203) = 1.964, p = 0.16, \eta^2_p = 0.010\) and episodic memory, gender and handedness \((F < 1)\) were not significant.

![Figure 3: Gender differences on mean scores on trial one and delayed recall on Verbal Paired Associates (VPA)](image-url)
Although significant gender differences were not present, as illustrated in figure 3, females have overall performed better than males. If factored with handedness, nominally speaking, inconsistent female handers seem to recall better than the other groups.

Since gender was not a significant factor, cells were collapsed and independent samples \( t \) tests were attempted to check for handedness differences across the episodic memory variables. Also, since each variable were assessed independently, all three variables for episodic memory were considered for in the \( t \) test analyses.

**Table 3: Correlation between the episodic memory variables (\( N = 207 \))**

<table>
<thead>
<tr>
<th>Variables</th>
<th>First trial</th>
<th>Total Scores</th>
<th>Delayed recall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First trial</strong></td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total scores (Four trials)</strong></td>
<td>0.79**</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Delayed recall</strong></td>
<td>0.43**</td>
<td>0.77**</td>
<td></td>
</tr>
</tbody>
</table>

*Note: ** - significant at \( p < 0.01 \); The three variables on verbal paired associates test*

Mean scores on the episodic memory factored by handedness are presented in table 2. Significant differences were present between the inconsistent handers outperforming consistent handers in trial one, \( t (205) = 2.327, p = 0.02, \) Cohen’s \( d = 0.33 \), in the total scores of the VPA, \( t (205) = 2.11, p = 0.04, \) Cohen’s \( d = 0.30 \). However, both groups did not significantly differ in the delayed recall, \( t (205) = 1.25, \) Cohen’s \( d = 0.18 \).

**SEM analysis**

Past studies have illustrated the independent roles of handedness, and WM on episodic memory. In keeping with those findings, the current study aimed at testing not
only the direct relations but also to check if WM processes mediated between handedness and episodic memory. Based on empirical findings from past research, the path model was proposed and is shown in figure 4.

**Figure 4: Proposed Path model**
*Note: WM = working memory; e = error; T1 = trial one; VPA = verbal paired associates; DR = delayed recall*

Handedness, WM capacity (as measured by the digit span) and complex WM (as measured by the LNS) were treated as exogenous variables (these are equivalent to independent variables). Direct and indirect paths were drawn from these exogenous variables to the endogenous (outcome) variable—Episodic memory (as measured by verbal paired associates). Episodic memory was treated as a “latent” construct, which is unobservable in nature. To measure this construct, three representatives (also referred to as “indicator” variables) were considered—trial one, total of four trials, and delayed recall of the paired associates test. The path model was estimated using AMOS, version 19.0 (Arbuckle, 2010).
Table 4: Mean and standard deviations and bivariate correlations between variables for the proposed Path analysis model (N = 207)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Absolute EHI score</th>
<th>Digit span total</th>
<th>LNS total</th>
<th>First Trial (VPA)</th>
<th>Total scores (VPA)</th>
<th>Delayed recall (VPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute EHI score</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Digit Span total</td>
<td>0.10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LNS total</td>
<td>0.06</td>
<td>0.55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>First trial (VPA)</td>
<td>-0.13</td>
<td>0.12</td>
<td>0.18</td>
<td>-</td>
<td>0.79</td>
<td>-</td>
</tr>
<tr>
<td>Total scores (VPA)</td>
<td>-0.09</td>
<td>0.17</td>
<td>0.20</td>
<td>0.79</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Delayed recall (VPA)</td>
<td>-0.04</td>
<td>0.13</td>
<td>0.15</td>
<td>0.43</td>
<td>0.77</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>77.39</td>
<td>12.20</td>
<td>21.62</td>
<td>6.43</td>
<td>42.05</td>
<td>12.96</td>
</tr>
<tr>
<td>SD</td>
<td>22.69</td>
<td>1.79</td>
<td>2.47</td>
<td>2.52</td>
<td>7.33</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Note: EHI: Edinburgh’s Handedness Inventory; LNS = letter number sequencing task; VPA = verbal paired associates

