Working Memory Performance in Children Born Preterm: The Effects of Prematurity and Training

by

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Abstract

Research clearly shows that preterm children have working memory (WM) impairments. However, the WM profile of preterm children is still unclear as the methodologies used in different studies are highly varied. It is unable to gain insight into the relative strengths and weaknesses of the different aspects of WM if only one area is examined. Working memory training has been proven effective in various populations. However, a recent review paper pointed out that the majority of the WM training studies involve a no-contact control group making it impossible to determine whether any training benefit is due to actual improvement or an expectancy effect. Moreover, the transfer effect of strategy training is not known as very few studies have examined the transfer benefits of strategy training. Alternatively, core WM training involves a compilation of tasks to tap multiple components of the WM. Evidence shows that core WM training not only has transfer benefits, but also has sustained gains. In Study One of the present study, school-aged preterm children were found to perform significantly worse than age-matched term-born children in Visuospatial WM but not in Verbal WM. Although, preschool preterm children had poorer WM performance than their age-matched term-born peers, the group difference only reached the marginally significance level (i.e., p =.09). However, significant correlation between verbal and visuospatial STM was found in the preschool preterm subgroup, suggesting that the verbal and visuospatial storages of WM in young preterm children were associable. Preschool-aged children of both preterm and control groups completed a 5-week online WM training at home and continued to participate in Study Two. Findings showed that training benefits in both Verbal and Visuospatial WM were found in the control group, while training-related gains were found only in Visuospatial WM in the preterm group. Moreover, longer period of time was required for the positive training effects emerged in the preterm group than in the control group. No significant transfer effects on visual attention and EF were found in either group. Taken together, findings suggested that preschool-aged preterm children might have the central executive component of the WM developed differently from their age-matched term-born peers.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter One
Introduction

A recent publication of the World Health Organization (WHO) reported that more than 1 in 10 of the babies born in 2010 were born prematurely (WHO, 2012). This figure not only informs us preterm birth has a high incidence, but it also led WHO to launch the advancement of prevention and care of preterm birth as a global strategy for women's and children's health and the health-related millennium development goals (WHO, 2012). Preterm birth is a high-priority topic that needs to be managed in the twenty first century. To address this public health issue, a comprehensive understanding of the long-term sequelae of preterm birth appears to be the first essential step. This action is important not only for policy making, but also for the early identification of high-risk preterm children and the implementation of early intervention.

Despite the recognition that preterm birth is a serious clinical and public health problem, advanced medical technology and greater registration of early-gestation birth have failed to lessen the rates of preterm birth. On the contrary, preterm birth rates are on a rise globally (WHO, 2012). In Canada, preterm birth rates have increased from 6.4% in 1981 to 8.2 % in 2004 (excluding Ontario) (Canadian Perinatal Health Report, 2008). In 2006-2007, approximately 1 in 7 babies across Canada were born preterm or small for gestational age (SGA) (Lim et al., 2009). These figures varied across the provinces. Data from 2004 showed that the preterm birth rate in Alberta was higher than that in any other provinces except the three territories. Moreover, the rate of small-for-gestational-age live births in Alberta was the highest in Canada (Canadian Perinatal Health Report, 2008).

Preterm birth is a major cause of infant mortality and morbidity in almost all economically developed countries (Blencowe et al., 2012). Being born preterm has an elevated risk of death due to infections or other birth complications. However, children surviving preterm birth are not more fortunate, they usually cannot avoid long-term adverse developmental consequences. While a small group of preterm children have major disabilities including sensory deficits or cerebral palsy, a large percentage of children born preterm suffer from relatively more subtle problems such as inattention, behaviour problems or learning problems, affecting their academic attainment (Luu, Ment, Allan, Schneider, & Vohr, 2010).

One learning-related cognitive skill that is commonly investigated by studies in children born preterm is working memory (WM). Research clearly shows that children born preterm have WM impairments (Luciana, Lindeke, Georgieff, Mills, & Nelson, 1999). However, the WM profiles of preterm children are still unclear as the methodologies used in different studies are highly varied. For example, although some researchers tested visuospatial WM in their studies (e.g., Saavalainen et al., 2007), others have focused on verbal WM only (e.g., Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009). Under such condition, one is unable to conclude whether working memory deficits in children born preterm are domain-specific (i.e., impairments found in either verbal or visuospatial WM) or domain-general (i.e., impairments found in both verbal and visuospatial WM). Knowing the working memory profile of children born preterm has considerable advantages. It not only informs researchers the developmental pattern of WM in this population, but also helps them to understand the relationship between early brain insults and consequent neurodevelopmental outcomes. What is more, a complete picture of preterm children's WM abilities can guide practitioners to plan targeted intervention and to use children's strengths to assist their weaknesses in order to optimize intervention outcomes.

Various WM training programs have been involved in research studies or clinical practice. One common approach employed in WM training is the use of strategies. There is evidence that strategy usage can improve WM capacity of both adults (Turley-Ames & Whitfield, 2003) and typically developing children (Schleepen & Jonkman, 2014). Loomes and collaborators (2008) also reported that children with Fetal Alcohol Spectrum Disorder (FASD) were able to recall a longer digit span after receiving training on the use of verbal rehearsal skills. Although strategy usage has positive training effects on WM, some researchers argued that such training benefits cannot be transferred to tasks that are not similar to the training tasks (Ericsson & Chase, 1982; Morrison & Chen, 2011). Thus, the use of strategy to improve WM is still inconclusive. Alternatively, core WM training involves a collection of tasks to tap multiple components of the WM. The diversity of tasks increases the chance that one of or some combinations of the training tasks will lead to desired training gains. Moreover, core WM training is designed to strengthen domain-general but not domain-specific WM mechanism (Morrison & Chen, 2012). Because of this characteristic, core WM training not only has transfer effect (Holmes, Gathercole, & Dunning, 2009), but also has sustained gains (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010). Hence, between strategy and core WM training, the latter method has more training gains.

WM training has been proven effective in various populations (Berhmer, Westerberg, & Bäckman, 2012; van der Molen, van Luit, van der Molen, Kluglist, & Jongmans, 2010). However, a recent review paper has pointed out that majority of the WM training studies either do not have a control group or involve a control group who does not participate in any training (Shipstead, Redick, & Engle, 2012). Such study designs cannot control the effects of maturation or expectancy on the training outcomes, making it difficult to draw conclusions based on the findings. Taken together, although evidence suggests that WM trainings are effective, trainings that involve no-contact control group and/or only use strategy training would have limited value.

Working memory is crucial for focusing attention, remembering instructions, and solving problems, it plays an essential role in learning. Children with poor WM are frequently observed to have difficulties listening to and following mutliple steps instructions given by a teacher, and/or have difficulties learning alphabets or numbers (Gathercole & Alloway, 2008). WM impairment is an underlying cause of the academic underachievement in children including children born preterm. If we can understand the WM profile of preterm children thoroughly, intervention can be planned according to their actual needs.

Moreover, a better understanding of preterm children's WM abilities can help them to use their own asset to cope with the demands from academic learning so as to relieve the burden on schools. Since there is evidence that WM training is effective for different populations. It is believed that core working memory training for children born preterm should have a positive effect. In order to examine this notion, the working memory profile of preterm children should be investigated in a systematic way. Only when the strengths and weaknesses of preterm children's WM abilities are fully known, the efficacy of a training program can be examined accurately and the intervention can be implemented effectively in the future.

The Present Research Project

The present research project had two major objectives. First, in Study One, I aimed to (1a) examine the WM profile of children born preterm; and (1b) to explore whether the WM profile of preterm children is similar to that of age-matched term-born children. In addition, I also evaluated (1c) the relationship between the performance-based and parent-rated WM in preterm children in order to better understand their WM profile. I hypothesized that preterm children would perform worse than their age-matched term-born peers on both verbal and visuospatial WM, and that the between-group difference would be greater for visuospatial than verbal WM. I also predicted that the WM profile in preterm children would be different from that in age-matched term-born children. Besides, I hypothesized that the two measures of WM would be significantly correlated.

Second, in Study Two, I planned to investigate the efficacy of a core WM training program (Cogmed, the Cogmed Cognitive Medical Systems AB, Sweden) on the WM abilities in children born preterm. Under this objective, I would like to examine (2a) whether improvement could be found in non-trained WM tasks after 5 weeks of Cogmed training (i.e., near transfer effect on non-trained WM) and at 5-week follow-up (i.e., lasting effect on non-trained WM), and (2b) whether training benefits could be extended to other cognitive functions such as attention and executive functions (EF) after training (i.e., far transfer effect on attention and EF) and at 5-week follow-up (i.e., lasting effect on attention and EF). In addition, I also evaluated (2c) whether the pattern of training-induced gains in preterm children is similar to or different from that observed in age-matched term-born participants. I hypothesized that training benefits on non-trained WM, attention and EF would be observed in both preterm children and their age-matched term-born peers after training and at 5-week follow up. I also predicted that the training-induced improvement patterns found in preterm children would be different from that observed in age-matched term-born children.

Chapter Two

Literature Review

Knowing whether preterm and term-born children have similar developmental trajectory in WM not only can build knowledge in the field of developmental psychology, but also able to inform intervention planning. In order to achieve this goal, there is a need to understand what prematurity is, the WM performance of children born preterm, and the efficacy of working memory trainings. A review of literature on these areas can definitely provide a solid background for it.

Prematurity

Preterm Birth

Preterm birth refers to births occurring prior to 37 completed weeks of gestation or fewer than 259 days since the first day of a woman's last menstrual period (WHO, 1975). It can be classified into three categories based on the gestational age: extremely preterm (< 28 weeks), very preterm (28 - < 32 weeks), and moderate preterm (32 - < 37 weeks). Since infants born prematurely are usually low in birth weight (< 2500 g), in addition to the criterion of gestational age, preterm birth can also be classified with reference to both immaturity and birth weight. Within this classification, preterm birth can be divided into three groups. The first group includes infants born less than 37 weeks but have appropriate birth weight for gestational age, this group is called preterm AGA. The second group consists of infants born before 37 weeks whose birth weight is small for gestational age, it is designated preterm SGA. The last group comprises infants born with very low birth weight (VLBW) (< 1500 g) or extremely low birth weight (ELBW) (< 1000 g). This group includes babies born very prematurely but at a birth weight appropriate for gestational age (Spreen, Risser, & Edgell, 1995).

Infants born preterm are vulnerable to many medical complications which can contribute to mortality or morbidity. A study found that preterm birth is the major cause of 75% of neonatal deaths (Goldenberg, Culhane, Iams, & Romero, 2008). Although preterm birth can cause high death rate, findings suggest that the survival rates of preterm infants are over 50% (Chan et al., 2001; Lorenz, 2001; Vanhaesebrouck et al., 2004). Among these survivors, more than 60% can escape major morbidities such as mental handicap, cerebral palsy, deafness or blindness (Anderson, & Doyle, 2008). However, infants who survive from preterm birth and escape severe disabilities still need to face adverse consequences on their later development. The severity of these impacts tends to increase with decreasing gestational age. For instance, IQ scores decrease by 1.7 points with each weekly decrease in gestational age (Johnson, 2007). Moreover, these adverse effects may persist throughout childhood and young adulthood (Taylor, Klein, Minich, & Hack, 2000; Taylor, Minich, Bangert, Filipek, & Hack, 2004).

Causes of Preterm Birth

Preterm birth can be triggered by many factors. One of the most common factors is inflammation of the protective membrane surrounding the fetus or intrauterine infection that originates in the vaginal tract. Preterm delivery can also be induced in cases of maternal hypertension or other health related conditions (e.g., pre-eclampsia) which are life threatening to the mother and infant (Taylor, Klein, Minich, & Hack, 2000). In recent years, multiple births become a more significant cause of preterm birth in Western societies as a consequence of infertility interventions, smoking or drug use during pregnancy (Luciana, 2003).

Preterm Birth and Early Brain Development

Normative sequences of early human brain development. Human brain development proceeds in overlapping stages which are intrinsically programmed by genetic factors. In this paper, for the purpose of easy understanding, distinct periods are used to describe the normative sequences of early human brain development.

Neurulation and neurogenesis. Brain development is initiated by a process called neurulation. In this process, approximately between the third and fourth weeks of gestation, the neural plate rises and subsequently folds and fuses to form the neural tube. The neural tube then differentiates along three dimensions: length, circumference, and radius. The length dimension will give rise to the forebrain and midbrain at one end and the spinal cord at the other. The circumferential dimension provides the foundation for the development of the sensory and motor systems. The dorsal (top-side) corresponds roughly to the sensory cortex, while the ventral (bottom-side) corresponds to the motor cortex, with the various association cortices locate somewhere in between. For the radial dimension, cell differentiation takes place and gives rise to the complex layering patterns and cell types find in adult brain (Johnson & de Haan, 2011). After the preliminary formation of the central nervous system (CNS), the process of neurogenesis begins. The progenitor cells, the cells lining the wall of the neural tube, will produce a vast amount of neurons and glia (Zillmer, Spiers, & Culbertson, 2008). The production of new cells slows down rapidly at the 26 to 28 weeks of gestation (Dorman & Katzir, 1994).

Cell migration and differentiation. Cell migration and differentiation occur in the second phase of human brain development. During cell migration, nerve cells travel towards their target destinations within the developing brain. This phase usually peaks between 12 and 20 weeks of gestation and almost completes by 26 to 29 weeks of gestation (Tau & Peterson, 2006). Evidence shows that disruption in the migration process can cause neurodevelopmental disorders such as autism (Korkmaz, Benbir, & Demirbilek, 2006). When nerve cells reach their destinations, they begin to transform into different subtypes in order to serve different functions in the CNS (cell differentiation). The rates of cell differentiation vary across regions of the brain. For example, the cells characterized for hippocampus differentiate at a faster rate than those of the cortex (Monk, Webb, & Nelson, 2001).

Dendritic and axonal growth. The growth of dendritic processes and axon projections to link with other neurons (pathfinding) represent the third phase of brain development. Dendrites and dendritic spines form synapses for gathering information to transmit to the neuron. In human, dendritic growth begins in the deepest cortical layers in the seventh month of gestation and the peak growth occurs from the eight month of gestation to 2 years after birth (Luciana, 2003). The development of dendrites is very sensitive to environmental stimulations.

This nature determines the growth and differentiation of the brain (Zillmer, Spiers, & Culbertson, 2008).

During neuronal migration, axons begin to develop rapidly and move toward other neurons of the brain. This process allows the cortical-cortical, cortical-subcortical, and interhemispheric communication (Zillmer, Spiers, & Culbertson, 2008). The inter-region communications are important for the integrative functions of the brain.

Synaptogenesis. The fourth phase of brain development is characterized by the process of synaptogenesis. During this period, an excess amount of synapses (i.e., a structure that permits a neuron to pass a signal to another cell) are formed. Synaptogenesis begins in the second trimester when neuronal migration is almost complete. The increase in synaptic density is closely linked with the advancement of cognitive functions. For example, an increase in synaptic density of the frontal cortex is associated with the development of executive functions in childhood (Nagy, Westerberg, & Klingberg, 2004). The overproduction of synapses is important for the plasticity nature of the young brain.

Myelination. Approaching the completion of cell migration, oligodendrocytes begin to produce a white insular sheath called myelin to encircle axons in order to provide a protective function. Because of the fatty characteristics, myelination also promotes efficient communication among neurons (Luciana, 2003; Shonkoff & Phillips, 2000). The process of myelination occurs at different times at different regions of the brain, but basically follows the posterior-to-anterior rule. For example, it begins in the spinal cord, proceeds to the subcortical regions and finally completes in the cortex. Within the cortical regions, myelination takes place in the posterior part first and moves anteriorly till reach the parietal and frontal lobes. The myelination of the parietal and frontal regions begins after birth, and the frontal region continues into adolescence (Zillmer, Spiers, & Culbertson, 2008). Myelination of a brain region also correlates with cognitive functions.

Pruning. The final phase of brain development is pruning. The overproduction of synapses in early life allows the selection and elimination of synapses in response to our life experiences in later times. One way to show the effect of experiences on synaptic pruning is the changes in the cortical thickness. O'Hare and Sowell (2008) found that vocabulary development in children is associated with a decrease in cortical thickness in diffuse regions of the cortex. Besides, an improvement in the hand dexterity of right-handers is associated with a decrease in cortical thickness in the hand region of the left motor cortex. Synaptogenesis and synaptic elimination appear to be occurred in different time in different cortical regions. For example, the synaptic density approaches the highest level at the age 3 months in the auditory cortex, while the highest value is observed at the age 3 years in the prefrontal cortex. Synaptic pruning appears to be completed by the age 12 years in auditory cortex, but appears to continue in the prefrontal cortex until mid-adolescence (Huttenlocher & Daholkar, 1997). Therefore, the synaptic architecture of our brain does not stabilize until adolescence.

The human brain is not a finished "product" at birth, it continues to develop until adolescence or young adulthood. This nature not only reflects the influences of gene but also the consequences of environment (experience) on our brain development. In view of it, some issues about early (both prenatal and postnatal) experiences and brain development have been arisen. First, the nature of early experiences determines how the dendrites and axons grow, the types of synapses formed and the types and amounts of synapses retained, what is an appropriate environment for the brain to develop normally? Second, in addition to the nature of experience, the timing of experience also plays a pivotal role in brain development. Does it really a matter when a child is exposed to particular experience? Can the brain recover or compensate if critical experiences are missed? Third, while preterm birth provides an unfavourable environment for an infant at the outset, what will be the impacts of prematurity on the early brain development?

The brain development of preterm infants. Before looking at the brain development of preterm infants, it is helpful to conceptualize preterm infants as fetuses who develop in extra-uterine settings at the time when their brains are developing at the peak period. Preterm birth has a "double jeopardy" effect on early human brain development. First, preterm birth interrupts the normal process of intra-uterine brain development by preventing it from having expected intra-uterine stimuli and factors which are crucial for growth (Shonkoff & Phillips, 2000). Second, premature birth predisposes the infant to pathological conditions that the human at this gestational age would not normally encounter. These conditions could be a minor event such as a wrong mixture of nutrients or more severe neuropathologies like intracranial hemorrhage.

Omission of factors important for normal brain development. There is evidence that the premature transition from intra-uterine to extra-uterine environment leads to a suboptimal development of the brain even in the absence of other neurological risk factors. A study found that children born extremely preterm (< 28 weeks gestation) and/or extremely low birth weight (< 1000 g) scored poorer than term-born normal birth weight peers on measures of IQ, visual matching, perceptual-motor abilities and inhibition and attention in early childhood. The group differences remained significant when scores were adjusted for corrected age (Orchinik, Taylor, Espy, et al., 2011). These findings suggest that the human brain develops in a unique fashion until the end of gestation and that a premature delivery disrupts this manner and causes subsequent developmental problems.

Brain insult due to preterm birth. Brain injury in preterm infants is usually caused by two conditions: intraventricular hemorrhage (IVH) or periventricular leukomalacia (PVL), each of which is closely related to hypoxia or ischemia in perinatal period (Volpe, 2009). IVH is a hemorrhage of the area surrounding the lateral ventricles. Structures and pathways that are vulnerable to insults include the caudate nucleus, the thalamus, the hippocampus, the optic radiations, and the corpus callosum (Luciana, 2003). The periventricular area in preterm infants is highly vulnerable to ischemia because this region has the arterial border zones. These zones are particularly sensitive to drops in cerebral pressure. Premature infants have a higher chance of experiencing a pressure-passive cerebral circulation and fluctuations in blood pressure, thus increasing the risk of ischemia when blood pressure falls. Infants with more severe IVH will have a greater risk of major handicap.

PVL is caused by ischemia that can cause necrosis (death) of the white matter surrounding the lateral ventricles (Volpe, 2009). During the third trimester of pregnancy, a period that preterm births are most likely to occur, glial cells in the periventricular region are actively produced specialized cells called oligodendrocytes. These cells are responsible for the formation of the myelin sheath of axons to speed up the nerve impulse conduction and information transmission. Necrosis leads to the formation of cysts (gliosis) and interrupts the formation of oligodendrocytes, as a result leads to disruption of myelination and causes cerebral atrophy, edema, and ventricular dialtion (Luciana, 2003). PVL can cause either focal or diffuse white and grey matter damage. Structures that are vulnerable to PVL include the brainstem, the basal ganglia, the cerebellum, the hippocampus, and/or the frontal cortex (Luciana, 2003).

Altered brain structures and functions in preterm individuals. The advancement of neuroimaging technology allows researchers to study the brain structures in detail. There is strong evidence that preterm individuals have a significantly smaller total brain volume, smaller white matter volume, and smaller grey matter volume than term-born peers. A recent meta-analysis study revealed that, when compared very preterm/very low birth weight (VBLW) to term-born children, total brain volume of very preterm/VLBW children was significantly reduced, with a combined effect size of d = - .58. In addition, there were reduction in white matter volume, with a combined effect size of d = - .53; and reduction in grey matter volume, with a combined effect size of d = - .62 (De Kieviet, Zoetebier, Van Elburg, Vermeulen, & Oosterlaan, 2012).

Smaller total brain volume, white matter volume and grey matter volume have been found associated with poorer performance on IQ test and various cognitive measures. For instances, reduced total brain volume has been described related to poorer performance in language, memory, and executive functions (Taylor et al., 2011). Altered white matter volume was linked to lower scores in measures of language, memory and executive functions (Allin et al., 2001; Taylor et al., 2011). And reduction in grey matter volume was correlated with impaired memory abilities (Taylor et al., 2011).

