How do children complete a motor and cognitive multi-task paradigm?

by

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ABSTRACT

HOW DO CHILDREN COMPLETE A MOTOR AND COGNITIVE MULTI-TASK PARADIGM?

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This thesis set out to deepen our knowledge surrounding the establishment of mature motor control strategies and attention focus for individual task performance as well as task integration in multi-task situations. Healthy children (age 7) and young adults (age 21) balanced a ball on a Frisbee on one hand, while reaching with the other to pick up a toy off the ground, in three postures (seated, standing, walking). An auditory Stroop task was administered simultaneous to onset of their reach. Children scaled their motor and executive function capabilities in order to complete the complex task successfully. In doing so, their response time and variability of control of motor synergies was significantly greater than adults. Children at this transitional age are searching for optimal control strategies over body kinematics. At the age of 7 children are establishing more mature motor control patterns, fine tuning their ability to perform tasks involving high levels of executive function and improving their ability to integrate more than one task.
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Chapter 1. Literature Review

The ability to perform more than one task at a time is a learned behaviour that takes place over the course of childhood (Assaiante, Thomachot, Aurenty & Amblard, 1998; Assaiante, 1998). Specifically, children must learn to integrate simultaneous cognitive and motor tasks efficiently, and without error, in order to avoid accidents in daily living. The following literature review provides background on the development of motor and cognitive task performance in early childhood. Of particular interest to this thesis, was the child’s progression towards the ability to perform simultaneous motor and cognitive tasks.

1.1 Dynamic Systems Theory

The Dynamic Systems Theory (DST) provides a framework for how highly sophisticated skills (i.e. walking) can occur without large amounts of cortical input. The body of scientific literature using this modeling approach has explored the mechanisms behind postural adjustments and reflexive actions as a skill that is developed and/or refined. The major themes of DST stem from the work of Nikolai Bernstein (1967). Bernstein viewed motor control as the integration between an initial central effector system and the auxiliary (i.e. peripheral) systems. Dynamic systems theorists expanded on this view of integration to suggest that motor behaviour occurs not only due to interacting subsystems (musculoskeletal, neurological, biological) but also interactions between the person, the task and the environment (Thelan, Ulrich & Jensen, 1989; Rose & Christina, 1997). The relationship between the subject and the environment is important, as information from the environment is readily available and meaningful for task performance (Rose & Christina, 1997).
Bernstein’s initial motor control theories are based on a redundant control system: there is more than one way for the central nervous system (CNS) to evoke and coordinate a given motor task. In other words, the same joint can make many different movements, as multiple muscles act across the same joint; kinetic chains are made up of multiple segments, muscles and joints. Bernstein named the multitude of factors to be controlled to perform a given movement the degrees of freedom of motor control (DF; Bernstein, 1967). The greater the number of DF between the central system and the periphery (i.e. the number of joints, muscles and forces to be controlled), the greater the complexity of organizational control required (CNS). Bernstein (1967) believed that coordination of a movement is actually controlled by the afferent input: collectively afferent information forms the central system input required to produce the skill or movement(s) required for task performance. Coordination is developed with practice, thus the initial difficulty with acquiring a new skill is the integration, coordination and control of a large number of DF. The CNS does not, when learning a new skill, know how to use the afferent input to create an effective and efficient movement. The first attempts at producing complex movement occur in childhood. To coordinate complex motions one must decrease the DF at the periphery, and in doing so, decrease the difficulty involved in coordinated the control over multiple joints and muscles. This type of strategy can also be observed when adults are learning a new skill. The ability to use a redundant number of DF for a given movement is the first indication of a maturing system (Bernstein, 1967). Bernstein argued that coordination, or the organization of control, is not its own activity or skill to be learned but rather coordination is evidence of one’s adaptability of skill and task performance.

Achievement of skill acquisition can be interpreted as an increase in the order or stability of the movement as multiple DF within the system are mastered (Bernstein, 1967). Variability,
another characteristic of interest within DST, is notably present during the intermediate state of skill acquisition. Between the first experience with a movement or task and its eventual mastery, we must learn to coordinate the redundant DF present (Schneiberg, Sveistrup, McFadyen, McKinley & Levin, 2002). Therefore it can be anticipated that with skill acquisition comes a decrease in overall variability of the movement(s). For example, in a seated reach task, Schneiberg and colleagues (2002) observed optimization (i.e. maturation to adult levels) of inter-joint coordination by 8 years of age, however variability of the children’s movements was greater than adults up to age 11 years. Overall, children used the same pattern of movement as adults therefore researchers speculated that children prioritize performance of the overall movement using other segments (i.e. the trunk) at their disposal. Interestingly, end performance produced by these children was correct however this control strategy resulted in greater trial-to-trial variability (Schneiberg et al., 2002). Dynamic system theorists view variability as a way of searching for the optimal kinematics of a given task. A mature and established motor control system would be expected to show a stereotypic kinematic response with minimal trial to trial variability (Thelan & Smith, 1994; Schneiberg et al., 2002). The work of Schneiberg and colleagues (2002) provides evidence of the fact that children of this age group are still in the process of developing adult-like movement patterns.