Figure 5 illustrates the path model with the standardized path estimates (β weights in the context of regression analysis). The negative direction of the estimates for handedness and episodic memory, seem to be in the expected direction, however, the rest of the estimates (direct and indirect) between handedness and WM and together in relation to episodic memory are in the positive direction. While a positive coefficient between WM and episodic memory is consistent with past research evidence, the relation between handedness and WM is not in the hypothesized direction. The model did not show good fit to the observed data, $\chi^2 (7, N = 207) = 81.87, p = 0.001, \text{CFI} = 0.85, \text{RMSEA} = 0.23, \text{and TLI} = 0.68.$
A significant chi square statistic suggests that the current model is not reflective of the model in the real world - but the significance could also be attributed to the sample size. However, the evaluation of the remaining fit indices further seems to suggest that the model fails to identify with the current data. The model therefore needed re-specification by identifying possible issues leading to poor fit statistics.

![Path model with standardized estimates](image)

**Figure 5: Path model with standardized estimates**

*Note: WM = working memory; e = error; T1 = trial one; VPA = verbal paired associates; Dr = delayed recall*

**SEM model - Re-specified**

Modification index between e2 and e3 (errors of digit span and LNS total respectively) was 62.858. This indicates that the two error terms may have some common variance. Adding a path that connects the two error terms would improve model fit and account for the shared variance. The latter is attributed to method bias (since both are
WM tasks, administered one after the other during testing, they seem to be sharing a common source of variance and both tasks also moderately correlate with each other).

In addition to drawing a correlation between the two WM error terms, a modification regarding one of the indicator variables was enforced prior to re-running the model.

As already discussed in the previous parametric analysis, episodic memory assumed the composition of immediate recall (in this case, Trials 1 to 4), and delayed recall (as is; measured after a gap of 12-16 minutes). In the current model, trial one was treated as an independent indicator because this is the first recall of the amount of information retained without sufficient rehearsal and feedback; Delayed recall on the other hand, was considered as a representation of the amount of episodic memory information that could be recalled after a short delay in time. In addition to both these indicators, the total scores on the four trials were treated as the total learning curve. However, there is an inherent problem in this arrangement.

Upon further investigation, an issue in the total scores was localized based on the correlation matrix (Table 4). Although, SEM literature suggests that indicator variables of a latent construct (particularly in the context of confirmatory factor analysis) must be adequately correlated as it confirms the internal consistency amongst items (Hair, et al., 2010), having high correlations can lead to a model misfit. The latter gains support from normative studies of WMS-III, where researchers reported that scores on immediate and delayed recall of verbal memory were highly correlated that lead to inadmissible estimates and therefore the total and delayed scores were intentionally excluded from the factor analysis models while norming the WMS-IV battery (Millis, Malina, Bowers, &
Ricker, 1999). As regards VPA scores of the WMS-IV, the correlation between the total scores on VPA (across four trials, also known as VPA I) and delayed recall (also known as VPA II) is reported to be 0.84 (WMS IV- Technical Manual, Wechsler, 2009). Additionally, adding scores of trial one to the total scores as well as considering trial one scores separately could be considered erroneous because scores of trial one are considered twice. In view of these reasons, total VPA scores were not considered for the next model run.