Neurodevelopmental Outcomes of Preterm Birth

A large body of evidence has shown that children born preterm have greater risk for “subtle” problems such as behavioural problems (Bohm, Smedler, & Forssberg, 2004; Johnson, 2007), neuropsychological impairments related to memory and executive functions which include planning, cognitive flexibility, inhibitory control and the incorporation of feedback (Bayless & Stevenson, 2007), and academic underachievement (Aarnoudse-Moens, Oosterlaan, Duivenvoorden, van Goudoever, & Weisglas-Kuperus, 2011). A recent meta-analysis study revealed that very preterm children and/or with low birth weight have moderate-to- severe deficits in academic achievement, attention problems, internalizing behavioural problems, and small-to-moderate impairments in working memory, cognitive flexibility and verbal fluency (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009). Executive functions (EF) have been found strongly associated with behavioural problems and academic achievement (St. Clair-Thompson & Gathercole, 2006). EF might explain the problems that preterm children face in the aspects of behaviour and learning. In fact, evidence shows that typically developing children have poorer working memory also encounter difficulties in learning of mathematics, spelling and reading (Gathercole & Alloway, 2008). Thus, it is possible that preterm children who have academic difficulties at school might also have poorer working memory compared to their term-born peers.

Working Memory

Working memory (WM) is defined as the ability to store and simultaneously process information in mind over brief periods of time (Baddeley & Hitch, 1974), it is the basic and essential skill to support our daily activities. WM is different from short term memory or long term memory. Short term memory refers to the situation that an individual simply has to store information without the need to mentally transform it at the same time, for example, remembering a telephone number. Seemingly short term memory and WM are distinct from each other, in fact, WM is an umbrella term for a larger system of which short term memory is a part of it.

Long term memory refers to memory of experiences that happened in the past or near present (e.g., episodic memory or autobiographical memory), and also for knowledge that has been acquired over long periods of time (e.g., semantic memory) (Gathercole & Alloway, 2008). Although WM is different from long term memory, materials store in the long term memory can facilitate our immediate memory performance by reducing the demand on the limited capacity of WM (Gathercole & Alloway, 2008). Therefore, we are more likely to remember a list of words that are meaningful to us (e.g., names of foods) than a combination of unfamiliar words. Many people use long term memory to supplement WM as a strategy for meeting the high memory demands of everyday activities.

Models of Working Memory

There are a range of theoretical accounts of WM namely attentional-based model (e.g., Cowan, 1995, 2000); resources-sharing model (e.g., Daneman and Carpenter, 1980, 1983); and time-based theories (e.g., Towse and Hitch, 1995). The most enduring and influential account is provided by the Baddeley and Hitch (1974) model. This model has three main components. Two of these components, the phonological loop and the visuospatial sketchpad, are slave systems that are specialized for temporarily storing verbal and visuospatial materials respectively. The last component is the central executive which is a higher level regulatory system and involves in controlling of attention. This model has been advanced by Baddeley into a four-component model over subsequent years (Baddeley, 1986, 2000).

The phonological loop. The phonological loop is responsible for temporarily storing of materials that expressed in sounds, phonemes or spoken language formats. However, representations store in the phonological loop will decay rapidly across time. In order to keep auditory information in the loop, a process called subvocal rehearsal plays a vital role. Subvocal rehearsal is a process that corresponds to overt articulation (speaking) but it does not involve the generation of sounds. During rehearsal, representations in the phonological loop are continuously rehearsed before they have time to decay, thus they can be stored in the phonological loop. Rehearsal is also a time-limited process in which lengthier items take longer time to activate than shorter items. Materials that are not presented in a language format but which are associated with verbal labels such as prints or pictures can be stored in the phonological loop through subvocal rehearsal. In this condition, rehearsal will generate the corresponding phonological representation of the non-verbal information from stored lexical knowledge (Gathercole, 2007).

The existences of a short-term store and a subvocal rehearsal process of the phonological loop are mainly supported by the experimental findings of the serial recall paradigm. In serial recall task, lists of items are presented serially for immediate recall of the original order. Evidence that verbal material is held in the phonological loop is provided by the findings that recall is poorer for sequences in which items are highly similar in phonological structure (e.g., C, G, B, V, T) than for those which have little overlap in phonological similarity (e.g., X, K, W, Q, M) (Gathercole, 2007). Evidence for the subvocal rehearsal process is based on the word length effect of serial recall. The accuracy of serial recall is impaired when the lists contain lengthy items (e.g., hippocampus, neuropsychology, prematurity) than short items (e.g., red, hand, car). In addition, a linear relationship between recall accuracy and the rate at which people can articulate the memory items is established: items that can be spoken more rapidly are recalled more accurately. This phenomenon can be interpreted as rehearsal requires more time to reactivate lengthy than short items. What is more, the phonological store and the subvocal rehearsal process also appear to relate to distinct regions of the left hemisphere of the brain. Neuroimaging studies show that verbal short-term store is associated with the left inferior parietal lobe, while rehearsal is linked with the Broca's area in the left premotor frontal area (Muller and Knight, 2006).

The visuospatial sketchpad. The second component of the Baddeley and Hitch (1974) model is the visuospatial sketchpad. This system is specialized in storing and manipulating information that presents in either visual or spatial format. The visual short-term store maintains the visual features of perceived objects, while the spatial component serves a recycling function analogous to subvocal rehearsal process of the phonological loop (Logie, 1995). Tasks that designed to tap the visuospatial sketchpad include remembering of the sequence in which a set of blocks are tapped (Corsi blocks task); recognizing the pattern of filled squares in a two-dimensional grid (Wilson et al., 1987); or recalling the path drawn in a maze (Pickering et al., 2001). Short-term store for visuospatial materials is associated with an increase activity in the right inferior prefrontal cortex, anterior occipital cortex, and posterior parietal cortex (Olesen, Nagy, Westerberg, & Klingberg, 2003).

Some researchers have proposed that the visual and spatial stores of the visuospatial sketchpad are two distinct subcomponents. This suggestion has been supported by studies on neuropsychological patients with acquired brain injuries. Findings reveal that patients with impairments in the visual store have preserved spatial short-term memory, while patients with deficits in spatial short-term memory have intact visual short-term memory (Della Sala & Logie, 2003).

In summary, although the understanding of the visuospatial sketchpad is less established compared to the phonological loop, two facts have been identified. First, the visuospatial sketchpad is independent with the phonological loop. Gathercole and Peaker (1998) found that when children were given memory span tasks that assessed phonological and visuospatial short term memory, there were no significant associations between these two types of tests, suggesting that they are two different types of WM. Second, the processes for storing and manipulating visual and spatial information are distinct from each other.

The central executive. The last but the most important component of the WM model is a limited-capacity domain-general system that supports a wide range of cognitive activities - the central executive. The central executive is responsible for controlling the WM system as it is closely associated with the controlling of attention, the monitoring of information flow within WM, and the retrieving of materials from the long term memory. In order to test the central executive functions, complex span tasks which demand both storage and processing are employed. One popular example of complex span tasks used in adult populations was developed by Daneman and Carpenter (1980) in which participants read aloud each of a list of sentences (i.e., processing), and at the end are required to recall the last word of each sentence in the same order as the sentences presented (i.e., storage). The number of sentences read on each trial is then increased until the participants can no longer recall the sequence of final words. Complex span tasks that used by young children include counting span task or the odd-one-out task. In counting span task, the child is required to count the number of items in a series of visual displays (i.e., processing), at the end of the sequence, he/she is asked to recall the tally of each array, in the same order as the presentation (i.e., storage). Researchers have suggested that complex span tasks can measure WM performance and at the same time reflect the functions of the central executive because the processing portions of complex span tasks are supported by the domain-general central executive component, while the storage parts are sustained by the specific domain-specific slave system (Baddeley & Logie, 1999). This view is supported by a study done by Alloway and co-workers (2004) in which the latent factor structure underlying children's performance on complex span tasks in verbal and visuospatial domains was investigated. The authors reported that the best-fit model is a construct consists of a domain-general factor corresponding to the central executive, plus structures consist of distinct but associated verbal and visuospatial short term storage components which corresponding to the phonological loop and visuospatial sketchpad (Alloway, Gathercole, Willis, & Adams, 2004).

Finally, the notion that central executive is a distinct component from the other two slave systems is supported by neuroimaging studies. Neuroimaging findings revealed that activities tax central executive are related to increased activations in frontal lobes of bilateral hemispheres of the brain and particularly in the prefrontal cortex, instead of in the brain regions which are related to either phonological loop or visuospatial sketchpad (Luciana & Nelson, 1998; Scherf, Sweeney, & Luna, 2006).

Development of Working Memory in Children

As aforementioned, the Baddeley and Hitch (1974) model suggests that working memory composes a domain-general processing component and two domain-specific storage systems. This adult-based model causes developmental scientists have interest to investigate whether children have the same functional organizations as what adults possess. In addition, the consistency of the developments of these structures across the childhood period also draws the attention of developmental researchers.

In order to better understand the cognitive mechanisms underpinning WM in children, Alloway, Gathercole, and Pickering (2006) conducted a study to explore the structure of verbal and visuospatial short-term and WM in children aged between 4 and 11 years. Findings based on confirmatory factor analyses revealed that the best account for the data is a model composes 3 separate factors which represent a domain-general construct incorporating both verbal and visuospatial WM, a verbal short-term memory construct, and a visuospatial short-term memory construct. Furthermore, the authors found that this 3-factor model also provided a good fit with the data when the sample was divided into 3 different age bands: 4 to 6, 7 to 8, and 9 to 11 years. These findings indicated that a tripartite structure of working memory is in place as young as 4 years of age. Besides, the underlying cognitive structure for WM appears to be consistent across this developmental period.

Another interesting finding from this study was the path between the constructs of WM and the visuospatial short-term memory was very high for the 4 to 6 age group ($r = .97$). When the correlation between these two variables was fixed to represent a perfect association, there was no significant decrease in the fit of the model for the youngest age group, but it was not the case for the older groups. This showed that younger children rely on the central executive to a larger extent than older children do when performing visuospatial short-term memory tasks (Alloway et al., 2006).

Verbal working memory. It has been observed that the memory span for verbal materials increases across childhood. For example, typically developing children can remember 3 numbers in a number sequence by the age of 5 years, 4 numbers by the age of 9, and 5 numbers by 11 years (Hitch, Halliday, Dodd & Littler, 1989). This developmental improvement in memory span has been explained by two hypotheses. The first view proposed that the memory capacity increases simply because the mechanism responsible for storage can hold more information, while the second notion suggested that it is related to processing efficiency as the processing speed that affects memory span improves with age. To extend the processing efficiency hypothesis, articulation rate has been proposed to be a key factor that affects the developmental increase in verbal memory capacity. Articulate rate refers to the speed that a person can repeat a single word over and over again, it is also called reading rate. In order to keep information in the phonological storage, one uses verbal rehearsal to refresh the memory trace in the store. Thus, if one can read or articulate faster, he/she will have a faster verbally rehearse rate and consequently a better memory span. With age, reading or articulating rates are improving which allow faster rehearsal rates, hence, higher memory spans are found in older children than younger children (Baddeley & Halliday, 1983).

Visuospatial working memory. The amount of visuospatial information that children can recall also improves with age. For examples, Issacs and Vargha-Khadem (1989) found that spatial memory, as measured by the Corsi blocks span test, increased from an average of 4.1 to 5.6 blocks in a sample of children aged between 7 and 15 years. Similarly, an age-related improvement in the performance on recalling the visual patterns of black-and-white squares in a grid has been reported by studies involving children aged 5, 7, and 10 years and adults (Miles, Morgan, Milne, & Morris, 1996; Wilson, Scott, & Power, 1987). Kwon, Reiss, and Menon (2002) also reported age-related increases in brain activation in brain regions related to visuospatial WM tasks. Age-related improvement in performance on both spatial memory and visual pattern were found in the above-mentioned studies, however, one would also have interest to know the cause of these improvements. One suggestion is children tend to shift their strategies from visual to verbal for coding visually presented information in early school years (Gathercole & Hitch, 1993). Hitch, Halliday, Schaafstal, & Scheraagen (1988) investigated immediate memory for visual similarity of drawings in children aged

5 and 10 years. In this study, children were tested on immediate memory for three sets of drawings of familiar objects: a visually similar set (e.g., pen, fork), a set with long names (e.g., umbrella, kangaroo), and a control set (e.g., pig, cake). The assumptions of this study were if children tried to remember the drawings as visual images, they would expect to have difficulty recalling visually similar objects. On the contrary, if children remember the pictures using their names, they would expect to recall fewer objects with longer names, but would not be affected by visual similarity. The authors found that children aged 5 years showed more difficulties in remembering visually similar objects, while children aged 10 years had more errors in recalling the long-named items (Hitch et.al., 1988). These findings demonstrated a clear evidence for a developmental shift from visual strategies at 5 years to verbal naming strategies at 10 years.

While there is evidence that visuospatial short-term memory is distinct from phonological short term memory, evidence also supports that the developments of the visual and spatial components of the visuospatial sketchpad are separate and independent of each other. Hamilton, Coates, & Heffernan (2003) examined the nature of visuospatial WM development in children aged between 6 and 13 years and adults aged 18 to 38 years, using visual span and spatial span measures. They reported that the visual component of the visuospatial sketchpad developed quickly between 6 years and adulthood, while the spatial component had a slower developmental improvement. These findings provided evidence that these two subsystems are developmentally fractionated.

Working Memory and Academic Learning

The relationship between working memory and academic achievement has been well studied in the past few decades. Consistent findings indicated that working memory is a good predictor of children's academic attainment. In a former study, Gathercole and Pickering (2000) assessed children aged 6 and 7 years (i.e., one year after entering school in the U.K.) on measures from the Working Memory Test Battery for Children and related the performances to the scores on English and mathematics from the national curriculum tests. Children were classified into three different groups according to their performances on English and mathematics: below average, average, and above average. Findings showed that WM performance was lowest in the below average group, and high for the above average group for English. In contrast, verbal short-term memory scores did not differ between the three ability groups. Similarly, this study also found a close link between WM and mathematic learning. The authors reported a linear relationship between these two performances, the below average maths group had the lowest WM performance while the above average maths group obtained the highest working memory scores. The verbal short-term memory scores did not differ between the below average and average groups. Taken together, these findings suggest that it is WM rather than short-term memory determines children's academic attainments in English and mathematics.

In order to examine whether the association between WM and academic attainments extends beyond the early school years, Gathercole and colleagues (2004) assessed the WM of children at the age of 14 years and related this ability to their English, mathematics, and science performances in the national curriculum tests. Results showed that children had higher WM scores also had higher attainment levels in these 3 subject areas. In addition, large WM differences were seen across the maths and science ability groups. These findings revealed that WM also affects academic learning in later years of education, particularly in maths and science.

Other research studies also show that the phonological loop links closely to the acquisition of language in children (Gathercole & Baddeley, 1989; Sansavini et al., 2007), while the visuospatial sketchpad plays an important role in arithmetic skills learning (Dark & Benbow, 1990).

Educational outcomes in children born preterm. Considerable research demonstrates that children born prematurely (< 37 weeks' gestation) and /or low birth weight (birth weight < 2500 g) are at higher risk for school-based learning difficulties (Anderson, Doyle, & the Victoria Infant Collaborative Study Group, 2003; Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Johnson, Wolke, Hennessy, & Marlow, 2011; Johnson et al., 2012). Preterm children are found to perform less well than term-born children on standardized achievement measures such as the Woodcock Johnson-III Tests of Achievement (WJ-III) (Pritchard et al., 2009) and in teacher ratings on learning progress (Taylor et al., 2011). Compared to term-born peers, preterm children with and without brain injury require more school services such as individual education plan (IEP) (FT,16% vs. PT with brain injury, 76% and PT without brain injury, 44%); and support in reading (FT, 9% vs. PT with brain injury, 44% and PT without brain injury, 28%), writing (FT, 4% vs. PT with brain injury, 44% and

PT without brain injury, 20%), and mathematics (FT, 6% vs. PT with brain injury, 47% and PT without brain injury, 30%) (Luu et al., 2009). Furthermore, group differences in academic achievement are also found in various ages such as preschool age (Taylor et al., 2011), childhood (Aarnoudous-Moens et al., 2011; Pritchard et al., 2009), and adolescence (Luu et al., 2009). Some studies showed that poorer academic attainments in preterm children are not related to lower IQ (Aarnoudous-Moens et al., 2011; Taylor et al., 2011). Instead, academic deficits in preterm children are closely linked to their gestational age and birth weight (Taylor, Hack, Klein, & Schatschneider, 1995), and the presence and severity of neurological impairments such as intraventricular haemorrhage (IVH) (Sherlock, Anderson, Doyle, and the Victorian Infant Collaborative Study Group, 2005).

Working memory impairments in children born preterm. Academic underachievement is consistently found in preterm children. At the same time, academic performance is closely related to WM. Thus, it is possible that children born preterm have impaired WM. In fact, this hypothesis is supported by some research studies.

Verbal working memory impairments. Aarnoudse-Moens and colleagues (2009) assessed the verbal WM in preterm and term-born children using backward word span test. The mean age of the preterm children was 5.9 years, and their mean gestational age was 28 weeks. The authors reported that the preterm group performed significantly poorer than the term-born control group on the backward word span task, group difference remained significant even after IQ was controlled. In addition to preschool aged preterm children, impaired verbal WM as measured by backward digit span test and letter-number sequencing test was also found in preterm children in middle childhood (Mulder, Pitchford, & Marlow, 2011); and preterm children with extremely low birth weight (Anderson, Doyle, and the Victorian Infant Collaborative Study Group, 2003).

Visuospatial working memory impairments. Other researchers have more interest to examine the visuospatial WM of preterm children. Luciana and coworkers (1999) used the Cambridge Neuropsychological Testing Automated Battery (CANTAB) to test the spatial WM of a sample of preterm children aged 7 to 9 years, with mean gestational age of 30 weeks. Their spatial memory span and spatial WM were then compared to age-matched term-born children. The authors found that preterm group made 25% more memory errors than the term-born control group. When examining the performance within each task difficulty level, there were no significant group differences in performance for searches of two and three items. However, for searches of four, six or eight items, preterm children had more memory errors than term-born participants. These findings suggested that preterm children had WM impairments relative to age-matched term-born children only when task is difficult.

Mixed findings. Some studies have examined both verbal and visuospatial WM in preterm children; however, the findings were mixed. Some studies found impairments only in visuospatial but not verbal WM in preterm children. For example, an earlier study reported a significant group difference in visuospatial WM when compared a group of preschool aged preterm children with very low birth weight to a sample of term-born children, with the performance favoured term-born controls. However, this group difference became non-significant after controlling for gestational age and/or birth weight. No significant group differences were found in verbal WM (Ni, Huang, & Guo, 2011). Similarly, Saavalainen et al. (2007) reported that adolescents born preterm performed less well on complex spatial span tasks than their term-born peers, even when verbal IQ and processing speed were partialled out. The authors also failed to find a group difference in verbal WM. In contrast, in a recent study, very preterm children were found to have significant deficits in both verbal and spatial WM relative to children born at term, with an effect size of 0.3 (Aarnoudse-Moens, Duivenvoorden, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2011). Another study reported that children born extremely preterm or with extremely low birth weight scored significantly poorer than term-born controls in both digit backward subtest and spatial span backward subtest from the Wechsler Intelligence Scale for Children – III edition (WISC-III) (Ford et al., 2011). Clark and Woodward (2010) examined the verbal and visuospatial WM in very preterm children with and without cerebral abnormalities. The authors found that overall very preterm children had poorer verbal and visuospatial WM than term-born children. When further examining the findings, very preterm children without cerebral abnormalities performed similarly to term-born children. In addition, verbal WM impairments were mainly confined to children with moderate-severe neonatal cerebral abnormalities, while children with mild and moderate-severe cerebral abnormalities had greater difficulties in visuospatial WM. Collectively, these findings suggested WM impairments in preterm children depend on the severity of cerebral abnormalities. Further, these findings revealed that very preterm children may be more vulnerable to visuospatial WM impairments than verbal WM deficits.

Why mixed findings. There are some possible explanations for the inconsistent pattern of findings when investigating the WM profiles of preterm children, there are some possible explanations for it. First, it is very common to use digit span test to assess verbal WM, however, some researchers tended to combine the scores for both forward and backward conditions together in order to generate a composite score for WM (e.g., Ford et al., 2011). This method makes verbal WM performance entangles with verbal short-term memory, hence obstructs accurate measurements. Second, researchers tended to use single task to assess WM abilities in their studies. The use of single task may induce at least two problems. One is generalization problem. Since different single task may tap on different variables of a construct, any group difference observed can only reflect the difference in the ability based on a specific test, it cannot be generalized to other tests of the same construct. Another drawback of using a single task as an outcome measure is significant group difference was only yielded when the difficulty level of a task is high but not low (Lucianna et al., 1999). Different single tasks may have different difficulty levels. Thus, it is possible that the single measure used in some studies may not be difficult enough to elicit WM impairments, while others are complex enough to induce so. Hence, inconsistent results are observed. Third, the outcomes measures used were highly varied among studies. For example, for measuring spatial WM, some studies conducted the spatial span test from the WISC (e.g., Saavalainen et al., 2007), while others employed Corsi blocks test (e.g., Clark & Woodward, 2010), Knox's Cube test (e.g., Ni et al., 2011), spatial span subtest of the CANTAB (e.g., Aarnoudse-Moens et al., 2011) or spatial span subtest from Wechsler Memory Scale (WMS) (e.g., Luu, Ment, Allan, Schneider, & Vohr, 2011; Ford et al., 2011) to test the spatial WM abilities. It is not meaningful to compare the findings between studies using different measures. Finally, the preterm sample in each study is very different from one another. For examples, some studies may recruit very preterm children, while others focus on extremely preterm children. In addition, some of the studies may include preterm children with neurological impairments, but others may set these as an exclusion criterion. Because the preterm sample groups of studies are quite various, hence, the findings are mixed.