1.2 Ontogenetic Model

Based on the DST and Bernstein’s formative theories of motor control, the Ontogenetic Model outlines two principles, describing the development of balance strategies and segment coordination required for postural control and locomotion (Assaiante 1998; Assaiante and Amblard 1995). The first principle states that there are two reference frames on which the child can base balance control: the supporting surface or the gravitational vector. Using the supporting
surface as a reference frame requires the child to use an ascending organization of segmental control, beginning with the feet and moving towards the head. The gravitational vector reference frame uses descending segmental organization, beginning at the head and moving downward along the body. The second principle stems directly from Bernstein’s theoretical framework and states that the child can manipulate the DF of each of the body segments that are to be controlled simultaneously. In order to simplify a more complex movement, the child decreases the number of DF present. Both the reference frame and the DF used are dependent upon the task performed and the child’s current motor capabilities (Assaiante and Amblard 1995; Assaiante 1998).

Assaiante and Amblard (1995) described four major stages within the ontogenetic scheme to describe how balance control is organized during development (See Figure 1.7.1). The first stage begins at birth and continues until the child is able to stand up independently. This stage is characterized by descending control over balance, beginning in the muscles of the neck and continuing to the rest of the body. Articulation of the operation of the head-trunk unit is present until independent upright stance is achieved. The second stage begins with independent standing through independent locomotion until six years of age. Stage 2 uses an ascending organization and while standing, the supporting surface provides the reference frame for balance control and balance organization occurs from the feet to the head. However, during locomotion, the supporting surface is intermittent in its ability to provide a stable reference frame for balance control and instead, balance organization begins at the level of the pelvis and continues to the head. Hip-centered organization aids the child in providing a constant reference frame on which to develop locomotion (Assaiante 1998; Assaiante, Mallau, Viel, Jover & Schmitz, 2005). During this time, operation of the head-trunk segment is said to be ‘en bloc’ and using an egocentric basis for control: the head-trunk unit is now organized as one larger segment by
contracting the neck muscles thereby reducing the DF to be controlled. The ‘en bloc’, or egocentric, strategy also allows sensory information from both the visual and vestibular systems to guide control of the entire upper body during this highly important transitional stage (Assaiante and Amblard 1995).

The third stage begins at seven years of age when the head and trunk are again articulated and balance organization returns to a descending path beginning at the head. Gradually the child is able to move their head independent from the position of their trunk (Assaiante and Amblard 1995). Finally, during adulthood the ability to perform articulated head and trunk movement is combined with selective control over the magnitude of head movement for the given task and environmental constraints (Assaiante and Amblard 1995; Assaiante 1998).

1.3 Development of Reaching

A trunk based reference frame is easily observed in seated infants (5 months of age). Stability and control of the head-neck-trunk system is required for the earliest experiences in visuomotor exploration and reaching while seated (Reed, 1989; Roncesvalles, Schmitz, Zedka, Assaiante & Woollacott, 2005). Motor developmental literature has reported that seated infants are eventually able to perform articulated head-trunk movements prior to independent upright stance (Assaiante 1998; Assaiante and Amblard 1995). Accurate execution of manual reaching tasks requires coordinated action of all body segments involved (i.e. head, trunk and extremities) while simultaneously coordinating these actions with gravity. As an early simplification tool, young children first orient their balance and control strategy to the supporting surface. This is apparent during dual motor tasks while seated: young children performing bimanual tasks requiring a change in trunk lean couple movements of their upper arm and forearm to their trunk. This adapted ‘en bloc’, or egocentric, strategy effectively reduces the DF required to maintain
balance and complete the task (Roncesvalles et al. 2005). Similarly, articulated use of the head-trunk unit during a seated reach task has been observed by age 4-5, however a head dominant reference frame has been suggested as the guiding framework for the reaching task given that scaling of children’s trunk motion was not mature in children at this age, but was present in older children (Sveistrup, Schneiberg, McKinley McFadyen & Levin, 2008).

The emergence of a mature reaching strategy does not follow the same chronological order as other balance control tasks (e.g. standing posture or walking). Head-trunk coordination has been shown to depend on task difficulty, subject motor control maturation as well as the environment in which the task is occurring (Assaiante, 1998; Bernstein, 1967; Sveistrup et al., 2008). A task specific frame of reference is also apparent during skill acquisition: movements requiring coordination of larger number of DF are later to mature (Schneiberg et al., 2002; Sveistrup et al., 2008). During simpler tasks, (e.g. seated unimanual reach- Sveistrup et al., 2008) an earlier ability to uncouple the trunk and arm is apparent compared to a more difficult motor task (e.g. bimanual task with trunk movement- Roncesvalles et al., 2005). For example, during a seated reach task requiring a trunk lean, the same amount of elbow and trunk excursion as young adults was present in children by age 4, including a mature temporal coordination of arm and trunk movements (Schneiberg et al., 2002). Interestingly, further refinements of this movement are still occurring as greater variability of trunk movements were observed up to 10 years of age with inter-joint coordination variability and overall seated postural control not mature until age 11 (Schneiberg et al., 2002; van der Heide, Otten, van Eykern & Hadders-Algra, 2003).