**Figure 6: Re-specified Path model with standardized estimates**

*Note: WM = working memory; e = error; T₁ = trial one; Dr = delayed recall*

SEM literature (e.g., Kline, 2005) recommends that a latent variable be represented by at least three indicator variables for the model to be identified (in other words, estimating parameters). At times two indicators may lead to problems in estimating the model; however, based on the argument presented above on the exclusion of the total scores, the re-specified model was run with only two indicator variables.
Among all the parameters estimated, only handedness and complex WM were statistically significant thus suggesting that they are directly and independently associated with episodic memory and the other non-significant parameters in the model may be considered unimportant to the model (Byrne, 2009). AMOS provides standardized and unstandardized estimates of the parameters, along with the SEs, the critical ratio (C.R.) and the significance level (default- 0.05 level). The C.R. operates like the z statistic, and its output is a product of the parameter estimate divided by its SE. Handedness has a C.R. of -2.01, \( p < 0.05 \), and complex WM has a C.R. of 1.96, \( p = 0.05 \). The standardized estimates were used to interpret the significant parameters. The estimated standardized path coefficients for handedness and complex WM are -0.17 & 0.20, respectively, interpreted as, a level of handedness 1SD below the mean predicts episodic memory almost 0.17 SD above the mean while controlling for complex WM. Likewise, a level of complex WM one SD above the mean is associated with episodic memory almost 0.20 SD above the mean, when handedness is controlled in the model. The magnitude of the direct effects of the two variables on episodic memory are almost equal, however the effects are in the expected opposite direction.

The re-specified model presented in figure 6, showed an improved fit to the observed data, \( \chi^2 (2, \ N = 207) = 1.029, \ p = 0.598, \ CFI = 1.00, \ TLI = 1.03, \ RMSEA = 0.01 \). Squared multiple correlations or \( R^2 \) were also calculated that represents the amount of variance accounted for in the outcome variable by the set of independent variables entered in the model. \( R^2 \) for trial one recall and delayed recall were 0.622 and 0.30 respectively. In other words, handedness, and WM accounted for 62.2% of the variation
in episodic memory assessed by trial one on the VPA and 30% of variation in episodic memory as assessed by the delayed recall on the VPA.

**Secondary (Exploratory) Analyses for WM**

Analysis of the data revealed that 60% and 33% of the sample had grouped numbers into units of 2’s, 3’s, and 4’s for the forward and backward digit span respectively. 2 x 2 ANOVAs with handedness and grouping numbers as a strategy as the between subjects variables were considered on digit span scores separately for forward and backward digit spans.

For the forward span, a main effect of grouping numbers, $F(1,203) = 17.704, p = 0.001, \eta_p^2 = 0.08$, was present with grouping as a strategy facilitating a significantly higher recall of numbers ($M = 7.13$) than not using this strategy ($M = 6.52$). Main effects of handedness, $F(1,203) = 2.037, p = 0.15, \eta_p^2 = 0.01$, and interaction effect of grouping and handedness ($F < 1$), were absent.

In the case of backward span, a main effect of grouping was present, $F(1,203) = 10.65, p = 0.001, \eta_p^2 = 0.05$, with grouping numbers resulting in a higher recall of numbers in the correct order ($M = 5.65$) than not grouping the numbers during the encoding phase ($M = 5.15$). Main effects for handedness, $F(1,203) = 1.73, p = 0.19, \eta_p^2 = 0.008$, and interaction effects for handedness and grouping ($F < 1$), were absent.
Table 5: Mean (SD) of working memory tasks and strategies factored by handedness groups

<table>
<thead>
<tr>
<th>Variables</th>
<th>Inconsistent Handed</th>
<th>Consistent Handed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Digit Span - Forward</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grouped numbers</td>
<td>7.07 (1.05)</td>
<td>7.17 (1.22)</td>
<td>7.13 (1.15)</td>
</tr>
<tr>
<td>No Grouping</td>
<td>6.30 (0.99)</td>
<td>6.64 (0.88)</td>
<td>6.52 (0.93)</td>
</tr>
<tr>
<td><strong>Digit Span – Backward</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grouped numbers</td>
<td>5.47 (1.22)</td>
<td>5.81 (1.04)</td>
<td>5.65 (1.13)</td>
</tr>
<tr>
<td>No Grouping</td>
<td>5.11 (0.97)</td>
<td>5.17 (0.94)</td>
<td>5.15 (0.95)</td>
</tr>
<tr>
<td><strong>Letter-Number Sequences</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simultaneous</td>
<td>22.48 (2.23)</td>
<td>22.54 (2.41)</td>
<td>22.52 (2.33)</td>
</tr>
<tr>
<td>Waited</td>
<td>21.85 (2.30)</td>
<td>20.65 (2.08)</td>
<td>21.25 (2.25)</td>
</tr>
</tbody>
</table>

Note: Grouping numbers = forming units of 2’s, 3’s or 4’s, while listening to the series of numbers being read out; in the letter number sequences, simultaneous = immediately arranging the sequences in the expected order, whereas, the waited condition = after the entire series is read out, the participant attempts to rearrange them in the expected order.