Working Memory Training

Working memory is critical to children's academic learning. It has been found that an increase in WM abilities can lead to significant improvements in mathematical performance as measured by the number of errors made in an addition task in children (Witt, 2011). Recent research also supported that WM training has a positive effect on various populations including elderly and young adults (Brehmer, Westerberg, & Bäckman, 2012; Chein & Morrison, 2010); typically developing preschool children (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009); typically developing children with low working memory capacity (Holmes, Gathercole, & Dunning, 2009); individuals with attention deficit/hyperactivity disorder (ADHD) (Beck, Hanson, & Puffenberger, 2010;

Halperin et al., 2012; Klingberg et al., 2005); adolescents with mild to borderline intellectual disabilities (Van der Molen, Van Luit, Van der Molen, Klugkist, & Jongmans, 2010); and adolescents born extremely preterm with extremely low birth weight (Løhaugen et al., 2011). Moreover, neuroimaging studies also demonstrated training-induced changes in brain activities which suggesting improved functions. For example, Olesen, Westerberg, and Klingberg (2004) found that after 5 weeks of working memory training, a group of healthy adults improved in their performances on Span board task, Stroop time, and Raven's advances progressive matrices. At the same time, increased activities in the middle frontal gyrus and superior and inferior parietal cortices were also found. Their findings showed a positive correlation between cortical activity and WM capacity in healthy adults. It also indicated that a change in brain activity could be evidence of training-induced plasticity in the neural systems underlie WM.

Working memory capacity has been found to associate with the integrity of white matter in the frontoparietal regions. In view of it, Takeuchi and colleagues (2010) investigated the effect of WM training on structural connectivity using voxel-based analysis (VBA) of fractional anisotropy (FA) measures of fiber tracts. They found a positive correlation between the amount of WM training and FA in the white matter regions adjacent to the intraparietal sucus and the anterior part of the body of the corpus callosum after training, these regions have been thought to relate to WM. Since changes in myelination lead to FA changes, the observed FA change possibly caused by training-induced increase in myelination. Hence, observed structural changes may underlie the improvement of WM capacity.

Transfer Effects of Working Memory Training

Empirical findings demonstrated that the effects of WM training can transfer to non-trained tasks. Such transfer effect is usually observed under a pretest-posttest design. Post-training improvement in tasks that are intended to measure WM capacity infers near transfer, while increased performance on tasks that are intended to measure related abilities implies far transfer (Shipstead, Redick, & Engle, 2012). Chien and Morrison (2010) studied the transfer effects of WM training on a group of undergraduates. Findings revealed that participants who completed 4 weeks of training demonstrated significant improvements in a complex WM span task (i.e., near transfer). Besides, they also had significant improvements in both the Stroop task and reading comprehension (i.e., far transfer). Similarly, Thorell and colleagues (2009) reported that a 5- week computerized training on visuospatial WM led to significant improvements in non-trained tests of spatial and verbal WM as well as far transfer effects to attention in preschool children. In addition to healthy or typically developing participants, transfer effects are also found in individuals with ADHD. A group of ADHD children aged 7 to 15 years received a computerized WM training 25 minutes each day for 5 to 6 weeks. At the end of training, they were assessed on measures of trained WM tasks and on non-trained visuospatial WM task and the Raven’s progressive matrices. Results showed significant improvements in both trained and non-trained WM tasks. In addition, ADHD symptom, as measured by the number of head movements during training, was significantly reduced. These findings indicated that WM training not only has near and far transfer effects, but also has the potential to reduce the clinical symptoms of ADHD (Klingberg et al., 2002).

Lasting Effects of Working Memory Training

In addition to transfer effects, research also demonstrates a long lasting effect of WM training. Løhaugen and co-workers (2011) evaluated the effect of WM training on both trained and non-trained verbal WM tasks in adolescents with extremely low birth weight. Extensive neuropsychological assessments were administered before and immediately after training, and at 6-month follow-up. The authors found that all participants improved significantly in both trained and non-trained WM tasks. Moreover, the effects were sustained till the 6-month follow-up assessment. Similarly, in a study to assess the efficacy of a 5-week WM training program in children and adolescents with ADHD, parents and teachers were asked to complete paper-and-pencil measures of WM, executive functioning, and ADHD symptoms at baseline, post-training, and 4-month follow-up. Parent ratings indicated that participants improved in inattention, overall number of ADHD symptoms, initiation, planning/organization, and WM at both post-training and 4-month follow-up assessments, indicating WM training has a lasting effect on improving WM, executive function and ADHD symptoms (Beck et al., 2010).

Approaches to Working Memory Training

Morrison and Chein (2011) suggested that the approaches for WM training can be classified into two main types: domain-specific and domain-general.

Domain-specific approach is characterized by teaching the trainees a method to remember increasing amounts of information of a particular type (e.g., strategy training), while domain-general approach refers to training involves repetition of demanding working memory tasks designed to tap domain-general working memory mechanisms (e.g., core training).

Domain-specific/Strategy training. Strategy training is a kind of domain-specific training. It involves teaching trainees effective techniques to encode, maintain, and/or retrieve information. In studies examining the use of strategy, researchers usually taught participants a kind of particular strategy and then provided practices for the strategy of interest. Some strategy trainings aimed at verbal rehearsal (e.g., Turley-Ames & Whitfield, 2003; Loomes, Rasmussen, Pei, Manji, & Andrew, 2008), while others focused on elaborative encoding strategies (Carretti, Borella, & De Beni, 2007: McNamara & Scott, 2001).

The rationale for rehearsal training is based on the notion that increased use of rehearsal corresponds with increases in memory capacity in children (Flavell, Beach, & Chinsky, 1966). This suggestion has gained support from a handful of studies. For example, Ford, Pelham and Ross (1984) reported that children could improve their WM performance through the use and practice with a verbal rehearsal strategy. Elaborative encoding strategy include practice with chunking (e.g., St Clair-Thompson, Stevens, Hunt, & Bolder, 2010), composes a mental story with items (e.g., McNamara & Scott, 2001), and uses of imagery to make items more salient (e.g., Carretti et al., 2007). This strategy technique stems from research on skilled memorizers. Expert memorizers can strategically encode relevant information and create meaningful associations between to-be-remembered items and information stored in the long term memory (e.g., semantic knowledge). This view has been supported by research studies. In the classic case study conducted by Chase and Ericsson (1981), an expert runner S.F. was taught to group digits into meaningful pattern. When tested on his digit span after training, he was able to recall 80 digits using a strategy of chunking the numbers into running times.

While strategy training have utility in healthy populations, some researchers have studied the effective of this technique in clinical populations such as children with Down syndrome (Comblain, 1994), and individuals with fetal alcohol spectrum disorder (Loomes et al., 2008). Similar training benefits were observed in these studies.

Although strategy training gains support from research studies, this training paradigm still faces the challenge of generalization. Refer back to Chase and Ericsson's (1981) classic study, S.F. was able to recall large amounts of numeric items, however, when the to-be-remembered information changed to words or other materials, his memory capacity dropped to a normal adult level. This finding revealed that strategy training yields increased performance only with tasks involve materials that are similar to the trained strategy but could not generalize to tasks that have different nature.

Domain-general/Core training. Core training usually involves repetition of demanding WM tasks which designed to tap domain-general WM mechanisms. Some core training programs include a compilation of tasks with various stimulus types to impact multiple components of the WM system. One example is the Cogmed computerized program (Holmes, Gathercol, & Dunning, 2009; Klingberg et al., 2005). This program composes of 12 tasks which tap on verbal short-term memory, visuospatial short-term memory, verbal WM and visuospatial WM. Another example is the COGITO, this program includes various WM, perceptual speed, and episodic memory tasks (Schmiedek, Lovden, & Lindenberger, 2010). The advantage of this training approach is different tasks could contribute to the training outcome in an additive fashion. However, the use of a variety of tasks and the involvement of many engaged processes make it difficult determining which components of the training program underlie subsequent WM improvements. Because of this drawback, some studies used a single task approach, the n-back paradigm. In this approach, participants are asked to determine if each subsequently presented item is the same as the one shown N items back. Due to the complexity of this task, it is also difficult to determine which specific WM mechanisms are responsible for improvements observed in the study (Morrison & Chien, 2011).

Since core training aims at improving WM capacity through strengthening domain-general WM mechanisms, it would expect to see transfer effects from this approach. In fact, many research studies on Cogmed have demonstrated both near transfer effect to non-trained WM tasks (e.g., Mezzacappa & Buckner, 2010), and far transfer to other tasks (e.g., Klingberg et al., 2005). For example, a group of children with ADHD received Cogmed training for 5 weeks and was tested on a battery of neuropsychological tests including processing speed, controlled attention, and inhibition tasks, as well as measures of mathematical and reading skills. Parent and teachers ratings on ADHD behaviours were obtained after training and at 8-month follow-up. Results showed that there was a significant training effect on psychomotor speed after training. Additionally, reading and mathematics were improved post-training and at the 8-month follow-up (Egeland, Aarlien, & Saunes, 2013).

Crucial Factors for a Successful Training Program

WM training demonstrates positive effects on WM in both healthy and clinical populations, however, training programs used across studies are highly varied. The variability of program content not only hinders the comparison of results across studies, but also reduces the chance for further developing the existing training programs.

To minimize the variability of program content and to enhance training efficacy, Klingberg (2010) proposed three factors that are crucial to a successful WM training program. First, training should not simply teach specific strategies for remembering information (e.g., rehearsal training). Since memory strategies seem to be context specific (Chase & Ericsson, 1981), people especially those with cognition deficits tend to have difficulty recognizing situations in which a strategy can be applied (Butterfield, Wambold, & Belmont, 1973). Hence, although strategy training is an effective approach, its effects are limited by generalization. Second, training should be specifically focused on working memory tasks. It is because the involvement of other tasks will be time-consuming and thus dilute the training effect. Third, training should be rigorous (i.e. at least 30-60 minutes each time for not less than 20 sessions), and be adaptive to the abilities of the participants. Adaptive means if the participant can meet the requirement of the task, the difficulty level should increase. In contrast, if the participant fails the task, the task difficulty should decrease, accordingly. The benefit for an adaptive program is the participant will consistently engage in the task at a level that is neither boring nor overtaxing (Lövden et al., 2010).

Based on literature review, Dahlin, Bäckman, Neely and Nyberg (2009) also suggested some similar factors for an effective WM training. They reported that higher levels of training-related changes were found in studies where participants received longer period (> 1 week) of training compared to studies where participants received shorter period (< 1 week) of training. Besides, they also reported that more training sessions resulted in larger effect size. In addition to a dose-dependent pattern, Dahlin and colleagues (2009) also proposed that an optimal degree of difficulty during the entire training period is important. One way to adjust task demands is to use adaptive training to meet the participants' performance.

In summary, based on the suggestions made by Klingberg (2010) and Dahlin et al. (2009), if one wants to design an effective WM training program, he/she should consider the following factors: (a) the intensity of training (in terms of length of training period and number of sessions), (b) optimal degree of difficulty and the use of adaptive training, (c) solely train on WM tasks and, (d) not only involve strategy training.

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Chapter Three

Study One: Working memory profiles of children born preterm

Working memory (WM) refers to the abilities to hold information in the mind and perform action on it simultaneously (Baddeley & Hitch, 1974). Literature documents that WM is closely linked with academic achievement especially mathematics (Bull, Espy, & Wiebe, 2008; Gathercole, Pickering, Knight, & Stegmann, 2004) and reading (Gathercole & Baddeley, 1993; Gathercole, Brown, & Pickering, 2003). Gathercole and Pickering (2000) found that students with low WM capacity had poorer education attainment than those with high WM performance. Working memory plays a crucial role in learning, however, WM difficulties are frequently found in various pediatric clinical groups such as preterm population (Baron et al., 2012; Garcia, Mammarella, Tripodi, & Cornoldi, 2014; Manji, Pei, Loomes, & Rasmussen, 2009; Skogan et.al, 2014).

Children born preterm are vulnerable to working memory impairments because of two major causes. The first cause is preterm infants are born in a period in which both grey and white matter are developing rapidly (Huppi et al., 1998). Due to the vulnerabilities of the oligodendrocyte precursors to hypoxia-ischaemia, white matter is susceptible to insults after premature birth (Volpe, 2009). Evidence also shows that white matter integrity is highly associated with WM performance (Allin et al., 2011; de Kieviet, Zoetebier, van Elburg, Vermeulen, & Oosterlann, 2012; Nagy, Westerberg, & Klingberg, 2004: Woodward, Clark, Bora, & Inder, 2012). Thus, infants born preterm have a high risk of WM impairments. The second factor is premature birth predisposes preterm infants to pathological conditions that human at this gestational age would not normally encounter such as an inappropriate nutritional support, leading to an elevated risk for adverse neurodevelopmental outcomes in preterm children.

Baddeley and Hitch (1974) proposed that working memory has four aspects: verbal short-term memory (vst), visuospatial short-term memory (vsst), verbal working memory (vwm), and visuospatial working memory (vswm). Research shows that children born preterm have an increased risk to have impairments in Verbal Working Memory (VWM) (i.e., vst and/or vwm) and Visuospatial Working Memory (VSWM) (i.e., vsst and/or vswm). Aarnoudse-Moens and colleagues (2009) examined VWM in a group of preterm children (mean gestational age = 28 weeks, mean age = 5.9 years) using backward digit span and backward word span tasks and compared their performance to a sample of age-matched term-born controls. The preterm group demonstrated poorer performance than the control group in VWM, even when controlling for intelligence. Luu, Ment, Allan, Schneider, and Vohr (2011) identified VSWM deficits in a group of adolescents born very preterm (birth weight ≤ 1250g) who performed worse than their term peers in backward spatial span task. Since some studies examined VWM while others investigated VSWM in preterm children, it is difficult to conclude whether WM impairments in children born preterm are domain-specific (i.e., impairments found in either Verbal or Visuospatial WM) or domain-general (i.e., impairments found in both Verbal and Visuospatial WM). Moreover, only examining at one area, it is unable to gain insight into the overall profile of WM which may reveal relative strength in some areas and possibly variations in presentation between individuals. Because of these, examining the overall WM profile of children born preterm is important. It not only can help researchers better understand the relationship between early brain insults and consequent neurodevelopmental outcomes, but also able to guide practitioners to plan targeted intervention and to use children’s strengths to assist their weaknesses in order to optimize intervention outcomes.

The Present Study

In view of the aforementioned limitations in research design and the benefits of knowing the WM profile of children born preterm, the present study had the following three objectives.

The first objective was to investigate the WM profile of children born preterm from a developmental perspective. There are three sub-objectives under the first objective: (1a) In order to have a better understanding of the overall WM profile of preterm children, I examined the four aspects of WM (i.e., vst, vsst, vwm, and vswm) in a group of preterm children using a standardized measure, the Automated Working Memory Assessment (AWMA). (1b) To investigate the effect of age/schooling on the WM profile of preterm children, the preterm group was divided into two subgroups based on children’s schooling experience (i.e., preschool and school subgroups), and the WM profile of preterm children in each subgroup was examined. (1c) As fractionation of brain structures for supporting different cognitive functions emerges during childhood and cognitive skills become independent with each other (Tsujimoto, Kuwajima, & Sawaguchi, 2007), to further understand the development of WM profile in preterm children, I explored the correlations among the four WM aspects in each subgroup in order to see whether VWM and VSWM is dependent with or separate from each other. I predicted that preterm children would have an uneven WM profile with worse performance on VSWM than VWM. And this profile would be more significant in the school subgroup than the preschool subgroup. I also predicted that the VSWM and VWM were significantly correlated in both preterm preschool and preterm school subgroups.

The second objective was to examine whether the WM impairments found in preterm children, if any, are domain-specific or domain-general. In order to address this objective, the performance on the 4 aspects of WM of the preterm group was compared to that in a group of age-matched term-born children. I hypothesized that preterm children would perform worse than age-matched term-born children on both VWM and VSWM, with a larger discrepancy in VSWM than VWM.

The third objective was to evaluate the relationship between performance-based and parent-rated WM in preterm children. I predicted that the relationship between these two measures on WM would be significantly correlated.

Method

Participants. Two groups of children were recruited in the present study. The preterm group consisted of 24 children (10 boys, 14 girls; age, M = 6.6 years, SD = 2.0, range = 4.2-11.2 years; gestational age (GA), M = 28.0 weeks, SD = 2.0, range = 24-32 weeks; birth weight (BW), M = 1106.5 grams, SD = 328.3, range = 642-1814 grams) who were recruited from the Neonatal and Infant Follow-up Clinic (NNFC) at the Glenrose Rehabilitation Hospital. The control group consisted of 22 age-matched term-born children (12 boys, 10 girls; age, M = 6.4 years, SD = 1.7, range = 4.2-9.8 years; GA, M = 39.1 weeks, SD = 1.5, range = 37-42 weeks; BW, M = 3183.9 grams, SD = 603.6, range = 2240-4394 grams) who were recruited in three ways: (i) preterm participants were asked to invite a classmate or a friend to take part as a control in the study; (ii) siblings of preterm participants were invited by the investigators to participate either as a control or a study participant depends on his/her gestational age at birth; and (iii) the study recruitment flyers were posted in the common areas at the Glenrose Rehabilitation Hospital and at the campus of the University of Alberta.

For children from multiple birth, all of them were invited to participate in this study if they met the selection criteria and had no sensory/motor impairments that would impede their participation in the assessment.

For birth history and perinatal complications, 33.3% of the preterm children and 18.2 % of the controls were born with multiple birth. In the preterm group, 95% of the children had respiratory distress, 20% had periventricular leukomalacia, another 20% had intraventricular hemorrahage, and 35% had retinopathy of prematurity. Yet, in the control group, none of the children had experienced similar problems after birth. Moreover, 25% of the preterm children had cerebral palsy, while only 9.1% of the controls had motor impairments. There were also more children in the preterm group (25%) than in the control group (9.1%) had received or were still receiving rehabilitation when being tested.

The present study was approved by the University of Alberta Health Research Ethics Board - Health Panel. Consent from parents and assent from children age 7 years or above were obtained before commencing testing. All children received a small toy and a $25 gift card as honoraria for their participation in the end of the testing session.

Procedure. Each child was tested individually in a quiet room at the Glenrose Rehabilitation Hospital for a session lasting up to 3 hours. Breaks were taken every 45 minutes or as requested by the child, drink and snack were offered during breaks. Parents were asked to stay in a waiting area and to complete the parent rating form and a demographic questionnaire during the testing session. Assessment tools were administered in a fixed sequence designed to vary task demands across successive tests (see Appendix 1A).

Measures.

Working memory. The Automated Working Memory Assessment (AWMA) was conducted to measure the Verbal and Visuospatial WM of each child. The AWMA is a computer program that consists of three tests for each of the verbal and visuospatial aspects of short-term memory and working memory. It can be administered to individuals age 4 years or above. The test trials are presented in block format and each block consists of six trials. The program generates a Report Summary of the child's performance in which standard scores (mean = 100, SD = 15) and percentiles are provided. In the present study, 8 tests, two for each aspect of working memory were administered on each child.

Verbal short-term memory. The Digit Recall and the Word Recall were conducted to test verbal short-term memory (vst). In these two subtests, the child heard a sequence of digits (for Digit Recall) or words (for Word Recall) and was required to immediately recall each sequence in correct order.

Verbal working memory. For testing verbal working memory (vwm), the Backward Digit Recall and the Counting Recall were conducted. In Backward Digit Recall, the child heard a sequence of digits and was asked to recall each sequence in backward order. In Counting Recall, the child was presented with a visual array of red circles and blue triangles. He/she was asked to count the number of red circles in an array and then recall the tally of numbers in sequence.

Visuospatial short-term memory. The Dot Matrix and the Block Recall were conducted to assess the visuospatial short-term memory (vsst). In Dot Matrix, the child was shown the position of a red dot in a series of four by four matrices and was asked to recall the position of dot by tapping the squares on the computer screen. In the Block Recall test, the child viewed a series of blocks being tapped and was asked to reproduce the sequence in correct order by tapping on the image of the blocks on the computer screen.

Visuospatial working memory. Mr. X and Spatial Recall were administered to assess visuospatial working memory (vswm). In Mr. X, the child was presented with a picture of two Mr. X figures. He/she was asked to identify whether the Mr. X with the blue hat is holding the ball in the same hand as the Mr. X with the yellow hat. The Mr. X with the blue hat might also be rotated. At the end of each trial, the child was asked to recall the location of each ball in the hand of Mr. X with a blue hat in the correct order by pointing to a picture with six compass points on the computer screen. In Spatial Recall, the child viewed a picture of two shapes where the shape on the right side has a red dot above it. The child was required to identify whether the shape on the right side is the same or opposite of the shape on the left side. The shape with the red dot might also be rotated. At the end of each trial, the child was asked to recall the location of each red dot on the shape in the correct order by pointing to the picture with three compass points on the computer screen.

Attention. Both auditory and visual attention were measured for each child.