Examination of the means (table 5) in the handedness groups for the grouping strategy revealed that the grouping strategy was advantageous to both handedness groups in the forward and backward spans conditions. However, digit span performance is seemingly better in consistent handers following the grouping strategy. In order to examine this further, the dataset was split by hand groups, (thus, results were assessed separately for the consistent and inconsistent handers, purely for exploratory purposes) and independent sample t tests were conducted using the grouping strategy on forward and backward span separately. The result showed that the grouping strategy helped both handedness groups significantly for the forward span, in the inconsistent handed group, t
(83) = 3.306, $p = 0.001$, Cohen’s $d = 0.75$ and the consistent handed group, $t (120) = 2.79, p = 0.006$, Cohen’s $d = 0.49$. However, the strategy was advantageous only for the consistent handers in the backward span, $t (120) = 3.29, p = 0.001$ Cohen’s $d = 0.65$, but not for the inconsistent handers, $t (83) = 1.482, p = 0.14$, Cohen’s $d = 0.32$.

A 2 x 2 ANOVA was conducted with handedness and strategy adopted for performing the task on the total scores of the LNS (data was available from 119 participants only). There was a significant difference between participants who were simultaneously arranging the sequences ($M = 22.52$) as compared to those who arranged the stimuli after listening to the entire series ($M = 21.25$), $F (1,118) = 7.92, p = 0.01$, $\eta^2_p = 0.064$. Main effects of handedness, $F (1,118) = 1.62, p = 0.21$, $\eta^2_p = 0.014$ and interaction between handedness and the arranging of the sequences, $F (1,118) = 1.965, p = 0.16$, $\eta^2_p = 0.017$ were absent.
Chapter Eight

Discussion

Handedness as an individual difference variable and WM as a cognitive process, are known to be associated with episodic memory processes. The current study therefore aimed to check for their direct and indirect effects on episodic memory. The study also assessed the role of individual differences (handedness and gender) in different WM paradigms (immediate memory span – simple WM, and complex WM) and episodic memory. Prior to discussing the path model, which is the primary goal of the study, the other results will be discussed - as these will lay the foundation for the path model findings.

a) WM

- Main findings

Results did not show handedness differences in either immediate memory span or complex WM; however, a gender difference was found in complex WM only, thus leading to the rejection of the proposed hypothesis.

The results for the association between handedness and WM were not in the expected direction (although non-significant); bivariate correlations showed a positive association, suggesting that being consistent handed was associated with better performance in WM tasks.

It was hypothesized that inconsistent handers would show a WM advantage because few past research studies had demonstrated this effect in WM (Gunstad, et al.,
Indirect evidence supported the role of WM in cognitive processes such as memorizing new words in a foreign language as a function of handedness (Kempe, et al., 2009). In addition, because of the possible bilateral frontal involvement as shown by neuroimaging studies (Haut, et al., 2000; Li, et al., 2012), it was speculated that interhemispheric interaction may be involved and therefore handedness, which is a behavioral proxy for its representation would have shown a significant effect in WM.

The possible reasons for not finding the handedness difference could be attentional compromises due to the adopted methodology in the study. WM tasks were filler tasks between the fourth trial and the delayed recall conditions of episodic memory. Some studies have suggested that similar neural areas such as the PFC and medial temporal areas are involved in episodic memory and WM (Ranganath et al., 2003; Cabeza et al., 2002). Given that LTM/episodic memory formation depends on STM/WM for the initial encoding and eventual consolidation, it could be speculated that engaging the WM in immediate succession would lead to some tradeoff for WM processing and would cause the inconsistent handed group to respond like the consistent handed group. However, secondary exploratory analyses on the use of strategy for WM tasks may probably account for the absence of handedness effect.

- **Role of Strategies in WM tasks**

Although, strategy use among handedness groups and its interpretation were beyond the scope of the study, these findings are being interpreted because they may help understand the possible fundamental differences in processing information at the WM level within these groups.
Strategies in cognitive processes are handy when task loads are high. Similarly, when WM demands are challenging, strategy use improves performance (Bor, et al., 2004). In the digit span task, grouping the numbers presented in the auditory modality into units of 2’s, or 3’s, or 4’s help recall digits in the presented order without straining the WM. And this may have driven the effects in the unexpected direction in the current sample. (Anecdotally, data collection for the study was conducted around the time in the semester when Psych 101 students are taught the “Memory” chapter that provides them with the knowledge about strategizing WM tasks. It is quite possible that the strategies were “available” and several participants utilized them to their advantage to reduce the WM load to perform optimally). Main effect of handedness or interaction effects were not present, therefore suggesting that both handedness groups were more or less grouping the numbers for the immediate memory span.

The findings on grouping strategy and digit span performance assessed separately in the handedness groups further revealed that only the consistent handed group significantly benefitted from the grouping strategy for backward digit span. This could be interpreted in two ways within the WM framework:

a) This strategy may have helped the consistent handers because of their ability to not only group the numbers to aid memory for later recall but also pay close attention to them while saying them in the reverse order. This could be taken as evidence for a relatively weaker central executive system that required the use of a strategy to cope with a relatively challenging immediate span task.
b) Inconsistent handers have performed more or less in a similar fashion, perhaps because they already possess an adequate central executive system and strategy use would not necessarily benefit them.

These speculations need to be researched further to understand the actual WM processing in the handedness groups. Further, it also remains unclear if the manner in which the numbers were grouped had a role in their recall (grouping numbers in short units vs. grouping numbers in larger units of 4’s and remembering many such units, especially the larger ones, could also affect performance, e.g., 417-293-586 vs. 4172-93586). Additional research is required to address these speculations and also explore the possible use of other strategies that may be playing an important role in performing WM tasks. These could include repetition, visualization, both repetition and visualization along with/without grouping numbers into units.

Complex WM measured by the LNS is predominantly a verbal task. It appears that the manner in which the series is processed may determine the successful encoding and retrieval of the information. In relation to the WM paradigm, this alludes to the possible involvement of not only the phonological loop but also the central executive for its abilities to allocate attention, manipulate information, arrange them in the required order, and even update the information while in its active state (Morris & Jones, 1990). A study by Crowe (2000) suggested that the LNS task seems to not only tap into the auditory components of WM but may also involve visuospatial abilities and speed of processing, both of which could be speculated may have been part of the strategy adopted for the task (arranging the sequence simultaneously vs. waiting).
In the LNS task, although findings were non-significant, the descriptive data seems to suggest that simultaneous presentation of the sequences benefitted the consistent handers and inconsistent handers more or less equally. However, in the waiting condition, nominally speaking, inconsistent handers have scored better than consistent handers. This could be taken as evidence for an adequate central executive system that can temporarily hold a set of numbers and letters for a longer duration and then manipulate/re-arrange them in the expected order.

The aforementioned reasons for strategy use in simple WM and the method of manipulating information in complex WM are solely based on interview data and are qualitative in nature. Yet, these need to be recognized and factored in as far as WM tasks, and undergraduate college samples are concerned.