Auditory Attention. The Auditory Attention (AA) subtest from NEPSY II is designed to test the selective auditory attention and the ability to sustain it in children age 5-16 years. In the present study, the AA subtest was not administered on children age 4 years because no standardized scores are available for this age. In AA, the child listened to a series of auditorially presented words and was asked to touch the red circle on the Stimulus Book as quickly as possible when he/she heard the word RED. A total of 180 words were presented which took about 3 minutes. The AA gave 4 primary scores: the number of correct responses, the number of commission errors, the number of omission errors, and the number of inhibitory errors. The primary scores were combined and transformed to scaled scores and two scaled scores were yielded: the Total correct scaled score (TCSS) and the Combined scaled score (CSS). High scaled score represents better performance.

Visual Attention. The Test of Variables of Attention (TOVA) is a computerized test designed to measure visual attention, impulsivity, and adaptability in individuals age 4-80^{+} years. In the first half of the test (the target infrequent half), a target is presented only once every 3.5 non-target presentations. In the second half of the test (the target frequent half), 3.5 targets are presented for every one non-target. The TOVA is 21.8 minutes long, a shorter version (10.9 minutes long) was administered to children age 4-5 years. The TOVA yielded four standard scores (mean = 100, SD = 15): the variability of response time (consistency), response time, commission errors (impulsivity) and omission errors (inattention). Scores lower than 70 are considered significantly below normal range.

General cognitive abilities. The Wide Range Intelligence Test (WRIT) was administered to measure the general intelligence of children. The WRIT assesses both verbal and non-verbal abilities by means of Verbal and Visual scales. The WRIT yields a Verbal IQ and a Visual IQ which generate a General IQ when combined (mean = 100, SD = 15).

Executive functions. Parents were asked to complete the parent rating form of the Behavior Rating Inventory of Executive Function (BRIEF). The BRIEF was standardized and validated for use with boys and girls, age 5-18 years. The parent ratings for 4-year-olds were excluded for data analyses in the present study as there are no standard scores for this age. The BRIEF Parent Form provides information on the child's behaviours at home. It contains 86 items within eight clinical scales that measure different aspects of executive functioning: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. The clinical scales form two Indexes, the Behavioural Regulation and the Metacognition, and an overall score, the Global Executive Composite. The raw score for each scale is converted to T score (mean = 50, SD = 10) and percentile with reference to the appropriate gender and age range. A high score represents executive dysfunctions.

Socio-economic status. Parents were also asked to complete a questionnaire that was designed based on the Hollingshead's Four-Factor Index of Social Position (Hollingshead, 1975). The Hollingshead score is a composite measure of the sex, marital status, educational attainment and occupational rank of the parent(s) in the family. An education score (1 through 7, with 1= less than a seventh-grade education, and 7 = graduate training) and an occupational score (1 through 9, with 1= farm labourers/menial services workers, and 9 = higher executives, proprietors of large business, and major professionals) were assigned for each parent. The computed scores ranged from 8 to 66, the higher score of a family, the higher the social status.

Data Analyses. Data analyses were conducted in three phases. For the first objective, to investigate the overall WM profile of preterm children, the performance of the preterm and the control groups on the 4 WM aspects were examined using descriptive statistics. To examine the age/schooling effect on the WM profile of preterm and control children, the preterm and the control groups were each divided into two subgroups (preschool and school subgroups) based on children's schooling experience and their performance on the 4 WM aspects were evaluated through descriptive statistics. To examine the associations between the different aspects of WM in preterm and age-matched term-born children, Pearson correlation coefficients between the four WM aspects were computed. The correlation pattern of the preterm group was then compared to that of the control group using descriptive statistics in order to determine any differences between the two groups. Similar Pearson correlation coefficients and descriptive statistics were repeated for the two preschool subgroups and the two school subgroups.

For the second objective, to examine whether the WM impairments found in preterm children, if any, are domain-specific or domain-general, two separate MANOVAs were conducted to compare the VWM and VSWM of the preterm to the control groups. MANOVAs instead of ANOVAs were used because the two measures for each aspect of WM are moderately correlated, rs ranged from .38 to .79, and it is important to take these correlations into account when performing the statistical analyses. In addition, if multiple ANOVAs were conducted independently, it might cause an inflated alpha error. In order to protect against Type I error that might occur, MANOVAs were performed. The first MANOVA was computed using the four tests associated with VWM (i.e., Digit Recall, Word Recall, Backward Digit Recall, and Counting Recall) as the dependent variable (DV), and the second one was conducted using the four tests associated with VSWM (i.e., Dot Matrix, Block Recall, Mr. X, and Spatial Recall) as the DV. Two similar sets of MANOVAs were repeated for the two preschool subgroups and the two school subgroups.

For the third objective, to examine the relationship between the performance-based and parent-rated WM in preterm children, Pearson correlation coefficients between the performance on each WM aspect and the BRIEF WM scale were computed.

Significance level for all analyses was set at $p < .05$. Bonferroni corrections were done for multiple comparisons with significance level set at $p < .05/n$, n was the number of comparisons done. For the second objective, the significance level was set at $p < .01$ (i.e., $p < .05/4$) when univariate analyses were performed following a significant overall test.

Results

Descriptive statistics. Data were screened for outliers. Univariate outliers were defined as children performed more than 3SD above or below the mean. No children in either group met this criterion.

The demographics of both preterm and term-born control groups were illustrated in Table 1.1. As expected, there was significant difference in gestational age between the preterm and the control groups. The preterm group had smaller gestational age than the control group. Besides, significant difference was found in birth weight between preterm children and age-matched term-born children, preterm children weighted less than age-matched term-born children at birth. No significant differences were found in age at assessment and SES between the preterm and the control groups.

There were significant differences in the IQ scores between the two groups. The preterm group had significant lower scores than the control group in

Verbal IQ, Visual IQ, and General IQ. For attention, MANOVA showed no significant difference in auditory attention between the preterm and the control groups, $F\,(2, 31) = 1.72$, $p > .05$, $\eta^2 = .10$. However, MANOVA revealed a significant group effect on visual attention, $F(4, 40) = 3.24$, $p < .05$, $\eta^2 = .25$, the preterm group had poorer visual attention than the control group. Given a significant group difference on visual attention was found, a Discriminant Function Analysis (DFA) was conducted. The overall chi-square test was significant, Wilks' $\lambda = .76$, chi-square = 11.53, df = 4, canonical correlation = .50, $p < .05$. The function extracted accounted for approximately 24.5% of the variance. Standardized canonical discriminant function coefficients indicated that omission error (0.948) was the only function that differentiated the group identity of children. MANOVA showed no significant difference in the BRIEF parent-rating between the preterm and the control groups, F (8, 37) = 2.0, p > .05, $\eta^2 = .30$.

Table 1.1

The Demographics, IQ Scores, Visual Attention, Auditory Attention, and Parent-rating of Executive Functions of the Preterm and the Control Groups

	Preterm group (n =24) Mean (SD), Range	Control group (n =22) Mean (SD), Range	F
Age (Years)	6.6 (2.0), 4.2-11.2	6.4 (1.7), 4.2-9.8	0.06
G.A. (Weeks)	28.0 (2.0), 24-32	39.1 (1.5), 37-42	451.0*
B.W. (Grams)	1106.5 (328.3), 624-1814	3183.9 (603.6), 2240-4394	201.1*
SES	41.0 (10.5), 23-57	47.6 (11.7), 24-62	3.9
Cognitive abilities			
VIQ	89.0 (11.8), 60-107	104.7 (10.3), 85-124	22.5*
PIQ	101.7 (14.7), 82-146	114.2 (13.6), 90-134	8.8*
GIQ	94.5 (12.1), 74-130	110.6 (10.4), 92-133	22.8*
Visual attention			
RT Variability	67.7 (26.1), 40-121	83.0 (22.4), 40-114	4.4
RT	87.9 (21.4), 41-114	93.2 (18.4), 57-116	8.8
Commission error	83.2 (24.8), 40-117	91.6 (25.1), 40-122	1.3
Omission error	61.3 (22.1), 40-110	82.9 (18.5), 42-110	12.6*
Auditory attention			
Commission error	3.4 (8.9), 0-39	2.9 (1.1), 0-44	1.6
Omission error	17.9 (16.1), 0-53	22.7 (21.3), 0-73	0.2
TCSS	9.1 (2.8), 4-14	10.5 (2.4), 6-14	2.3
CS	9.0 (2.7), 5-15	10.7 (2.6), 7-16	3.2
BRIEF			
Inhibit	43.8 (19.8), 12-80	38.6 (14.3), 13-65	1.0
Shift	44.6 (23.7), 9-91	39.4 (16.4), 9-64	0.8
Emotion control	41.7 (18.8), 12-72	41.8 (17.3), 14-73	0.0
Initiate	42.3 (21.7), 9-73	39.7 (16.8), 9-68	0.2
WM	46.3 (20.3), 12-78	40.9 (16.0), 13-68	1.0
Planning	47.0 (22.4), 12-85	45.0 (17.6), 12-72	0.1
Organization	41.0 (20.0), 11-70	43.2 (19.6), 9-69	0.1
Monitor	43.2 (20.0), 13-73	39.5 (18.5), 9-75	0.4

Note. G.A. = gestational age; B.W. = birth weight; SES = Socio-economic status; RT = reaction time; TCSS = total correct scale scores; CS = combined scores.
*$p < .01$

Working memory profiles of the preterm and the control groups. The mean score of each WM test for the preterm and the control group were shown in Table 1.2. Both preterm and control groups had scores within ± 1SD of the norm mean (mean = 100, SD = 15) in all WM tests. The preterm group had scores ranged between 93 and 104 across the tests, while the control group had scores ranged between 100 and 111 across the tasks. Both groups had similar variability in the performance on all WM tests except the two vwm tests.

Table 1.2

The Verbal and Visuospatial Working Memory Performance of the Preterm and the Control Groups

	Preterm group (n =24) Mean (SD), Range	Control group (n = 22) Mean (SD), Range
Verbal short-term memory		
Digit	96.5 (17.2), 47-120	105.5 (14.7), 86-137
Word	96.4 (20.8), 59-129	101.7 (15.8), 76-130
Verbal working memory		
Counting	94.5 (22.8), 57-139	103.5 (11.5), 84-136
Backward Digit	94.9 (18.4), 58-127	100.7 (11.9), 78-134
Visuospatial short-term memory		
Dot matrix	93.4 (14.8), 69-133	102.1 (15.0), 69-130
Block	93.2 (16.4), 64-139	103.4 (16.8), 73-136
Visuospatial working memory		
Mr. X	104.8 (15.9), 88-150	111.9 (18.8), 83-148
Spatial	100.5 (19.6), 55-135	111.0 (15.0), 83-139

The WM profiles of both groups were displayed in Figure 1.1. The profiles of both groups were quite similar to each other. For examples, both groups had the highest score on vswm tests. Besides, both groups had better performance on short-term memory than working memory of the verbal aspects and an opposite performance pattern in the visuospatial aspects.

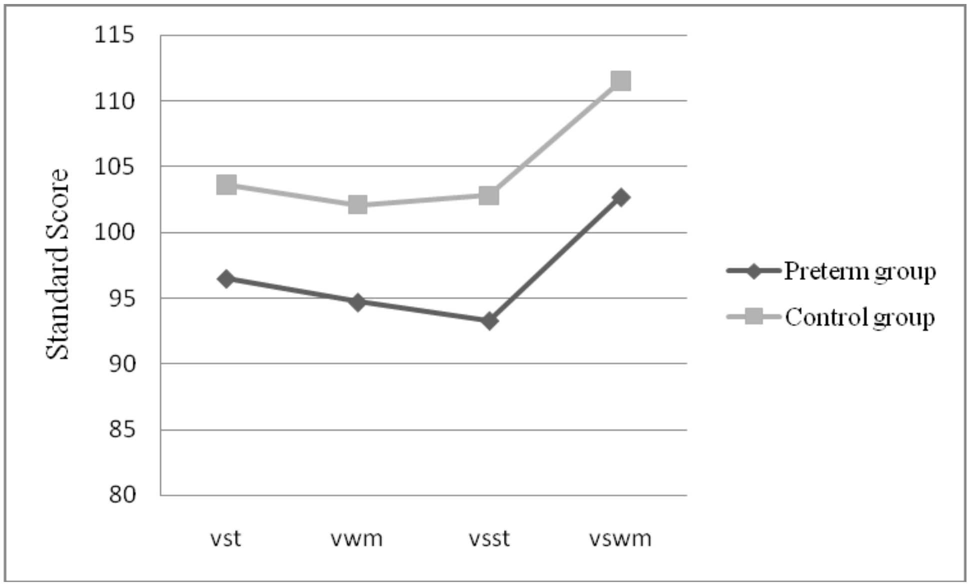

Figure 1.1. Working memory profiles of the preterm and the control groups.

Working memory profiles of the preschool preterm and the preschool control subgroups. Table 1.3 showed the demographics of both preschool preterm and preschool control subgroups. One-way ANOVA revealed no significant group difference in age between these two subgroups, $F(1, 22) = .21$, $p > .05$. For IQ, significant differences were found in Verbal IQ, $F(1, 22) = 19.87$, $p < .01$; Visual IQ, $F(1, 22) = 6.18$, $p < .01$, and General IQ, $F(1, 22) = 22.38$, $p < .01$. Preschool preterm children had lower Verbal IQ, Visual IQ and General IQ scores than their age-matched term-born peers. MANOVA showed a non-significant main effect of group on visual attention, $F(4, 19) = 1.50$, $p > .05$, $\eta^2 = .24$. Since majority of the children in these two preschool subgroups were younger than 5 years of age and no scaled scores for their auditory attention were available, thus MANOVA was not performed on the auditory attention between these two subgroups. MANOVA showed no significant difference in the BRIEF parenting rating between the preschool preterm and the preschool control subgroups, $F(8, 16) = 1.5$, $p > .05$, $\eta^2 = .24$.

Table 1.3

The Demographics, IQ Scores, Visual attention, and Parent-rating of Executive Functions of the Preschool Preterm and the Preschool Control Subgroups

	Preschool Preterm Subgroup (n =14) Mean (SD), Range	Preschool Control Subgroup (n =11) Mean (SD), Range	F
Age (Years)	5.3 (0.8), 4.2-6.9	5.1 (0.6), 4.2-6.0	0.2
G.A. (Weeks)	27.9 (2.4), 24-32	39.4 (1.6), 37-42	181.6*
B.W. (Grams)	1100.8 (364.3), 680-1814	3390.3 (697.3), 2240-4394)	112.7*
SES	41.2 (10.2), 27-57	48.9 (13.1), 24-62	2.7
Cognitive abilities			
VIQ	89.3 (12.1), 60-103	109.5 (9.6), 94-124	19.9*
PIQ	98.5 (12.70, 82-125	112.7 (15.3), 90-134	6.2*
GIQ	92.9 (10.4), 74-112	112.6 (9.9), 100-133	22.4*
Visual attention			
RT Variability	71.5 (23.0), 40-113	79.0 (20.5), 40-114	0.7
RT	88.8 (20.0), 44-114	88.3 (18.9), 51-116	0.0
Commission error	86.0 (24.3), 40-117	81.6 (31.8), 40-122	0.2
Omission error	61.2 (18.5), 40-93	77.0 (17.7), 42-110	4.5
BRIEF			
Inhibit	36.5 (20.0), 12-65	32.3 (16.6), 13-65	0.3
Shift	37.0 (25.8), 9-80	29.6 (16.8), 9-53	0.7
Emotion control	36.9 (21.0), 12-68	34.6 (18.1), 14-63	0.1
Initiate	31.8 (21.2), 9-55	29.2 (15.7), 9-47	0.1
WM	38.0 (22.1), 12-78	33.6 (17.8), 13-58	0.3
Planning	38.0 (23.3), 12-85	34.0 (16.3), 12-61	0.2
Organization	33.6 (21.9), 11-70	31.6 (19.8), 9-52	0.1
Monitor	34.8 (20.2), 13-65	27.4 (15.6), 9-57	1.0

Note. G.A. = gestational age; B.W. = birth weight; SES = Socio-economic status; RT = reaction time; TCSS = total correct scale scores; CS = combined scores.
*$p < .01$

Table 1.4 showed the performance on all WM tasks of both preschool subgroups. The preschool preterm subgroup performed worse than the preschool control subgroup in all WM tests except the two tests on vswm, both subgroups had similar performance on these two tasks. The preschool preterm subgroup had scores ranged between 88 and 103 across the tests, while the preschool control subgroup had scores ranged between 95 and 103 across the tasks. Besides, the preschool preterm subgroup showed more performance variability than the preschool control subgroup in both vst and vsst.

Table 1.4

The Verbal and Visuospatial Working Memory Performance of the Preschool Preterm and the Preschool Control Subgroups

	Preschool Preterm Subgroup (n =14) Mean (SD), Range	Preschool Control Subgroup (n =11) Mean (SD), Range
Verbal short-term memory		
Digit	92.7 (20.2), 47-117	103.6 (10.5), 87-124
Word	95.3 (19.0), 69-124	99.8 (12.5), 78-118
Verbal working memory		
Counting	85.7 (20.7), 57-139	101.6 (11.3), 84-126
Backward Digit	91.8 (18.9), 58-123	96.7 (11.6), 78-113
Visuospatial short-term memory		
Dot matrix	88.1 (11.4), 69-103	95.4 (11.9), 69-108
Block	94.8 (13.2), 73-122	97.5 (13.8), 73-117
Visuospatial working memory		
Mr. X	103.5 (18.1), 88-150	103.0 (15.1), 83-116
Spatial	101.0 (15.7), 83-135	102.7 (9.7), 83-117

When examining the WM profile of the two preschool subgroups visually (Figure 1.2), slightly different patterns were found. Although both subgroups had the highest score on vswm, lowest score was found on vwm in the preschool preterm subgroup and on vsst in the preschool control subgroup. Moreover, the performance differences between groups were greater in verbal aspects than in visuospatial aspects.

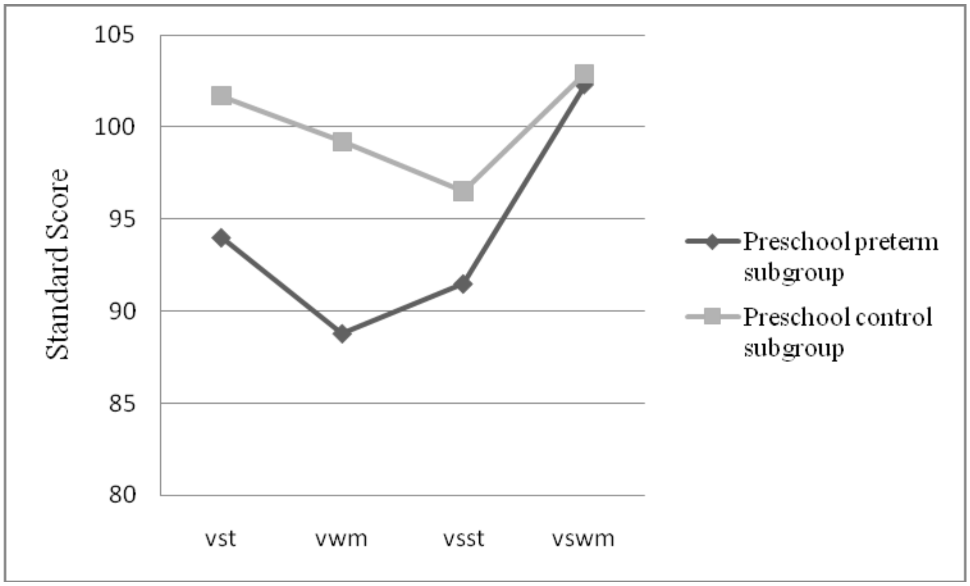

Figure 1.2. Working memory profiles of the preschool preterm and the preschool control subgroups.

Working memory profiles of the school preterm and the school control subgroups. Table 1.5 illustrated the demographics, IQ scores, visual attention, auditory attention, and the BRIEF parent rating on executive functions of both school subgroups. One-way ANOVA revealed no significant difference in age between these two subgroups, $F(1, 19) = 1.07$, $p > .01$. For IQ, significant differences were found in Verbal IQ, $F(1, 19) = 6.04$, $p < .01$, and in General IQ, $F(1, 19) = 4.69$, $p < .01$. The school preterm subgroup had lower Verbal IQ and General IQ scores than the school control subgroup. ANOVA showed no significant difference in Visual IQ between the two school subgroups, $F(1, 19) = 2.43$, $p > .01$. MANOVAs also showed no significant group effect in auditory attention, $F(2, 18) = .71$, $p > .05$, $\eta^2 = .07$; visual attention, $F(4, 16) = 2.25$, $p > .05$, $\eta^2 = .36$; and BRIEF parent rating, $F(8, 12) = 3.2$, $p > .05$, $\eta^2 = .48$.