-Complex WM and Gender

A gender difference was found in the LNS performance, with males outperforming females in the task. Past studies have shown a male advantage in some WM tasks, LNS being one of them (Sluie, et al., 2006). Gender asymmetries in such tasks could be present in the central executive system that is mainly involved in how attentional resources are allocated and using strategies for performing complex WM task. According to Speck, et al. (2000), gender differences probably exist because a majority of males approach such tasks from a problem solving perspective. This speculation was made in the context of differential brain activation during an N back task in their study. Interestingly, studies that have assessed gender differences in spatial memory processes
report that females showed higher left hemisphere activation and the use of verbal strategies whereas males showed higher right hemisphere activation for the very same tasks, and the reliance on non-verbal strategies (Frings, Wagner, Unterrainer, Spreer, Halsband, & Schulze-Bonhage, 2006; Sandstorm, Kaufman & Heuttel, 1998).

Gender differences have also been observed when performing WM tasks under stress. A study by Qin, Hermans, van Marle Luo, and Fernandez (2009) showed that females when exposed to psychological stress (induced by applying self referencing effects while watching aversive clips of a movie) tended to show reduced frontal activity and nominally lower scores on an N back task as compared to the control group. In the current context, with tasks such as the LNS, it may be possible that females were experiencing a stress reaction to the increasingly demanding nature of the task, which in turn may have affected the performance. Evidence suggests that females tend to react strongly to even minor daily stressors (Matud, 2004) and stress is known to affect PFC functioning, which in turn would interfere with WM functioning (Arnsten, 2009; Mizoguchi, Yuzurihara, Ishige, Sasaki, Chui, & Tabira, 2000). Additionally, it may also be possible that males are relatively more motivated than females to perform better on tasks that are demanding and/or challenging in nature. In generic terms, there are gender asymmetries in motivational behaviors- with males being driven internally to acquire rewards which in turn act as reinforcers for future behaviors (Becker & Taylor, 2008). Together, these interpretations propose that the central executive plays a crucial role in deciding the use of strategies and also may be vulnerable to stress reactions while performing the task.
b) Episodic Memory

In terms of episodic memory performance, the hypothesis on the presence of handedness differences, and the absence of gender differences was accepted. Results revealed a significant inconsistent handed advantage in recall specific to trial one of the VPA supporting findings from previous studies (Christman, et al., 2004; Lyle, et al., 2008). Effect sizes for the current study are similar to Lyle, et al. (2008) study, whereas Chu, et al. (2012) reported Cohen’s $d$ of 0.52 and 0.64 for the immediate and delayed recalls on the CVLT.

The findings suggest that inconsistent handers have greater access to right hemisphere (Tulving, et al., 1994), which are reflective of better source monitoring (Christman, et al., 2004). This is not to say that consistent handers are not retrieving any information. Instead, the findings generally refer to the inconsistent handers’ greater ability to retrieve a greater amount of information during recall, than consistent handers. This could be corroborated with the study by O’Donnell, et al. (2010) that has provided some preliminary evidence on the association between degree of handedness and white matter symmetry and their association to cognitive processes. White matter in the brain basically refers to the myelin sheath that is casted around neurons for electrical insulation and faster speed of passing along electrical signals through the neurons. Higher right frontal white matter integrity is strongly implicated in speed of processing, and executive functioning and their respective roles in learning and memory retrieval (Brickman, Zimmerman, Paul, Grieve, Tate, Cohen, Williams, Clark, & Gordon, 2006).

Interestingly, significant gender differences in episodic memory were not observed in the current study. But it is worth mentioning that female inconsistent handers
have nominally better scores on both trial one and delayed recall of the VPA than the other groups. Past studies have showed a female advantage in episodic memory paradigms (Geffen, et al., 1990; Herlitz, et al., 1997; Herlitz & Rehnman, 2008; Hultsch, et al., 1991). This has been attributed to a variety of reasons that include the hormone-neurotransmitter dynamics (e.g., Kimura & Hampson, 1994; Mozley, et al., 2001), differential activation of certain brain regions during retrieval (e.g., Nyberg et al., 2000) and even different abilities in encoding information for a better recall (e.g., Krueger & Salthouse, 2010). One possibility for not finding a significant gender difference could be the type of stimuli used to measure episodic memory. Stimuli that are emotional in nature tend to elicit a female advantage in episodic memory retrieval (Davis, 1999), whereas the current study used word pairs that were more or less neutral in nature.

Results also showed that performance on the first trial of the VPA was significantly lower than the delayed recall. From the methods point of view, in keeping with the standardized format of the test, this difference was expected because, participants were provided with four trials for encoding the word pairs, and were also provided with the correct responses if they were unable to recall and/or gave incorrect responses during the learning stage. In addition, based on the results, a wide difference is present between the handedness groups for the first two trials; however, performance on the last two trials of the VPA during the learning phase is more or less similar for both handedness groups. It is possible that both groups may have differed initially in encoding the word pairs episodically, however, once the information was well encoded, a process of semantization may have taken place that eventually led to similar performances. This
interpretation has gained support from past studies, which reported an absence of handedness difference in semantic memory (Propper, Christman, & Phaneuf, 2005).

In terms of delayed recall, a time gap of about 10-16 minutes between trial four of the VPA and delayed recall may be considered a short interval for a decline and perhaps even more since normal participants were recruited for this study. Besides, WMS normative studies have consistently shown a higher rate of delayed recall especially in the young (16-25 years) population (e.g., Uttl, Graf, & Richter, 2002; Wechsler, 1997, 1987).

c) Roles of Handedness and WM in Episodic Memory

The SEM path model was attempted to assess the contributions of handedness and WM in episodic memory retrieval and to check if WM mediated between handedness and episodic memory. Results suggested that handedness and complex WM showed direct effects on episodic memory retrieval. No mediating effects were present, therefore suggesting that the two variables were dissociated from one another.

Past studies have confirmed the finding that WM capacity is linearly related to long term memory retrieval (Unsworth & Spillers, 2010). The more interesting finding is that complex WM has significantly contributed to episodic memory retrieval more than simple WM. This could be attributed to the nature of complex WM that plays an important role in organizing the information, differentiating between relevant and irrelevant cues that aid successful recall (Unsworth, 2007; Unsworth & Engle, 2007). Episodic memory retrieval is dependent on the immediate memory capacity but more importantly, it is enhanced by complex WM, as it aides the recall information correctly in
view of interferences and competing responses and individuals with a higher WM capacity are likely to recall more. In terms of the temporal context framework, it is suggested that higher WM capacity individuals are successful at using temporal information to narrow their search during recall such that a recalled word may immediately take up the role of a hook to search for the rest of the items (Spillers & Unsworth, 2011). In the current study, with the fourteen word pairs that were expected to be remembered, an individual with a higher complex WM capacity would have managed to encode and retrieve the information successfully by inhibiting competing responses, retrieving the context in which the information was encoded (e.g., making a specific association that eventually plays the role of a cue between the words in a pair during encoding) and choosing responses amidst the interferences from other word pairs, and even past knowledge – tasks that are dependent on the WM.

Based on the qualitative findings on the manner in which the complex WM task was performed, participants who were simultaneously processing the information were more likely to correctly report the numbers and letters in the expected order for the immediate recall. The path analysis further showed a significant positive relation between complex WM and episodic memory retrieval. It could therefore be deduced that the manner in which the information is encoded and processed, is characteristic of the WM capacity and this is also reflective of the amount of information that can be recalled at a later point. Thus, in the current model, and in keeping with past findings, the role of complex WM in episodic memory retrieval is ascertained.

In terms of handedness showing a significant direct effect on episodic memory, the findings gain support from past studies that have repeatedly theorized and shown the
role of greater access to right hemisphere during retrieval, with inconsistent handers being at an advantage. It is also possible that inconsistent handers are able to successfully retrieve a significantly higher amount of information and this could be due to good source memory.