Table 1.5

The Demographics, IQ Scores, Visual attention, Auditory Attention, and Parent-rating of Executive Functions of the School Preterm and the School Control Subgroups

	School Preterm Subgroup (n =10) Mean (SD), Range	School Control Subgroup (n =11) Mean (SD), Range	F
Age (Years)	8.4 (1.6), 6.8-11.2	7.8 (1.2), 5.8-9.8	1.1
G.A. (Weeks)	28.0 (1.2), 26-30	38.7 (1.3), 37-41	355.9*
B.W. (Grams)	1116.4 (276.9), 624-1430	2977.5 (430.4), 2502-3913	114.1*
SES	40.8 (11.6), 23-53	46.3 (10.5), 24-62	
Cognitive abilities			
VIQ	88.6 (12.0), 72-107	100.0 (9.2), 85-113	6.0*
PIQ	105.8 (16.8), 85-146	115.7 (12.2), 101-133	2.4
GIQ	96.7 (14.3), 79-130	108.7 (11.0), 92-125	4.7*
Visual attention			
RT Variability	62.9 (30.3), 40-121	87.0 (24.5), 40-113	4.1
RT	86.8 (24.2), 41-114	98.1 (17.3), 60-116	1.5
Commission error	79.5 (26.3), 40-110	101.6 (9.4), 80-112	6.8
Omission error	61.3 (27.1), 40-110	88.7 (18.2), 62-103	7.5
Auditory attention			
Commission error	0.5 (0.9), 0-28	0.5 (0.4), 0-1.1	0.0
Omission error	9.0 (7.9), 0-23.3	8.5(11.6), 0-36.7	0.0
TCSS	9.3 (3.0), 4-14	10.8 (2.7), 6-14	1.5
CS	9.4 (3.0), 5-15	11.0 (3.1), 7-16	1.4
BRIEF			
Inhibit	54.1 (15.1), 36-80	45.0 (7.6), 38-58	3.2
Shift	55.3 (16.1), 36-80	49.2 (8.4), 37-64	1.2
Emotion control	48.5 (13.5), 36-72	48.9 (13.6), 35-73	0.1
Initiate	56.9 (12.3), 36-73	50.3 (10.1), 36-68	1.8
WM	57.8 (9.8), 40-73	48.2 (10.1), 35-68	4.9
Planning	59.5 (14.1), 37-85	56.0 (10.9), 37-72	0.4
Organization	51.5 (11.2), 37-66	54.9 (10.5), 37-69	0.5
Monitor	55.0 (12.6), 38-73	51.6 (12.2), 35-75	0.4

Note. G.A. = gestational age; B.W. = birth weight; SES = Socio-economic status; RT = reaction time; TCSS = total correct scale scores; CS = combined scores.
*p< .01

Similar to the preschool preterm subgroup, the school preterm subgroup performed worse than the school control subgroup in all WM tests. The school preterm subgroup had scores ranged between 91 and 106 across the tests, while the school control subgroup had scores ranged between 103 and 120 across the tasks. Besides, school-aged preterm children had more performance variability than their age-matched term-born peers on vsst and vswm tests (Table 1.6).

Table 1.6

The Verbal and Visuospatial Working Memory Performance of the School Preterm and the School Control Subgroups

	School Preterm Subgroup (n =10) Mean (SD), Range	School Control Subgroup (n = 11) Mean (SD), Range
Verbal short-term memory		
Digit	101.4 (11.5), 84-120	107.4 (18.3), 86-137
Word	97.7 (24.0), 59-129	103.6 (19.0), 76-130
Verbal working memory		
Counting	106.8 (20.7), 71-130	105.5 (11.8), 95-136
Backward Digit	99.3 (17.6), 63-127	104.7 (11.4), 93-134
Visuospatial short-term memory		
Dot matrix	100.4 (16.4), 71-133	108.8 (15.2), 84-130
Block	91.2 (20.4), 64-139	109.3 (17.9), 85-136
Visuospatial working memory		
Mr. X	106.6 (12.9), 91-130	120.7 (18.5), 95-148
Spatial	99.9 (25.0), 55-121	119.3 (15.0), 91-139

When examining the WM profile of both school subgroups visually (Figure 1.3), the school control subgroup had slightly better performance in visuospatial aspect than verbal aspect. Although a relatively even profile was found in the school preterm subgroup, lowest score was found in vsst. The performance differences between groups were greater in visuospatial aspects than in verbal aspects.

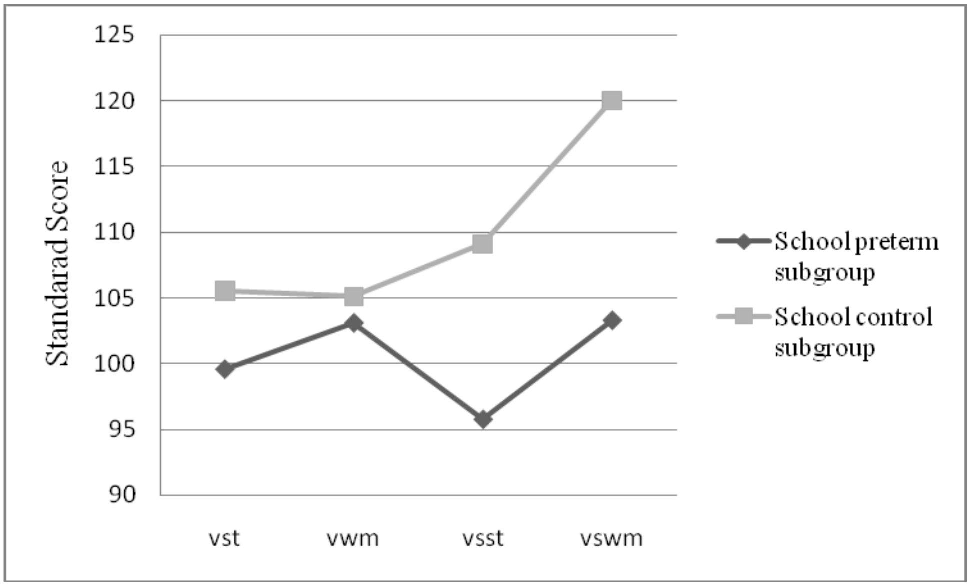

Figure 1.3. Working memory profiles of the school preterm and the school control subgroups.

Correlations between different working memory aspects in the preterm and the control groups. The zero-order correlations between the different WM tests in the preterm group (the upper triangle) and in the control group (the lower triangle) were shown in Table 1.7. In the preterm group, the correlations between the tests tapping the same WM aspects were small-to-moderate in magnitude. All rs except the r for vswm tests were significant ($p < .01$). Cross-modalities correlation patterns were found in the preterm group. For example, the two vst tests were significantly correlated with the two vsst tests and with the two vswm test. Additionally, one of the vwm tests (Counting Recall) was highly correlated with the two vsst tests, Dot Matrix and Block.

In the control group, the correlations between the tests tapping the same WM aspects were small-to-moderate in magnitude. No specific correlation patterns between the two modalities were found in the control group.

Table 1.7

Correlations among all Working Memory Tasks for the Preterm Group in the Upper Triangle and for the Control Group in the Lower Triangle

	1	2	3	4	5	6	7	8
1.Digit recall	-	.66**	.54**	.36	.67**	.66**	.54**	.37
2.Word recall	.39	-	.42*	.46*	.72*	.56**	.52*	.59*
3.Counting recall	.26	.44**	-	.60**	.67**	.64**	.46*	.39
4.Backward digit	.61**	.51*	.65**	-	.38	.40	.59**	.49*
5.Dot matrix	.04	.43*	.28	.24	-	.79**	.49*	.62**
6.Block recall	.10	.26	.52*	.46*	.57**	-	.65**	.51*
7.Mr. X	-.04	.15	.65**	.49*	.56**	.49*	-	.38
8.Spatial recall	.16	.32	.72**	.51*	.54**	.54*	.77**	-

*p < .05; **p < .01

Correlations between different working memory aspects in the preschool preterm and the preschool control subgroups. The zero-order corrections between WM tests of the preschool preterm subgroup (the upper triangle) and the preschool control subgroup (the lower triangle) were displayed in Table 1.8. In the preschool preterm subgroup, the correlations between the tests tapping the same WM aspects were moderate-to-high in magnitude. All rs except the r for vswm tests were statistically significant at the .01 probability level. It was worth noting that the correlations between vst and vsst were high in the preschool preterm subgroup. In the preschool control subgroup, the correlations between the tests tapping the same WM aspects were small-to-moderate in magnitude. High correlations were found between vwm and vswm test.

Table 1.8

Correlations among all Working Memory Tasks for the Preschool Preterm Subgroup in the Upper Triangle and for the Preschool Control Subgroup in the Lower Triangle

	1	2	3	4	5	6	7	8
1. Digit recall	-	.77**	.44	.39	.68*	.78**	.51	.42
2. Word recall	.15	-	.40	.28	.69**	.63*	.42	.35
3. Counting recall	-.01	.51	-	.69**	.57*	.61*	.48	.49
4. Backward digit	.32	.44	.79*	-	.53	.43	.66*	.52
5. Dot matrix	.55	.60	.40	.28	-	.83**	.47	.67**
6. Block recall	.27	.19	.57	.44	.58	-	.66**	.46
7. Mr. X	.29	.67*	.74**	.89**	.42	.44	-	.29
8. Spatial recall	.10	.75*	.89**	.71**	.62*	.49	.74**	-

*p < .05; **p < .01

Correlations between different working memory aspects in the school preterm and the school control subgroups. The zero-order correlations between WM tests of the school preterm subgroup (the upper triangle) and the school control subgroup (the lower triangle) were displayed in Table 1.9. In the school preterm subgroup, the correlations between the tests tapping the same WM aspects were moderate in magnitude. However, none of the correlations were statistically significant ($p < .01$). Similar to the preschool preterm subgroup, the two vst tests were highly correlated with Dot Matrix in the school preterm subgroup. Moreover, the vst tests were also moderately correlated with vswm tests.

In the school control subgroup, the correlations between the tests tapping the same WM aspects WM tests were small-to-moderate in magnitude. However, none of the correlations were statistically significant ($p < .01$). Unlike the school preterm subgroup, no cross-modalities correlation pattern was found in the school control subgroup.

Table 1.9

Correlations among all Working Memory Tasks for the School Preterm Subgroup in the Upper Triangle and for the School Control Subgroup in the Lower Triangle

	1	2	3	4	5	6	7	8
1. Digit recall	-	.61	.71*	.58	.65*	.46	.64*	.35
2. Word recall	.46	-	.47	.61	.86**	.49	.73*	.77**
3. Counting recall	.33	.40	-	.74*	.64*	.69*	.51	.44
4. Backward digit	.74**	.54	.46	-	.46	.44	.64*	.47
5. Dot matrix	-.27	.32	.10	.13	-	.75*	.60	.80**
6. Block recall	-.06	.28	.33	.35	.52	-	.63	.63
7. Mr. X	-.31	-.19	.43	.06	.66*	.37	-	.57
8. Spatial recall	.11	.12	.51	.25	.51	.43	.66*	-

*p < .05; **p < .01

Working memory performance between the preterm and the control groups. Two separate MANOVAs were conducted to test the differences in the performance on VWM and VSWM between the preterm and control groups. The MANOVA performed on the four tests associated with VWM (i.e., Digit Recall, Word Recall, Backward Digit Recall, and Counting Recall) yielded a non-significant group effect, $F(4, 40) = 1.42$, $p > .05$, $\eta^2 = .13$. Similarly, the MANOVA computed on the four VSWM tests (i.e., Dot Matrix, Block Recall, Mr.X, and Spatial Recall) showed no significant difference between the preterm and the control groups, $F(4, 41) = 1.05$, $p > .05$, $\eta^2 = .09$.

Since WM performance is associated with IQ and significant differences in IQ scores were found between the preterm and the control group, two separate MANCOVAs were computed to test the group effect on VWM after controlling for Verbal IQ, and to test the group effect on VSWM after adjusting Visual IQ. The group differences remained non-significant in VWM after controlling for

Verbal IQ, $F(4, 39) = .98$, $p > .05$, $\eta^2 = .09$, and in VSWM after adjusting Visual IQ, $F(4, 39) = .22$, $p > .05$, $\eta^2 = .02$.

WM is also closely related to attention (Cowan et al., 2005) and a significant group effect on visual attention was found, therefore, a MANCOVA was done in order to determine the group effect on VSWM after controlling for omission error. The result revealed that group difference remained non-significant between the preterm group and the control group, $F(4, 39) = .52$, $p > .05$, $\eta^2 = .05$.

To sum, no significant difference was found in either VWM or VSWM between the preterm group and the control group, even after the effect of IQ or visual attention was partialled out.

Working memory performance between the preschool preterm and the preschool control subgroups. Two separate MANOVAs were performed on the 4 tests associated with VWM and on the 4 tests associated with VSWM respectively in order to identify any performance differences in these two domains of WM between the two preschool subgroups. No significant group difference was found in VWM, $F(4, 19) = 1.38$, $p > .05$, $\eta^2 = .23$. But group difference in VSWM was close to significance level, $F(4, 20) = 2.34$, $p = .09$, $\eta^2 = .32$. After partialling out the effect of Visual IQ on VSWM, significant group effect was found, $F(4, 18) = 3.70$, $p < .05$, $\eta^2 = .45$. The preschool preterm subgroup had higher scores than the preschool control subgroup in all VSWM tests except Dot Matrix after Visual IQ was adjusted.

To sum, no significant differences were found in either VWM or VSWM when comparing the preschool preterm subgroup to the preschool control subgroup. However, when the effect of Visual IQ on VSWM was controlled, significant group difference was found. The preschool preterm subgroup had better performance than the preschool control subgroup on VSWM.

Working memory performance between the school preterm and the school control subgroups. Similar to the preschool preterm subgroup, the school preterm subgroup had poorer performance than the school control subgroup in all WM tests. However, MANOVA performed on the 4 VWM tests revealed a non-significant group effect, $F(4, 16) = 1.17$, $p > .05$, $\eta^2 = .23$. Group difference remained non-significant after controlling for the effect of Verbal IQ, $F(4, 15) = .40$, $p > .05$, $\eta^2 = .10$. MANOVA performed on the 4 VSWM tests showed a significant group effect, $F(4, 16) = 3.10$, $p < .05$, $\eta^2 = .44$. The school preterm subgroup performed worse than the school control subgroup on VSWM tasks. A Discriminant Function Analysis (DFA) was conducted to test the hypothesis that the school preterm subgroup and the school control subgroup would differ significantly on a linear combination of the 4 VSWM tests: Dot Matrix, Block Recall, Mr. X, and Spatial Recall. The overall chi-square test was significant, Wilks' $\lambda = .56$, chi-square = 9.74, df = 4, canonical correlation = .66, $p < .05$. The function extracted accounted for approximately 43.6% of the variance. Standardized canonical discriminant function coefficients indicated that both Dot Matrix (-1.28) and Spatial Recall (1.04) were the functions that differentiated the school preterm subgroup from the school control subgroup.

To sum, no significant difference in VWM was found between the school preterm subgroup and the school control subgroup, even after the effect of Verbal

IQ was controlled. However, significant group difference in VSWM was yielded, the school preterm subgroup had poorer performance than the school control subgroup on VSWM tests. Dot Matrix and Spatial Recall were the tests that differentiated the two subgroups.

Parent ratings on executive functions. Since there are no standard scores for children age 4 years, only the parent ratings of the school subgroups were analyzed. The parent ratings of the 8 clinical scales in the school preterm subgroup ranged between 51.47 (Emotional Control) and 58.88 (Plan/Organization), while those in the school control subgroup ranged between 45.00 (Inhibit) and 52.71 (Plan/Organization and Organization of Materials). Both groups had the highest rating on the Plan/Organization Scale. None of the clinical scales reached statistically significant difference between the school preterm subgroup and the school control subgroup. Further, no scales in either group had a rating reached the clinical significance region (i.e., > 65).

Correlations between the performance-based (AWMA) and the parent-rated (BRIEF) measures of WM were computed for the school preterm and the school control subgroups. The rs ranging between - .60 and - .03 for the school preterm subgroup, and between - .38 and .53 for the school control subgroup, none of the rs were statistically significant (all ps > .05).

Discussion

The present study had three objectives. The first objective was to investigate the overall WM profile of children born preterm from a developmental perspective; the second objective was to examine whether the WM impairments found in preterm children, if any, are domain-specific or domain-general; and the third objective was to evaluate the relationship between the performance-based and parent-rated WM in preterm children.

Findings showed that preterm children performed worse than age-matched term-born children in all WM tests, regardless of their schooling experiences. This finding agreed with findings in previous studies (Ford et al., 2011; Vicari, Caravale, Carlesimo, Casedi, & Allemand, 2004). However, the WM profile of preterm children was found to be age- or education-dependent. For examples, while the preschool preterm subgroup displayed an uneven profile with the worst performance in vwm, the school preterm subgroup displayed a relatively even profile with the worst performance in vsst. Moreover, performance differences between the two preschool subgroups were greater in verbal aspects than in visuospatial aspects, while differences between the two school subgroups were more obvious in visuospatial aspects than verbal aspects. Age-related differences in the executive functions (EF) profile of preterm children have been reported by other researchers. Ritter and co-workers (2013) found that although young preterm children (age between 8.00 and 9.86 years) demonstrated poorer performance than age-matched full-term children in inhibition, working memory, and shifting, older preterm children (age between 9.87 and 12.99 years) were found to perform worse than their age-matched full-term peers in shifting only. Working memory is underpinned by the various regions and mechanisms of the prefrontal cortex (Luciana & Nelson, 1998). Age- or education-dependent changes in the WM or EF profile of children born preterm are likely due to the maturation of the prefrontal cortex and a plethora of other causes such as schooling. Although the present study is not longitudinal in nature, the findings on WM profile revealed that older preterm children had more difficulties than younger preterm children with VSWM. This notion was supported by a systematic review in which the effect sizes for VSWM impairments in preterm children were reported to be greater in older than in younger age groups (Mulder, Pitchford, Hagger, & Marlow, 2009).

Another interesting finding in the first objective of the present study was that both preschool and school preterm subgroups showed significant correlations between verbal and visuospatial short-term memory tests which were not observed in the control subgroups. This type of correlation pattern has been reported in previous studies of typically developing children (Alloway, Gathercole, & Pickering, 2006; Hale, Bronik, & Fry, 1997). Hale and associates (1997) used dual-task paradigms to test the interdependence between verbal and visuospatial WM in two groups of children. In the group of 8-year-olds, interference effects were found during WM tasks regardless of whether the secondary task was from the same or a different modality, whereas in the group of 10-year-olds, interference was found only when the second task was from the same domain. The authors concluded that verbal and visuospatial short-term memory systems are interrelated in young children, but approach adult-like independence by age 10. In other words, the younger the child, the greater the interdependence will be between verbal and visuospatial short-term memory. In the present study, verbal and visuospatial short-term memory were correlated in preterm children but not in term-born children, it is possible that preterm children are less mature than age-matched term-born children in the development of their WM.

Alloway and co-workers (2006) used confirmatory factor analyses to investigate the structure of WM and the developmental changes in the relationships between the components of WM in a group of children aged 4-11 years. The authors reported a moderate correlation between the verbal and visuospatial short-term memory components in the three age bands. The correlation between these two components increased slightly from the age band 4-6 years to the older age bands (7-8 years and 9-11years). The authors posited that this age-related change in the association between verbal and visuospatial short-term memory was due to the use of strategies such as verbal rehearsal to assist encoding of visual materials in older children. In the present study, there were no age-related changes found in the strength of association between the two short-term memory components. Based on the observations during testing, 80% of the preterm children did not use any strategies to help them memorize either verbal or visuospatial materials, 20% of the children used verbal rehearsal to aide verbal WM tasks and none of the children used strategies to support visuospatial WM tasks. It is unlikely that the significant correlations between verbal and visuospatial short-term memory in preterm children were due to the use of verbal strategies to encode both verbal and visuospatial information.

The cross-modalities correlation pattern found in preterm children could be explained by the developmental changes in prefrontal cortex. During childhood, changes in the structural architecture of the prefrontal cortex and cognitive maturation occur concurrently. In order to provide efficient processes to support different cognitive functions, the prefrontal cortex undergoes a series of changes that lead to a structural/functional shift from diffuse and undifferentiated to focal and fine-tuned. Because specific neural networks are formed for complex cognitive functions, the intercorrelations between various cognitive abilities become weaker throughout development (Casey et al., 2005; Durston et al., 2006; Tsujimoto, 2008). Such developmental changes of the prefrontal cortex have been described in a neuroimaging study done by Tsujimoto, Kuwajima, and Sawagushi (2007). In this study, typically developing children aged 5-6 years recruited common regions in the lateral prefrontal cortex (LPFC) when performing verbal and visuospatial n-back tasks, while children aged 8-9 years recruited different neural systems for tasks of these two modalities. Because, significant correlations between verbal and visuospatial STM were found in children aged 5-6 years but not in children aged 8-9 years, these findings suggested that young children use the same neural regions in the prefrontal cortex for storing verbal and visuospatial materials in WM. This neural mechanism is exhibited by the significant correlations between verbal and visuospatial STM. With age, different neural systems are recruited for verbal and visuospatial short-term memory and the correlations between these two WM systems become weaker. Therefore, it is possible that the correlations between verbal and visuospatial short-term memory in preterm children reflect a prefrontal cortex of lesser maturity than that of their age-matched term-born peers and that preterm children use a not-yet-fractionated working memory system to support different WM functions such as verbal and visuospatial short-term memory.

The second objective of the present study was to examine whether WM impairments found in preterm children, if any, are domain-specific or domain-general. Findings showed that children born preterm performed less well than their age-matched term-born peers across measures of Verbal and Visuospatial WM. Although no significant differences were found in either VWM or VSWM between the preterm and the control groups, significant group difference was found in VSWM when comparing the two school subgroups. This finding was consistent with an earlier study in which a group of preterm children (GA < 32 weeks, mean age = 7.5 years) performed a dot matrix task and were asked to reproduce the sequences of dots presenting in a 4 x 4 grid in both forward and backward orders. Finding showed that school-aged preterm children had poorer performance in visuospatial WM than age-matched full-term controls (de Kieviet, Elburg, Lafeber, & Oosterlaan, 2012). Given there were no significant group differences in Visual IQ or visual attention between the school preterm and school control subgroups, the VSWM impairments found in the school preterm subgroup was unlikely due to their lower Visual IQ or poorer visual attention. Consequently, this provides evidence that the VSWM impairments in the school preterm subgroup were not general cognitive deficits, but rather specific cognitive impairments.

WM impairments were found only in the VSWM of school-aged preterm children, this finding provided further evidence that children born preterm had a less mature prefrontal cortex than their age-matched term-born peers. In a fMRI study on preterm children aged 7-12 years, dot matrix recall was used to investigate the neural network for VSWM. The older preterm children were found to recruit a WM network similar to the term-born controls when performing the dot matrix task, while the younger preterm children were found to involve less frontal regions than their full-term peers when recalling the location of dots (Mürner-Lavanchy et al., 2014). Because the younger preterm children performed less well than their term-born peers in the task, the authors suggested that the poorer performance in the younger preterm children was related to the recruitment of an altered neural network for visuospatial WM task. Since children in the school preterm subgroup had similar age (mean age = 8.40 years) to the younger preterm children in that fMRI study, it is possible that children in the school preterm subgroup also recruited an altered neural network to maintain and manipulate visuospatial information, therefore, they performed significantly worse than their term-born peers in VSWM tasks.

In addition to the recruitment of an inefficient neural network for VSWM, VSWM impairments in preterm children could be also due to the characteristics of visuospatial WM tasks per se. Baddeley (1996) suggested that VSWM depends on the central executive heavily especially in young children, performing visuospatial WM task demands a large amount of central executive resources. Thus, visuospatial WM tasks induce a high cognitive load in children. There is evidence that WM performance is load-dependent. In a former study, a group of children age 7-12 years performed WM tasks with varying amount (load) of information, brain activation across WM loads were recorded and compared to adults. Findings showed that children made more disproportional errors than adults as WM load increased. Besides, children failed to exhibit the same degree of increasing brain activation across WM loads as was shown by adults in different frontal and parietal regions (Thomason, Race, Burrows, Whitfield-Gabrieli, Glover, & Gabrieli, 2008). These findings indicated that increasing the load of WM task induces more difficulties on it, particularly in children. Although stronger brain activations were observed across WM loads in children, the magnitude of the increasing brain activities is not enough to cope with the demand of task. It is possible that school-aged preterm children might face double challenges when performing visuospatial WM tasks. On one hand visuospatial WM tasks are demanding, on the other hand preterm children might recruit inefficient neural processes to meet the demand from visuospatial WM tasks, resulting in a decrement of performance.

Findings show that the preschool preterm subgroup did not performed significantly worse than the preschool control subgroup in VSWM. This finding was not in line with previous research reporting that preschool children born preterm had impairments in VSWM (Ni, Huang, & Guo, 2011). However, other researchers have reported that very preterm children with no cerebral abnormalities performed similarly to term-born children in Backward Block Recall (Clark & Woodward, 2010). Finding from this study provided a potential explanation for these differences in the research as well as the non-significant group difference in VSWM between the preschool preterm and the preschool control subgroups found in this study, as the majority of the preschool preterm children in the present study had no major brain injuries. Moreover, Aarnoudse-Moens and colleagues (2011) reported an effect size of 0.3 for spatial working memory when compared a group of very preterm children (mean age = 8 years 2 months; mean GA = 28.1 weeks) to a sample of term-born participants, showing that the effect size for VSWM is small. Based on the small sample size of the preschool preterm subgroup, it was not enough to reveal a significant group effect if the effect size is small.

The finding that preterm children had more parent-rated EF impairments than age-matched term-born children is consistent with previous studies (Loe, Chatay, & Alduncin, 2014). However, no significant difference was found in parent-rated EF between the preterm group and the control group. Moreover, no preterm children had rating reached the clinical significance region in any scales. These findings suggested that the preterm children in the present study were not perceived by their caregivers as impaired in their executive functioning. The correlations between performance-based WM and parent-rated WM of school-aged children were not significant in either group. This suggested that even a child behaves well in his/her daily living, he/she may still have problems with memorizing information that is required for supporting his/her daily functions. Because of this, the use of both performance-based measures and parent report to characterize children's WM skills is important.

The present study had some limitations. First, the sample size for both preterm and control groups was small which not only reduces the external validity of the present study, but also make the study lacks power to detect significant group differences. Second, the wide age range in both groups reduces the power of the present study. For example, there were 24 children in the preterm group, however, the age of participants ranged between 4 and 11 years. The wide age range may induce a high variability in performance within group, reducing the power to detect group differences. In view of this, a narrower age range should be considered in future studies. Third, children born before 32 weeks of gestation were recruited for the preterm group, as evidence showed a longer gestational period gives an advantage for neurodevelopment (Davis et al., 2011), thus the findings in the present study cannot be generalized to age-matched preterm children who born after 32 gestational weeks. Finally, as the present study is not longitudinal in nature it is impossible to make any conclusions about the developmental trajectory of WM in preterm children based on the findings.

To conclude, findings in the present study provide convergent evidence that preterm children performed significantly worse than their age-matched term-born peers in WM. It is possible that the poorer WM performance and the cross-modalities correlation pattern found between verbal and visuospatial WM aspects in preterm children are due to a lesser mature prefrontal cortex. No significant group difference in WM was found between the two preschool subgroups, however, school preterm subgroup performed significantly worse than school control subgroup in VSWM. This confirms that working memory impairments are observed only when WM tasks have high cognitive load (Luciana, Lindeke, Mills, & Nelson, 1999). Preterm children did not perform significantly worse than their age-matched term-born peers in preschool period does not mean that they will not have difficulties with WM when get older. When children enter school, less subtle forms of WM problems may become apparent as the demands from school and life become more challenging. Thus, it is crucial to monitor the WM development of young preterm children. If needed, early intervention programs should be designed and provided for them in order to minimize the frustrations in learning due to WM difficulties.

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Appendix 1A

The Sequence of Measures Administered in the Testing Session

Measures	Time (minutes)
AWMA	45
Break	15
NEPSY-Auditory Attention	30
WRIT	30
Break	15
TOVA	30

Chapter Four

Study Two: The effects of working memory training on children born preterm

Working memory (WM) impairments can lead to many challenges in our daily life such as forgetting where an object was placed or having difficulty doing mental arithmetic while grocery shopping. Due to the negative consequences of WM problems, training programs that can meliorate WM difficulties have become popular. In the face of this growing popularity researchers have been challenged to determine whether these training programs are truly producing benefits to daily functioning. Consequently, many WM training programs have been involved in research studies or clinical practices, and of these interventions, strategy training in particular is a widely employed approach.

Strategy training involves teaching the use of approaches such as rehearsal, grouping, or imagery to encode, maintain, and/or retrieve information. In addition, participants are required to practice the strategy repetitively in order to lead to an improvement in WM (Morrison & Chein, 2011). Strategy usage has been proven to be effective in increasing the WM capacity of healthy young adults (Turley-Ames & Whitfield, 2003). Similar benefits are seen in children with FASD. Loomes and collaborators (2008) reported improvements in digit span after teaching a group of FASD children the use of verbal rehearsal strategy to remember numbers. Although the use of strategies has benefits on WM capacity, some researchers argue that such benefits cannot be transferred to other cognitive skills or daily functions (Morrison & Chein, 2011; Schubert, Strobach,

& Karbach, 2014). In a classic case study conducted by Ericsson and Chase (1982), an expert runner S.F. was taught to chunk digits into meaningful patterns in order to enhance his memory span. When S.F. was tested on his digit span, he was able to remember 80 digits by grouping the numbers into running times. However, when he was tested on letter span, this exceptional memory ability was disappeared. These results indicate that strategy training is domain-specific which can increase the performance with tasks of material that is similar to the training activity, but not to tasks of different materials or context.

In recent years, a computerized WM training program, Cogmed, has been widely used in various research studies. Cogmed is designed based on the assumption that WM is central to attention, problem solving, and impulse control; enhancing WM capacity can lead to an enduring improvement in these advanced cognitive skills (Cogmed, 2011). The Cogmed program includes both verbal and visuospatial memory tasks, and because of this domain-general characteristic the developers posit that the training gains can be transferred to other skills and functions. Moreover, the list of to-be-remembered items is adjusted according to the participant's performance during training, in other words participant's maximum WM capacity is always challenged. This adaptive nature is thought to be able to yield better training outcome than non-adaptive mode of training. Taken together, it is believed that the Cogmed training program has some advantages over other WM trainings.

There is accumulating evidence that the training benefits from Cogmed can be extended from WM to other functions such as mathematics and English performance (Holmes & Gathercole, 2014; Witt, 2011), abilities to follow instructions (Bergman-Nutley & Klingberg, 2014), and reduction in ADHD behaviours (Beck, Hanson, & Puffenberger, 2010). In addition, some researchers have reported that the training benefits from Cogmed can last for several months (Gray et al, 2012; Wong, He, & Chan, 2014). Cogmed has been used to enhance the WM capacity and other cognitive functions in different populations. Researchers report that Cogmed not only improves the WM abilities of individuals with Attention Deficit and Hyperactivity Disorder (ADHD), but also induces benefits on their reasoning (Klingberg et al., 2005) and learning skills (Egeland, Aarlien, & Saunes, 2013). Similar training gains are observed in other populations such as children with typical development (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009), individuals with low working memory (Holmes, Gathercole, & Dunning, 2009; Wong, He, & Chan, 2012), and individuals with intellectual disabilities (Van Der Molen, Van Luit, Van Der Molen, Klugkist, & Jongmans, 2010). Researchers have also shown that Cogmed is a viable WM training program for both adults (Brehmer, Westerberg, & Bäckman, 2012) and children (Passolunghi & Costa, 2014).

Individuals born preterm have increased risk of WM impairments (Ford et al., 2011; Saavalainen, et al., 2007; Vicari, Caravale, Carlesimo, Casadei, & Allemand, 2004). However, only a few studies have investigated the effects of WM training on preterm population and only two studies have investigated the viability of Cogmed to improve the WM abilities and other related functions in preterm individuals. Løhaugen and colleagues (2011) evaluated the training effects of Cogmed on a group of adolescents born preterm (n =16; mean gestational age = 25.8 week; mean birth weight = 778 g) and then compared the results to that of a group of age-matched term-born participants (n = 9). In this study, both preterm and control groups received Cogmed training for 5 weeks and were tested on non-trained WM tasks and verbal learning tasks immediately after training and at 6-month follow-up. Parent-ratings on ADHD symptoms were also obtained for all participants at these two time points. The authors found that both preterm and control groups had improvements in trained and non-trained verbal WM tasks and in remembering a verbal history and a word list after completing training and at 6-month follow-up. Preterm group also had lower ADHD-total scores and inattention scores after than before training, although this benefit did not persist to 6-month follow-up. These results indicate that Cogmed has both a transfer effect and a lasting effect on verbal working memory of preterm adolescents. The same group of researchers investigated the Cogmed training effects on preschool aged preterm children. Gunewaldt and collaborators (2013) used a stepped wedge design to examine the transfer effect of Cogmed on 20 preterm children aged 5 to 6 years (mean gestational age = 28.8 weeks; mean birth weight = 1099 g). Children were split into two groups by random assignment. Participants in group one (n = 9) started the training program while those in group two (n = 11) waited. Four weeks after group one completing training, both groups were tested on non-trained WM tasks, auditory attention, phonological awareness, memory for faces, narrative memory, and sentence repetitive. Group two then started training and was retested on the same tasks 4 weeks after training. Results indicated that preterm children performed better at trained WM tasks and backward spatial recall at post-training than pre-training. Additionally, children also showed improvements in auditory attention and had a reduction in hyperactivity/impulsivity scores after training. The authors concluded that preterm preschoolers benefit from Cogmed training and the training gains can be generalized to other skills such as auditory attention and ADHD behaviours.

Results of the above-mentioned studies suggest that Cogmed may be an effective WM training program for preterm preschoolers and adolescents. However, some researchers have posited that when evaluating the efficacy of a WM training program, transfer effect, maintenance effect, and control group are the three key factors to be examined (Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012). Transfer effect refers to the training-related improvements in abilities other than the trained skill itself. There are two types of transfer effect. A near transfer effect refers to the improvement in tasks that are the same as the training task but are not involved in the training program, while a far transfer effect refers to the improvement observed in other abilities that are closely related to the training task. Maintenance effect refers to how long the training benefits can last after training period. The purpose of including a control group is to provide a comparison to make sure the training program is not just working because the study group is doing something different. Some studies include no control group or may use a control group for demographics and developmental factors but do not involve them in any training; these designs make it difficult to rule out confounding factors such as maturation or expectancy effect. Therefore, the involvement of an active control group is important.

The Present Study

Given these three factors are important aspects for evaluating the effectiveness of a training program, it is clear that more studies are required to establish the efficacy of the Cogmed WM training in preterm population. In view of this, the present study had two major objectives. The first objective was to investigate the training effects on non-trained WM in a group of preschool aged preterm children. Under this objective, I examined (1a) whether improvement could be found in non-trained WM tasks after 5 weeks of Cogmed WM training (i.e., near transfer effect) and at the 5-week follow-up (i.e., lasting effect on non-trained WM), and (1b) whether the pattern of training-induced gains in non-trained WM in preterm children is similar to or different from that in age-matched term-born participants. The second objective was to examine the training effects on other cognitive skills (i.e., attention and EF) in preschool aged preterm children after 5 weeks of Cogmed WM training. Under this objective, I evaluated (2a) whether training benefits could be extended to attention and executive functions (EF) after training (i.e., far transfer effect) and at 5-week follow-up (i.e., lasting effect on other cognitive skills), and (2b) whether the pattern of training-induced gains in attention and EF in preterm children is similar to or different from that in age-matched term-born participants. I hypothesized that training benefits on non-trained WM, attention and EF would be observed in both preterm children and their age-matched term-born peers after training and at 5-week follow-up. I also predicted that the training-induced improvement patterns found in preterm children would be different from that observed in age-matched term-born children.

Method

Participants. Children were invited to participate in the present study after taking part in another study in which I examined the developmental profiles of their working memory (i.e., Study One).

Preterm group. Seventeen preterm children agreed to participate in the present study. All of them completed pre-training testing and 15 children were able to perform the Cogmed training at home. During the training period, three children discontinued participation before completing the required number of training sessions due to heavy school work or difficulty getting access to the internet. Therefore, only 12 preterm children completed the WM training and participated in both post-training and 5-week follow-up testing sessions. The mean age of the preterm group was 5.6 years (SD = 1.0, range = 4.3-6.7).

Control group. Eighteen term-born children participated in the present study. All of them completed pre-training testing and 14 children were able to perform the WM training at home. Four children discontinued the WM training before the post-training testing session and therefore only 10 term-born children finished the WM training and participated in both post-training and 5-week follow-up testing sessions. The mean age of the control group was 5.5 years (SD = .6, range = 4.8-6.5).

Study design. The present study consisted of a 5-week WM training and 3 testing sessions: pre-training (T1), post-training (T2) and 5-week follow-up (T3). The WM training was implemented at home through the internet, while the three testing sessions were conducted at the Glenrose Rehabilitation Hospital. At the end of T1, the investigator showed the parents how to get access to the training program through the internet. Both parents and child were shown how to perform the training tasks, and the child was asked to do the practice trials after demonstration. The child was asked to begin the training on the Monday after the pre-training testing session. He/she was then required to perform the training about 15 minutes a day, 5 days a week for 5 weeks.

Post-training testing (T2) was conducted within one week after training, and no training or special tasks were provided for the child after T2. Follow-up testing (T3) was done in the 6th week after training. Figure 2.1 showed the time frame of the present study.

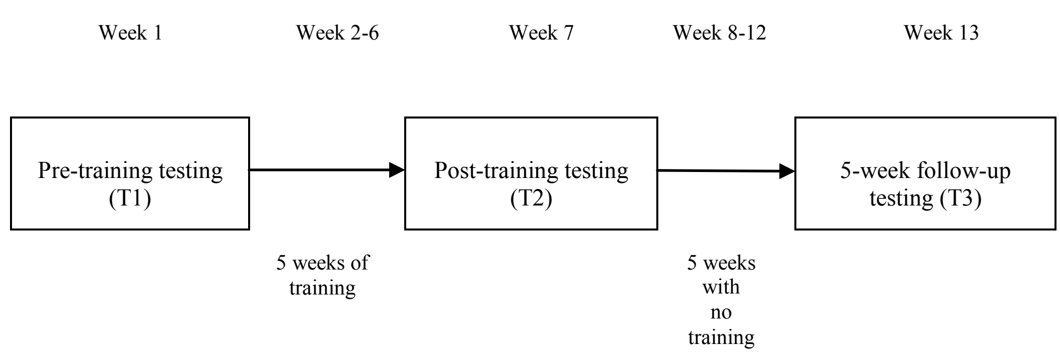

Figure 2.1. Time frame of the present study.

Training program. The Cogmed program was used as the WM training in the present study. Cogmed resembles a video game that a child can do it with a computer at home through the internet. Cogmed contains both verbal and visuospatial WM span tasks. During training, child observes a span of to-be-remembered items or stimuli and is asked to repeat the order of stimuli by clicking with a mouse on the targets on the computer screen. For children who do not have adequate eye hand coordination for controlling the mouse, they are asked to give the responses verbally and parents are asked to click on the target on the screen for them. Training begins at a level of 2 items and with successful completion of a level the task difficulty increases until the set training time is up. If the child completes the items incorrectly, the difficulty level will decrease. Each training session starts at the task difficulty level where the child ended in the previous session. Cogmed has 3 training versions to suit the age of participants, based on the age of children who were able to perform the WM training, the Cogmed JM was used in the present study.

Cogmed JM. Cogmed JM is designed for preschool children between 4 and 6 years of age. It consists of visuospatial WM tasks only. The exercises do not include verbal WM tasks as it is not expected that all children age 4 to 6 years will have knowledge of numbers and letters. There are 7 exercises in Cogmed JM. The child is asked to do 3 exercises, chosen by the program, in a training session each day. The time for each training session is approximately 15 minutes. After completing a training session, the child will receive a fish to add to an aquarium which is a daily reward for his/her work in the training (see Appendix 2A for the description of the Cogmed JM exercises).

Training indices. The Cogmed program provides three indices to reflect the child's training performance. The Start Index is based on the average performance of the best 2 exercises on Days 2 and 3 of training. As the child progresses through the training, the mean best performance will be averaged from these same tasks and is called the Max Index. The Improvement Index is the difference between the Max and Start Indices.

Cogmed also provides a measure of performance on non-trained tasks throughout the training, the Cogmed Progress Indicator (CPI). Two tasks (Following instructions and Shapes) were done on Days 1, 2, 10, 15, 20, and 25. On these days, the number of training exercises was reduced to two in order to keep the total training time for that day similar to the days when the CPI is not included. Parents can also report their child's attention throughout training on these days.

Across the training period, parents received a weekly phone or email contacts from an investigator who acts as a training coach. The training coach provided feedback and motivational support for child and parent on the basis of the child's performance from the last 5 training days before the contact.

Measures. The following measures were conducted in a fixed sequence in order to accommodate the various cognitive demands from different tests (see Appendix 2B for the sequence). They were administered at all three testing sessions.

Working memory. The Automated Working Memory Assessment (AWMA) was conducted to assess the visuospatial and verbal WM of children in both preterm and term-born control groups. There are 12 tasks in the AWMA, 3 for each aspect of WM: verbal short-term memory (vst), verbal working memory (vwm), visuospatial short-term memory (vsst), and visuospatial working memory (vswm). To control for the effect of practice, different tasks for the same aspect of WM were administered at T1, T2, and T3 (see Appendix 2C for the WM subtests administered in each testing session).

Verbal short-term memory. Word Recall, Nonword Recall, and Forward Digit Recall were administered to test the verbal short-term memory (vst) of all children at T1, T2, and T3 respectively. In these three tests, the child heard a sequence of stimuli (word in Word Recall, nonword in Nonword Recall and digit in Forward Digit Recall) and was required to immediately recall each sequence in correct order.

Verbal working memory. To test verbal working memory (vwm), Counting Recall, Listening Recall and Backward Digit Recall were conducted at T1, T2 and T3 respectively. In Counting Recall, the child was presented with a visual array of red circles and blue triangles. He/she was asked to count the number of red circles in an array and then recalled the tally of numbers in sequence. In Listening Recall, the child heard a series of individual sentences and judged if each sentence is true or false. At the end of trial, the child was asked to recall the last word of each sentence in the correct order. In Backward Digit Recall, the child heard a sequence of digit and was required to recall each sequence in backward order.

Visuospatial short-term memory. Block Recall, Mazes Memory and Dot Matrix were conducted to assess children’s visuospatial short-term memory (vsst) at T1, T2 and T3 respectively. In Block Recall, the child viewed a series of blocks being tapped and was asked to reproduce the sequence in correct order by tapping on the image of the blocks on the computer screen. In Mazes Memory, the child viewed a maze with a red path drawn through it. He /she was asked to use a finger to trace in the same path on a blank maze presented 3 seconds later on the computer screen. In Dot Matrix, the child was shown the position of a red dot in a series of four by four matrices and was asked to recall the position of dot by tapping the squares on the computer screen.