However, given that both WM and episodic memory retrieval are lateralized to the right frontal during retrieval, and that complex WM plays an important role in episodic memory retrieval, it was surprising that results did not support the mediating effects of WM between handedness and episodic memory. Past studies have made indirect references to the possible role of WM in new information acquisition (e.g., Kempe, et al., 2009) however the role was not confirmed in the present study. The reason for this as mentioned before could be that strategy use in WM tasks that may have over ridden the effects of handedness. Additionally, the path analysis may show the mediation effects with a larger sample.
Chapter Nine

Conclusions

Given the current findings of the path analysis in the study, and in the light of past findings on handedness, WM and episodic memory, it may be concluded that there is an inconsistent handed advantage in episodic recall that is not dependent on WM. The independent contribution of handedness therefore needs to be considered in episodic memory studies to better account for individual differences.

Second, although complex WM independently contributes to episodic recall, the lack of a mediating relationship between handedness and episodic memory via WM further supports the notion that handedness differences in episodic recall are specific to retrieval (e.g., better source memory).

Finally, it could be hypothesized that the handedness finding is reflective of the association between a higher symmetry of white matter between brain hemispheres (O’Donnell et al., 2010) that directly aids memory recall. With the other finding in the path model, the role of WM is more representative of a cognitive process aiding another cognitive process for its actualization. It may therefore be logical to put forth that perhaps WM is not necessarily dependent on the higher symmetry in white matter for its functioning (as evidenced in the absence of mediation effects). But further research will be required to test this model with a different sample and different age groups to generalize the above findings.
Chapter Ten

Limitations

1) Sample size

Although this point was not addressed in depth in the discussion section, it is important to acknowledge that the sample size used for the current study is just adequate for an SEM analysis. It is quite possible that sample size may have played a crucial role, as SEM analysis requires large samples, and future studies in this area will need to take this factor into consideration.

2) Path model

The estimated path model attempted in the study may be considered “risky” as the latent factor on episodic memory was estimated using only two indicators variables. Although literature suggests that using two variables is do-able, it cannot be denied that there could have been a risk in estimating and interpreting the model. In addition, using two separate episodic memory tasks could be considered as a better representation of episodic memory retrieval because of the high correlation that existed between immediate and delayed recalls of the same memory task (cf. WMS IV- technical manual). In addition, the path model could have used WM as a latent variable with DS forward, backward and LNS total scores as the observed variables. Future studies could peruse over the limitations of the current model to propose a wholesome model that encompasses a larger and a reliable representation of WM and episodic memory.
Gender was a significant factor for WM but not for episodic memory. Given this finding, gender was not included in the path analysis. However, in view of past studies that have suggested the role of gender in episodic memory, and the presence of nominally better scores in VPA amongst the females in addition to the presence of a significant gender asymmetry in WM, future studies could attempt SEM models on the gender groups separately.

3) Methods - WM

Given that strategies used for WM tasks may have accounted for most of the variance, perhaps using digit span and LNS may not have been an optimal choice. Future studies could use WM tasks that cannot necessarily be strategized. Tasks such as the operation span, letter span, are experimental in nature, yet show a moderate to high correlation with the clinical based tasks. These are reported to be challenging and may show a handedness effect if WM is dependent on inter-hemispheric interaction.

4) Methods – VPA

In the normal population, the high positive correlation between the total VPA and delayed recalls are acknowledged even by authors who have normed this test. One of the reasons for having the almost ceiling scores is the feedback element that is part of the standardized battery. Future studies could consider administering the same task without the feedback across four trials. This would help closely examine the handedness effects on a relatively tougher task than is considered to be.
In closing, although the current study did not entirely evolve in the expected direction, the preliminary findings on the dynamics between handedness and two cognitive processes (WM and episodic memory) may be considered as a step towards adding to the existing understanding about strength of handedness. If subsequent studies show the validity of handedness as a behavioral marker for white matter integrity in the brain, then it could be safe to deduce its contributions for some if not for all cognitive processes. Although initial studies considered only the corpus callosum as the primary index, it may now be a relevant time to broaden the scope of localizing these differences— in other words, considering regional and overall white matter symmetries (an index suggested by O’Donnell et al., 2010) in relation to handedness and applying it to account for individual differences in cognitive processes.
References


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