Visuospatial working memory. Spatial Recall, Odd-One-Out and Mr. X were administered to assess children's visuospatial working memory (vswm) at T1, T2 and T3 respectively. In Spatial Recall, the child viewed a picture of two shapes where the shape on the right side has a red dot above it. The child was asked to identify whether the shape on the right side is the same or opposite to the shape on the left side. The shape with the red dot might also be rotated. At the end of each trial, the child was asked to recall the location of each red dot on the shape in the correct order by pointing to the picture with three compass points on the computer screen. In Odd-One-Out, the child viewed three shapes, each in a box presented in a row, and attempted to identify the odd-one-out shape. At the end of each trial, the child recalled the location of each odd one out shape in the correct order by tapping the correct box on the screen. In Mr. X, the child was presented with a picture of two Mr. X figures. He/she was asked to identify whether the Mr. X with the blue hat is holding the ball in the same hand as the Mr. X with the yellow hat. The Mr. X with the blue hat might also be rotated. At the end of each trial, the child was asked to recall the location of each ball in the hand of Mr. X with a blue hat in the correct order by pointing to a picture with six compass points on the computer screen.

Attention. Visual attention was measured using the Test of Variables of Attention (TOVA). The TOVA yields standard scores (mean = 100, SD = 15) for the four measures of visual attention: reaction time, reaction time variability, commission error, and omission error. The higher the standard score, the better the performance. For examples, high standard score of commission error represents good impulse control; high standard score of omission error indicates good attention.

General cognitive abilities. The Wide Range Intelligence Test (WRIT) was administered to measure the general intelligence of children. The WRIT assesses both verbal and non-verbal abilities by means of Verbal and Visual scales. The WRIT yields a Verbal IQ and a Visual IQ which generate a General IQ when combined (mean = 100, SD = 15).

Executive functions. Parents were asked to complete the parent rating form of the Behavior Rating Inventory of Executive Function (BRIEF) in each testing session. The BRIEF parent rating has 8 clinical scales that can be combined to form two indices: the Behavioral Regulation Index (BRI) and the Metacognition Index (MI). The BRI is comprised of the Inhibit, Shift, and Emotional scales which represent a child's ability to shift cognitive set and modulate emotions and behaviours via appropriate inhibitory control. The MI is comprised of the Initiate, Working Memory, Plan/Organize, Organization of

Materials, and Monitor scales. It represents the child's ability to initiate, plan, organize, and sustain future-oriented problem solving in working memory. The Global Executive Composite (GEC) is a summary score that incorporates all 8 clinical scales of the BRIEF. High rating scores represents executive dysfunctions, with score > 65 falling into the clinical significance region. In the present study, due to the small sample size of both groups, the BRI, MI, and GEC instead of the 8 clinical scales were used for data analyses.

Data Analyses. Data analyses were performed in three phases. First, in order to examine the training effects on trained WM, descriptive statistics were compiled to evaluate the Cogmed training scores and improvements (i.e., Start Index, Max Index, Improvement Index, and Cogmed Progress Indicator) of children in both preterm and control groups. In addition, univariate ANOVAs were computed to compare the training indices between the preterm and the control groups in order to explore any group difference in training effect on trained WM.

Second, in order to address the first objective: (1a) to investigate whether improvement in non-trained WM could be found after 5 weeks of training (i.e., near transfer effect) and at 5-week follow-up (i.e., lasting effect on non-trained WM), and (1b) to explore whether the preterm and the control groups had similar or different patterns of performance changes in non-trained WM across time, descriptive statistics were compiled to examine the pattern of performance changes in non-trained WM across time in both preterm and control groups. Then four separate Repeated Measures ANOVAs, one for each aspect of WM, were computed to test whether the preterm group had performance changes in non-trained WM tasks across time. Similar Repeated Measures ANOVAs were conducted for the control group in order to test the near transfer effect and the lasting effects on non-trained WM in term-born children.

Third, in order to address the second objective: (2a) to examine whether training benefits could be extended to attention and EF after training (i.e., far transfer effect) and at 5-week follow-up (i.e., lasting effect on other cognitive skills), and (2b) to explore whether the pattern of training-induced gains in attention and EF in preterm children is similar to or different from that in age-matched term-born participants, descriptive statistics were compiled to examine the pattern of performance changes in attention and EF across time in the preterm and the control groups. Then a set of Repeated Measures MANOVAs were computed to test the far transfer effect and the lasting effect on attention and parent-rated EF in the preterm group. Similar Repeated Measures MANOVAs were performed for the control group in order to test the far transfer effect and the lasting effect of the Cogmed training on attention and EF in term-born children. MANOVAs instead of multiple ANOVAs were used because MANOVA can protect against Type I error that may occur if multiple ANOVAs were conducted independently. In addition, since both attention and EF comprise of several correlated variables, in order to take these correlations into account and to explore how group differentially influences the different variable(s) of attention or EF, MANOVAs were preformed.

Significance level for all analyses was set at $p < .05$. Bonferroni corrections for multiple comparisons were done with the significance level was set at $p < .05/n$, n was the number of comparisons. For both attention and EF, the significance level was set at $p < .01$ when univariate tests were performed after a significant overall test.

Results

Table 2.1 illustrates the demographics and the pre-training performance of both preterm and control groups. As expected, a non-significant difference was found in age between the preterm and the control groups ($F(1, 20) = .18$, $p > .05$, $\eta^2 = .01$). However, there were significant differences in Verbal IQ ($F(1, 20) = 17.11$, $p < .01$, $\eta^2 = .46$) and General IQ ($F(1, 20) = 12.05$, $p < .01$, $\eta^2 = .38$) between preterm and control participants. Preterm children had lower Verbal IQ and General IQ than their age-matched term-born peers. Visual IQ did not reach statistical significance between the two groups, $F(1, 20) = 3.14$, $p > .05$, $\eta^2 = .14$. ANOVAs revealed that the preterm group was not significantly different from the control group in verbal short-term memory ($F(1, 20) = .02$, $p > .05$, $\eta^2 = .00$), verbal working memory ($F(1, 20) = .14$, $p > .05$, $\eta^2 = .01$), visuospatial short-term memory ($F(1, 20) = .01$, $p > .05$, $\eta^2 = .00$), and visuospatial working memory ($F(1, 20) = .04$, $p > .05$, $\eta^2 = .00$). After adjusting the effect of Verbal IQ on verbal short-term memory and working memory, group differences remained non-significant. Additionally, results of MANOVA indicated that the preterm group did not perform differently from the control group on visual attention task ($F(4, 17) = 1.38$, $p > .05$, $\eta^2 = .25$). Yet, significant group difference in executive functions was found between the preterm and the control groups, $F(3, 18) = 4.73$, $p < .05$, $\eta^2 = .44$. Univariate tests showed that the preterm group had higher parent-ratings than the control group in BRI ($F(1,20) = 9.38$, $p < .01$, $\eta^2 = .32$) and MI ($F(1, 20) = 5.44$, $p < .01$, $\eta^2 = .21$).

Table 2.1
The Demographics, Pre-training Working Memory, Pre-training Visual Attention, and Working Memory Training Indices of the Preterm and the Control Groups

	Preterm (n =12)	Control (n =10)	F
	Mean (SD)	Mean (SD)	
Age (years)	5.6 (1.0)	5.5 (0.6)	0.18
G.A. (weeks)	28.3 (2.3)	38.9 (1.9)	138.77*
B.W. (grams)	1152.7 (364.1)	3216.1 (642.5)	81.36*
Verbal IQ	91.1(8.7)	108.0 (10.7)	17.14*
Visual IQ	100.8 (13.5)	111.6 (15.2)	3.13
General IQ	95.42 (0.4)	111.2 (12.0)	12.04*
Pre-training WM			
vst	103.2 (17.1)	104.1 (13.9)	0.02
vwm	94.3 (9.0)	96.5 (17.0)	0.14
vsst	98.3 (12.4)	98.8 (16.4)	0.006
vswm	106.4 (1.9)	105.1 (15.8)	0.04
Pre-training Attention			
RT	96.4 (12. 4)	95.7 (16.4)	0.01
RT Variability	67.4 (21.9)	82.9 (20.7)	2.86
Commission Error	80.1 (24.0)	82. 6 (31.1)	0.03
Omission Error	60.0 (20.2)	75.6 (17. 7)	3.65
Pre-training EF			
BRI	55.0 (9.1)	43.3 (8.8)	9.38*
MI	63.3 (12.0)	69.0 (6.0)	5.44*
GEC	79.5 (30.1)	68.1 (26.3)	0.88
WM Training Indices			
Start Index	47.1 (8.7)	49.5 (3.0)	0.71
Max Index	68.1 (7.1)	69.0 (6.0)	0.10
Improvement Index	21.0 (5.5)	19.5 (6.0)	0.56

Note. G.A. = gestational age; B.W. = birth weight; vst = verbal short-term memory; vwm = verbal working memory; vsst = visuospatial short-term memory; vswm = visuospatial working memory; RT = reaction time.
*p< .01

Training effects on trained working memory. Both groups took a similar number of days to finish all 25 training sessions (preterm, M = 25.0 days, SD =

2.7, range = 20-32; control, M = 24.9 days, SD = .74, range = 23-26), $F(1, 20) = .01$, $p > .05$, $\eta^2 = .00$. The mean Start Index of the preterm group was not significantly lower than that of the control group, $F(1, 20) = .71$, $p > .05$, $\eta^2 = .34$. In addition, the mean Max Index of the preterm group was not significantly different from that of the control group, $F(1, 20) = .10$, $p > .05$, $\eta^2 = .01$. Furthermore, a non-significant group difference in the Improvement Index was found between the two groups, $F(1, 20) = .56$, $p > .05$, $\eta^2 = .03$, showing that both groups had similar improvements in trained WM tasks.

For the Cogmed Progress Indicators, preterm and term-born children showed different improvements in following instructions and parent reported attention. Eleven (91.7%) children in the preterm group showed improvement in following instructions (improvement range = 1-77%), while eight (80%) children in the control group had gains in this indicator (improvement range = 10-67%). For parent reported attention, six (50%) children in the preterm group and nine (90%) children in the control group had improvements after training (preterm, improvement range = 2-78%; control, improvement range = 2-30%). However, it was worth noting that five (41.7%) children in the preterm group and one (10%) child in the control group had decrement in parent reported attention after training. Preterm children had reduction in attention between 3% and 15%, while the children in the control group reduced 25% of attention.

Training effects on non-trained working memory. To evaluate the training effects on verbal short-term memory, Word Recall at T1, Nonword Recall at T2, and Digit Recall at T3 were used for data analyses. To examine the training effects on verbal working memory, Counting Recall at T1, Listening Recall at T2, and Backward Digit Recall at T3 were compared. For examination of the training effects on visuospatial short-term memory, Block Recall at T1, Mazes Memory at T2, and Dot Matrix at T3 were used for data analyses. Finally, for evaluation of the training effects on visuospatial working memory, Spatial Recall at T1, Odd-One-Out at T2, and Mr. X at T3 were included for data analyses.

Transfer and lasting effects on non-trained working memory. Figure 2.2 presents the performance of the preterm and the control groups on the various WM tasks at the 3 different time points. When visually inspecting the performance of the preterm group, better performance was noted in all WM aspects at T2 compared to T1. However, although verbal working memory showed a linear increase across time, verbal short-term memory dropped to an above-T1 level after T2. The performance on visuospatial short-term memory and working memory were relatively stable between T2 and T3. Similarly, the control group had better performance in all 4 WM aspects at T2 when compared to T1. However, although verbal working memory and visuospatial short-term memory continued to improve after T2, verbal short-term memory and visuospatial working memory dropped to an above-T1 level at T3.

To sum, both groups had gains in non-trained verbal short-term memory and working memory tasks after training. However, preterm and control groups had very different training-induced changes in their visuospatial short-term memory and working memory.

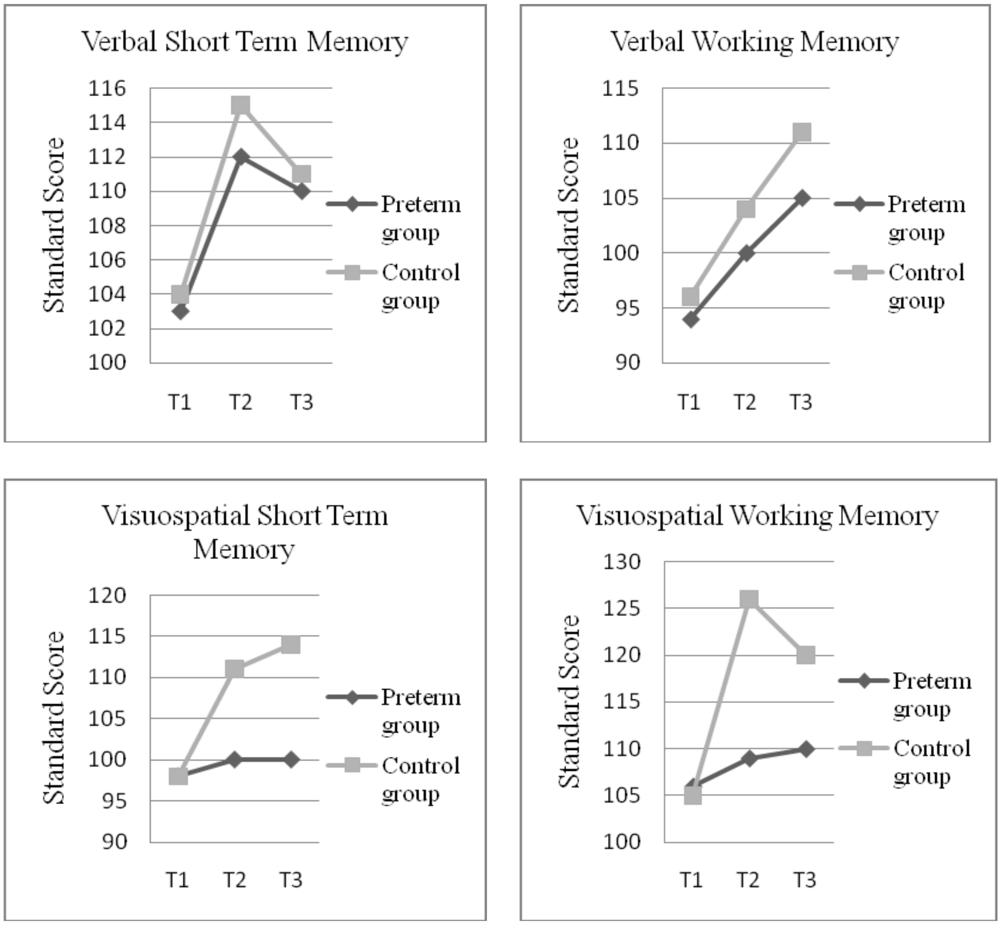

Figure 2.2. Verbal short-term memory, verbal working memory, visuospatial short-term memory, and visuospatial working memory of the preterm and the control groups.

Table 2.2 illustrates the performance on different WM aspects of the preterm group and the control group at the 3 time points. For the preterm group, Repeated Measures ANOVA showed that the changes in verbal short-term memory over the 3 time points was non-significant, $F(2, 10) = 3.36$, $p > .05$, $\eta2 = .40$. However, it is worth noting that $p = .076$ which is close to the significance level .05. For verbal working memory, results showed a significant difference across time ($F(2, 10) = 8.11$, $p < .05$, $\eta2 = .62$). Preterm children performed significantly better at T3 than T1 ($p < .01$). No significant differences were found between T1 and T2 (p > .01) or between T2 and T3 (p > .01). For visuospatial short-term memory, Repeated Measures ANOVA yielded a non-significant difference across time (p > .05), suggesting that preterm group performed similarly across time. Similar results were found for visuospatial working memory; preterm group had similar performance across time (p > .05).

For the control group, Repeated Measures ANOVA showed a non-significant difference in verbal short-term memory over the 3 time points ($F(2, 8) = 1.80$, $p > .05$, $\eta^2 = .31$), suggesting that term-born children performed similarly on verbal short-term memory tasks across time. For verbal working memory, the results showed a non-significant difference across time ($F(2, 8) = 3.20$, $p > .05$, $\eta^2 = .26$), however, p = .067 which is close to the significance level .05. For visuospatial short-term memory, Repeated Measures ANOVA yielded a significant Time effect ($F(2, 8) = 4.69$, $p < .05$, $\eta^2 = .54$). Univariate tests revealed that the control group performed significantly better at T2 than T1 (p < .01) and at T3 than T1 ($p < .01$) No significant difference between T2 and T3 was found. For visuospatial working memory, Repeated Measures ANOVA yielded a significant Time effect ($F(2, 8) = 10.07$, $p < .05$, $\eta^2 = .72$). Univariate tests revealed that the control group performed significantly better at T2 than T1 ($p < .01$) and at T3 than T1 ($p < .01$) No significant difference between T2 and T3 was found ($p > .05$).

To sum, near transfer effects on visuospatial short-term memory and visuospatial working memory were evident in the control group after training (T2). These positive training effects remained at the 5-week follow-up (T3). Positive training gain in verbal working memory was found in the control group although it was not strong enough to reveal a significant effect. For the preterm group, no training benefits in non-trained visuospatial short term and working memory were found at either T2 or T3. Significant training gains in verbal working memory were identified at T3; while training gain in verbal short term memory was not strong enough to reveal a significant effect.

Table 2.2

The Verbal Short-term Memory, Verbal Working Memory, Visuospatial Short-term Memory, and Visuospatial Working Memory of the Preterm and the Control Groups at Pre-training, Post-training, and 5-week Follow-up

	Preterm (n =12)			Control (n =10)		
	T1 Mean (SD)	T2 Mean (SD)	T3 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	T3 Mean (SD)
vst	103 (17.1)	112 (23.4)	110*(12.4)	104 (14.0)	115 (12.7)	111 (7.7)
vwm	94 (9.0)	100 (15.5)	105* (8.4)	96 (17.0)	104 (15.2)	111* (11.0)
vsst	98 (12.4)	100 (15.0)	100 (15.4)	98 (16.4)	111* (10.6)	114* (20.0)
vswm	106 (16.0)	109 (21.5)	110 (22.3)	105 (15.8)	126* (11.3)	120* (19.2)

Note. vst = verbal short-term memory; vwm = verbal working memory; vsst = visuospatial short-term memory; vswm = visuospatial working memory ; T1 = Pre-training; T2 = Post-training; T3 = 5-week Follow-up
*$p < .01$ when compared to T1

Training effects on attention. Visual attention as indexed by reaction time (RT), reaction time variability (RTV), commission error (CE), and omission error (OE) of the preterm group and the control group at the 3 different time points were depicted in Figure 2.3.

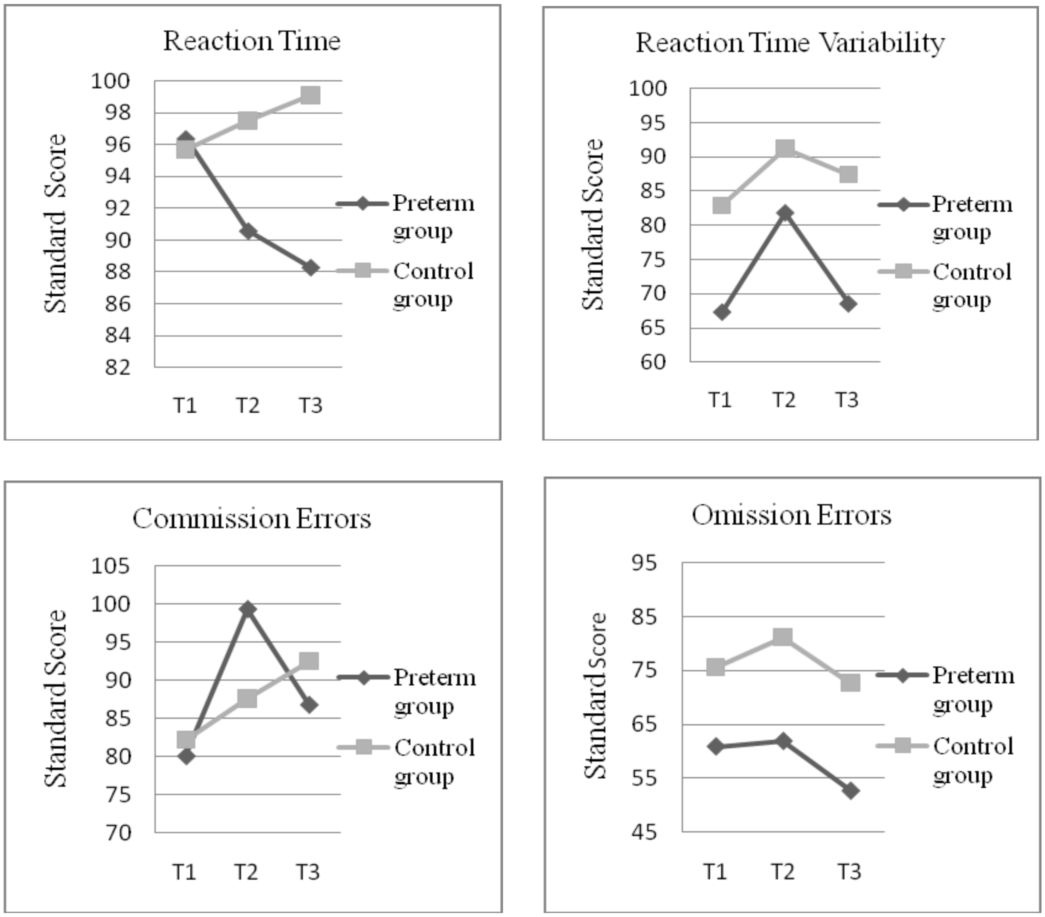

Figure 2.3. Reaction time, reaction time variability, commission error, and omission error of the preterm and the control groups.

When visually inspecting the performance on visual attention of the preterm group at the 3 time points, higher scores for both reaction time variability and commission error were found at T2 than T1, while a lower score for reaction time was found after training. Scores for omission error were similar at both T2 and T1. After T2, scores for all four indices dropped, the scores for reaction time and omission error were dropped to a below-T1 level.

For the control group, higher scores in all 4 indices were noted at T2 than T1, indicating term-born children had better visual attention after training. However, although the scores for both reaction time and commission error continued to improve after T2, the scores for reaction time variability and omission error declined after T2.

Transfer effect and lasting effect on attention. Since the data of two preterm children could not be saved after testing, the data of only 10 preterm children were available for the transfer effect analyses. In order to examine the changes of visual attention across time in each group, two separate Repeated Measures MANOVAs were computed. For the preterm group, results showed a non-significant difference across the 3 time points ($F(8, 2) = 1.32$, $p > .05$, $\eta^2 = .84$), suggesting preterm children had similar performance in all measures of visual attention across time. Similarly, for the control group, results showed a non-significant Time effect (F(8, 2) = 1.00, p > .05, η2 = .80), indicating term-born children performed similarly in all measures of visual attention across time.

. ***Training Effects on executive functions.*** Figure 2.4 displays the BRIEF parent-ratings on the Behavioral Regulation Index (BRI), the Metacognition Index (MI), and the Global Executive Index (GEC) of the preterm and the control groups. Parent-ratings did not vary too much across time in both groups, showing that all children did not have any obvious behavioural changes after training. When visually inspecting the parent-ratings on the 3 indices in the preterm group, lower ratings on BRI and GEC were found at T2 than T1. Parent-ratings on MI were similar at both T1 and T2. After T2, parent-ratings on GEC increased slightly but BRI and MI remained stable. When visually examining the parenting ratings of the BRI, MI, and GEC in the control group, interestingly, slightly higher ratings on all 3 indices were found at T2 than T1. Both MI and GEC dropped to a below-T1 level, while BRI continued increasing after T2.

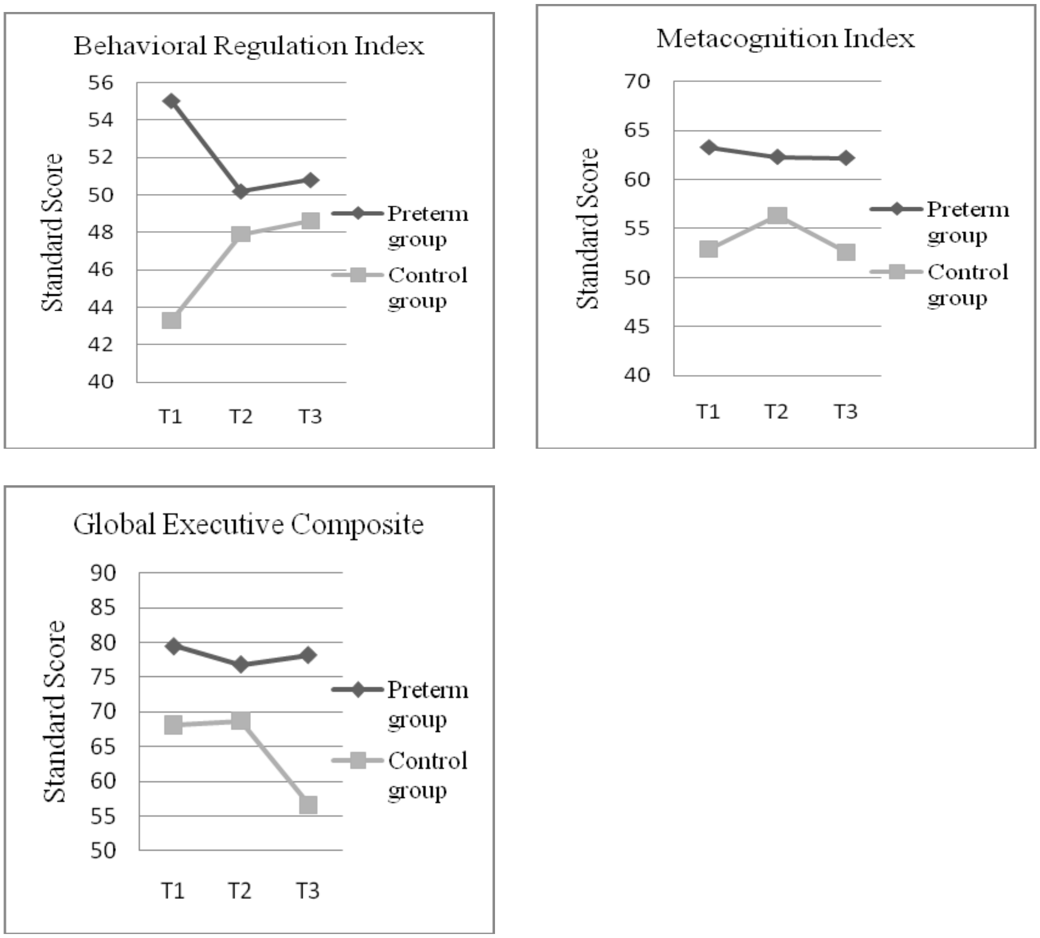

Figure 2.4. Behavioral Regulation Index (BRI), Metacognition Index (MI), and Global Executive Composite (GEC) of the preterm and the control groups.

Transfer effect and lasting effect on EF. In order to examine the changes on parent-rated EF across time in each group, two separate Repeated Measures MANOVAs were computed. For the preterm group, results showed a non-significant difference across the 3 time points ($F(6, 6) = 1.50$, $p > .05$, $\eta 2 = .60$), suggesting there were no significant changes in behaviours of preterm children across time. Similarly, for the control group, Repeated Measures MANOVA revealed no significant difference across the 3 time points, $F(6, 4) = 2.29$, $p > .05$,

η^2 = .77. This suggested that term-born children had no significant behavioural changes across time.

Discussion

The present study investigated the efficacy of a WM training program (Cogmed) on preterm children from two perspectives. First, we investigated the training benefits on non-trained WM in preterm children by examining its transfer and lasting effects. We also explored whether preterm and age-matched term-born children had similar or different pattern of performance changes in non-trained WM after training. Second, we examined the far transfer effects of the Cogmed WM training by investigating whether training benefits would be extended to attention and EF. In addition, we also explored whether the pattern of performance changes in these two cognitive skills in children born preterm is similar to or different from that observed in age-matched term-born children.

Findings showed that both preterm and control groups improved in some trained and non-trained WM tasks suggesting that near transfer effects are observed. That said there was some difference between the two groups as training benefits were evident in both non-trained verbal and visuospatial WM in the control group, while training gains were observed only in non-trained verbal WM in the preterm group. Moreover, training benefits in non-trained visuospatial WM were observed at both post-training and 5-week follow-up in the control group, while improvements in non-trained verbal WM were evident 6 weeks after training in both groups. These patterns of improvements suggest that WM training induced different training benefits in preterm and term-born children. No training benefits in visual attention and EF were observed in either group, implying that no far transfer effects were found.

Cogmed JM was used as the training program to boost WM of both preterm and term-born children in the present study. Cogmed JM consists of visuospatial WM tasks only in the training exercises; therefore, it is reasonable to expect improvements in children's non-trained visuospatial WM after training. However, such improvements were observed only in the control group. It is unclear why the preterm group had no improvements in visuospatial WM at either post-training or 5-week follow-up. There is the possibility that improvements in visuospatial WM would be observed in preterm children in later time. Holmes and colleagues (2009) found that significant improvements in WM but not mathematical reasoning were observed in a group of children after completing 20 sessions of training. However, training gains in mathematical reasoning were found 6 months after the completion of training. These findings suggest that not all training-induced improvements are observed right after training, some can be emerged in a later period of time after training as it takes time for these skills to advance in performance and reveal effects. In a similar vein, researchers have reported a moderate effect size for visuospatial WM and a large effect size for verbal WM after training (Melby-Lervåg & Hulme, 2013; Mezzacappa & Buckner, 2010). Since the effect size for visuospatial WM is not as large as verbal WM, it is possible a more intensive training and/or a longer training time is required for inducing gains in visuospatial WM (Bergman-Nutley & Klingberg, 2014).

Another potential explanation for the absence of measured training-induced improvements in visuospatial WM in the preterm group is that different neural mechanisms might be recruited by preterm and term-born children in response to WM training. Mürner-Lavanchy and collaborators (2014) found that when performing visuospatial WM task, task accuracy was positively related to brain activation in left and right superior parietal region in preterm children with low WM performance, while task accuracy was positively associated with left frontal region and right precuneus in term-born children. These findings showed that preterm children with low WM performance used an atypical neural network, which does not involve the frontal region, for visuospatial WM tasks. Although the preterm group did not perform significantly worse than the control group in visuospatial WM, it is possible that preterm children used an atypical neural mechanism to support visuospatial WM in the present study. If a less efficient neural mechanism is recruited for visuospatial WM tasks by preterm children, improvements in visuospatial WM may only be visible when additional resources such as more intensive training or longer training time are involved.

That said Grunewaldt and collaborators (2013) found training-induced improvements in visuospatial WM in preterm preschoolers four weeks after training. In this earlier study, backward spatial span task was used as the outcome measure for visuospatial WM after training and children were required to recall the location of a string of visual stimuli in backward order which is quite similar to the training tasks. In the present study, spatial recall, odd-one-out, and Mr. X were used as the outcome measures for visuospatial WM at pre-training, post-training and 5-week follow-up respectively. All of these tasks required children to make judgments and to remember the location of the stimuli in backward order. Because higher WM load was imposed on these tasks, training-induced improvements were more difficult to be observed. It is possible that the inconsistent results between studies are due to the use of different outcome measures in different studies.

Interestingly, although Cogmed JM consists of visuospatial WM training tasks only, training gain in verbal WM was observed in both preterm and control groups even though the training effect observed in the control group was just close to the significance level statistically. This finding is consistent with the work done by Thorell and associates (2009) in their work with a group of typically developing preschoolers who performed WM training on visuospatial tasks 15 minutes a day for 5 weeks. The authors reported training gains in non-trained spatial and verbal WM after training, revealing that WM training may lead to a transfer effect between modalities. Some researchers suggested that transfer will most typically take place under two conditions. One is the non-trained and the training tasks share some common behaviours such as both tasks involve recalling the item sequence in reverse order. The other is the non-trained task draws on the same neural resources as the training task, in other words there is neuronal overlapping between the training and the non-trained tasks (Von Bastian & Oberauer, 2014). Neuronal overlapping between visuospatial and verbal WM is a potential explanation for the between-modalities transfer effect found in the present study. Lycke and coworkers (2008) used a 2-back paradigm with a phonological and a spatial task to localize the brain areas that are associated with verbal or visuospatial WM. The authors reported that both tasks activated a bilateral network involving the occipito-parietal regions (BA 7/19/40). Additionally, there was bilateral activation in the inferior frontal gyrus (BA 47) for both tasks. These findings reflect an overlapping between the neuronal networks for visuospatial and verbal WM tasks. It is possible that visuospatial WM training leads to a plastic change in the functional connectivity for visuospatial WM which induces improvements (Jolles & Crone, 2012); this process also induces some positive effects on the neural network for verbal WM. Therefore, it is not surprising to observe improvements in non-trained verbal WM following training on visuospatial WM tasks in the present study.

No training benefits in visual attention were observed in either group in the present study, this finding is consistent with the results of the study conducted by Van Dongen-Boomsma et al. (2014). The authors investigated the training effects on visual attention in a group of young children (5-7 years) with ADHD using the sustained attention dots task - version 02K as the outcome measure. Reaction time with accuracy as a covariate before and after training was compared. The results showed that young children with ADHD did not show any significant improvements in visual attention after 5 weeks of adaptive Cogmed training. Although Thorell and colleagues (2009) reported significant improvements in visual attention in a group of typically developing preschoolers after 5 weeks of WM training, cautions should be taken when interpreting the results. Although the authors admitted that the results were marginally significant, they made the conclusion based on a significance level of $p < .1$ which showed that the training effect actually was very small. More importantly, only the number of omission errors on the Go/No-go task was used as an index for visual attention in this study, it may not able to reflect participant's actual visual attention. For example, participants can perform the task by pressing on the response button continuously in order to avoid missing targets. As a result, participants not only have less omission errors but may also have high commission errors. Under this condition, low omission error rate definitely is not the consequence of good sustained attention. Because visual attention was not fully reflected in this former study, the conclusion that significant training benefits in visual attention in young children is still unknown.

One interesting finding for visual attention is noted in the present study. When closely examining the patterns of change in reaction time and accuracy (i.e., both commission errors and omission errors) across time, there is a linear increasing trend for the scores of both reaction time and commission error in the control group. This pattern of performance changes suggests that term-born children reacted faster but had less commission errors across time. In other words, term-born children had improvements in their visual attention after training, although these improvements were not significant enough to reveal an effect statistically. In the preterm group, a different pattern of performance changes was observed. In this group, children reacted slower but had more omission errors over time. This pattern of performance changes implies a sign of decrement in vigilance in the preterm group. It is not clear why preterm children had deterioration in visual attention after training. It is possible that preterm children might have used a maladaptive strategy to tackle tasks with high cognitive demands like the TOVA. This notion is supported by the study done by Espy et al. (2012). In this study, delayed alternation task, a task similar to the format of the AB task, was used to examine the memory of preterm preschoolers. The authors found that instead of the expected previously rewarded location, preterm preschoolers chose a previously unrewarded location more often than term-born peers in the task. They suggested that this preservative behaviour was due to the use of a maladaptive strategy when performing the task.

Finally, no significant difference was found in the BRIEF parent ratings across time in either group. This finding is not surprising as it is not easy to detect behavioural changes within a relatively short period of time (i.e., about 13 weeks). Additionally, although parents knew that their child received training and therefore may expect some improvements, their judgments on whether their child has certain EF problems are influenced by his/her previous experience of the child's behaviours (Gathercole, 2014). Therefore, parents may not rate their child's EF differently across time except there are very large behavioural changes observed.

There are notable limitations to the present study. First, due to the small sample size in the present study, it was not possible to have a waitlist control condition for the preterm group, thus it is not clear the extent to which the beneficial training effects relate to maturation in preterm children. However, the inclusion of an age-matched term-born control group attempted to compensate for this drawback. Second, since some cognitive skills such as visuospatial WM and visual attention may need a longer time to have the training effect revealed, in future studies, longer-term follow up or multiple follow up assessments should be considered in order to detect the training-induced changes in these skills. Third, the small number of participants in each group could reduce the statistical power for detecting significant improvements across time. Nevertheless, significant training-induced improvements in verbal WM were found in the preterm group, suggesting that WM training has benefits for preterm children. Finally, the present study investigated the training effects on preterm children born with gestational age ≤ 32 weeks and aged between 4 and 6 years, the results cannot be generalized to school-aged preterm children or children born with gestational age > 32 weeks.

The results of the present study provide a preliminary support for the benefits of WM training in preterm children between 4 and 6 years of age. Near transfer effects were observed in non-trained WM. Although far transfer effect on attention and EF were not found after training or at 5-week follow-up, it is possible that preterm children might have used a maladaptive strategy for coping with highly demanding attention tasks. Collectively, the major findings of the present study are of theoretical as well as clinical interest as researchers can better understand the brain plasticity of children born preterm and practitioners can plan intervention based on the characteristics of the training-induced improvements in preterm children. For future studies, the relationship between WM training and training-induced strategy use in preterm population could be an interesting topic for examining. Given children born preterm also have a high risk of attention problems and attention is closely related to WM, WM training effects on attention should be investigated in a more systematic way in order to relate which processes of WM training can induce training gains in what types or what aspects of attention.

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Appendix 2A

Description of the Cogmed JM Exercises

Exercise	Description
Pool	A number of frogs will jump up from the pool in succession. The child needs to remember the order in which they jumped up. When the instruction "your turn" showed up on the screen, the child must click on the frogs in the same order that they jumped up.
Bumper Cars	A number of bumper cars will move in succession. The child needs to remember the order in which the cars moved. When the instruction "your turn" showed up on the screen, the child must click on the bumper cars in the same order that they moved.
Animals	A number of animals in a farm will light up in succession. The child needs to remember the order in which they lit up. When the instruction "your turn" showed up on the screen, the child must click on the animals in the same order that they lit up.
Rollercoaster	A number of cars will light up in succession. The child needs to remember the order in which they lit up. When the instruction "your turn" showed up on the screen, the child must click on the cars in the same order that they lit up.
Ferris Wheels	A number of cars will light up in succession. The child needs to remember the order in which they lit up. When the instruction "your turn" showed up on the screen, the child must click on the cars in the same order that they lit up.
Hotel	The window of rooms in a hotel will open in succession. The child needs to remember the order in which they opened up. When the instruction "your turn" showed up on the screen, the child must click on the windows in the same order that they opened up.
Twister	A number of cars will move in succession. The child needs to remember the order in which they move. When the instruction "your turn" showed up on the screen, the child must click on the cars in the same order that they moved.

Appendix 2B

The Sequence of Measures Administered in the Pre-training Testing, Post-training Testing, and the 5-week Follow-up Testing

	Measures	Time (min)
Pre-training Testing (T1)	AWMA	45
	Break	15
	NEPSY-Auditory Attention	30
	WRIT	30
	Break	15
	TOVA	30
Post-training Testing (T2)	AWMA	45
	Break	15
	NEPSY- Auditory Attention	30
	Break	15
	TOVA	30
5-week Follow-up Testing (T3)	AWMA	30
	Break	15
	NEPSY- Auditory Attention	30
	Break	15
	TOVA	30

Appendix 2C

The AWMA Subtests Administered in the Pre-training Testing, Post-training Testing, and the 5-week Follow-up Testing

AWMA tasks	Pre-training Testing (T1)	Post-training Testing (T2)	5-week Follow-up Testing (T3)
Verbal STM			
Digit Recall	X		X
Word Recall	X		
Nonword Recall		X	
Visuospatial STM			
Dot Matrix	X		X
Block Recall	X		
Mazes Memory		X	
Verbal WM			
Backward Digit	X		X
Counting Recall	X		
Listening Recall		X	
Visuospatial WM			
Mr. X	X		X
Spatial Span	X		
Odd-One-Out		X	

Note. X = task conducted in the testing session.

Chapter Five

Conclusion

The major findings in Study One show that preterm children performed worse than age-matched term-born children in WM tasks especially in those of visuospatial domain. Significant group difference in visuospatial WM was observed between school aged preterm and term-born children. When closely examining the developmental profiles of WM in preterm and term-born children, greater difference in verbal WM was found at preschool age, while difference in visuospatial WM was more apparent in school age period. These findings provide evident that visuospatial WM impairments in preterm children are more significant with age. In addition, preterm children are likely to have a delayed development in WM compared to age-matched term-born children. High correlational patterns between verbal and visuospatial WM were found in preterm children but not in age-matched term-born children, revealing that the WM components are not yet fractionated to support the various WM functions in preterm children.

Findings from Study One provide us a better understanding of the developmental profiles of WM in preterm children at both preschool and school ages. This can help parents and teachers understand more about the potential causes for preterm children's academic, behavioural and social problems. More importantly, it is expected that teachers and parents may consider using different instructions to suit the learning needs of preterm children. For example, preterm children are more vulnerable to visuospatial WM deficits, teachers and parents should use verbal instead of visual instructions and cues to aide them to encode and retrieve information. If visual modality must be used such as in reading comprehension, strategies like breaking down information into small pieces and giving each piece a verbal meaning should be taught to them. Although preterm children did not perform significantly worse than age-matched term-born children in WM at preschool age, preterm children had a less maturely developed WM than their age-matched term-born peers. In view of it, it is unable to exclude the possibility that preterm preschoolers will have WM difficulties in a later stage when WM demand is higher. This notion is supported by the finding that school-aged preterm children had significant WM impairments in the present study. Working memory is the fundamental skills for learning, academic needs have high demands on WM. Thus, early screening and intervention should be provided for preschoolers who are suspected to have WM problems in order to avoid difficulties with learning when they begin formal education.

Children who participated in Study One were also invited to participate in Study Two. Due to the high time commitment, only 12 preterm and 10 term-born children from preschool subgroups were able to complete all training sessions and participated in post-training and the 5-week follow-up testings. Results show training-induced improvements in trained and non-trained WM tasks in preterm children aged between 4 and 6 years. Although the results are preliminary and more studies are required for proving the benefits of WM training especially for visuospatial WM, a domain-general WM training like Cogmed could be considered as a choice of intervention for boosting WM of preterm children before they start formal education.

Finally, it is important to bring WM training from laboratory to real life situations so children can apply what learned from the training to their daily activities. One way to achieve this goal is to conduct the training in school setting. Children can perform the training in classroom and teachers can set up individual program plan for them based on their progress in the training. Recently, there are many research studies explored the viability of conducting WM training in classroom. The majority of these studies showed positive results and supported that WM training can be conducted out of laboratory (Holmes & Gathercole, 2014; Mezzacappa & Buckner, 2010; Passolunghi & Costa, 2014). In fact, school-based training not only can provide children the opportunities to practice the learned skills in real life situations, but also can build a bridge between researchers and community partners (i.e., school personnel, teachers, and parents) for them to communicate, collaborate and transfer knowledge.

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