Schneiberg and colleagues (2002) concluded that with age, we learn to master redundant DF as we learn the different combinations of DF that lead to the desired movement. Even when young
children can perform a given task properly, we still see continuing improvements in skill performance with age (Sveistrup et al., 2008).

Older children are, eventually, able to uncouple movements of the trunk and arm. Gradually they begin to reorient the position of their upper arm and forearm to the support surface rather than couple movement of their upper extremity to the orientation of their trunk (Roncsvalles et al., 2005); this transition appears to occur after six years of age. Development of postural control is non-linear; a major transition period for motor and balance control is between the ages of 5-8 years for postural control (Assaiante & Amblard, 1995; Assaiante et al., 2005), seated reach (van der Heide et al., 2003; Roncesvalles et al., 2005; Schneiberg et al., 2002; Sveistrup et al., 2008), and gait tasks (Assaiante, 1998; Shumway-Cook & Woollacott, 2007). For example, postural control studies have revealed that children aged 7-8 years have independent control of the head, pelvis and shoulder while walking on a flat surface, a relatively easy motor task at this stage of development. However, as the difficulty of the motor task increases, the child’s temporal organization regresses to previous stages of balance control. They no longer use an ascending organization but rather switch erroneously between ascending and descending control (Assaiante et al. 2005). Assaiante and colleagues (2005) have concluded that at certain transitional developmental periods, the control of segmental movement onset and timing seems to be the most challenging to obtain.

1.4 Development of Executive Function and Attention

Throughout early childhood, significant cognitive developmental changes are occurring. Executive function (EF) refers to higher levels of cognitive function which facilitate voluntary attention processes (Yogev-Seligmann, Hausdorff & Giladi, 2008). Information from the body’s cortical sensory systems is processed using EF to produce cognitive and behavioral responses
responsible for executing goal directed actions (Sheridan & Housdorf, 2007; Yogev-Seligmann, Hausdorff & Giladi, 2008). The major domains of EF encompass initiation or inhibition of movement, working memory, and attention selection (Sheridan & Housdorf, 2007). It is through EF that aspects of central processing, motor control, memory and attention are all interconnected. Cognitive inhibition, or the ability to suppress the more dominant response for another, is an example of executive function. In order to accurately inhibit the correct response, central processes must integrate the appropriate response with relevant rules (i.e. which response to suppress, which response to answer) within working memory (Guy, Rogers & Cornish, 2012). As opposed to typical working memory tasks (i.e. counting backwards), automation of EF responses are less likely making EF tasks a more desirable experimental paradigm for exploring dual-task capabilities.

The Stroop task is an ideal cognitive task to use to address research questions about the influence of EF on a simultaneous motor task. Typical Stroop paradigms (e.g. visual or auditory) provide a test of inhibition and interference. Interference occurs between the two dimensions of the task: the irrelevant dimension (i.e. during auditory Stroop: the word) is processed faster than the relevant dimension (i.e. the pitch). In the auditory version of the Stroop task, the subject is asked to identify the pitch (high or low) of the words “high” and “low”. Increased reaction time is expected for incongruent trials (i.e. the word “high” in a low pitch; Guy et al., 2012; Jerger, Martin, & Pirozzolo, 1988). It has been shown that a high level of attention is required to respond quickly and correctly to the auditory stimulus (Kelly, Creigh & Bartolotti, 2010; Weerdesteyn, Schillings, Van Galen, & Duysens, 2003). A cognitive load ‘ceiling effect’ has been revealed in children 6 years of age using this paradigm. Auditory Stroop tests with children age 3-6 years show rapid improvements in reaction time until age 5 at which points
improvements seem to taper. By age 6, most children can integrate both dimensions of the task (pitch and word) and answer congruent and incongruent trials correctly and more quickly than younger children (Guy et al. 2012; Jerger et al. 1988).

The most commonly used presentation of the Stroop effect is generated using a visual stimulus. However, in an experimental paradigm where participants are required to visually sample their environment, the auditory version is, arguably, a better option; when visual gaze information from the environment has to be split between the motor task and a visual Stroop task, structural interference may occur (Huang & Mercer 2001; MacLeod, 1991). The use of the auditory Stroop task in previous work has revealed its reliability as a consistent and accurate measure of EF in both adults (Kahneman & Chajczyk, 1983; Morgan & Brandt, 1989) and children (Guy et al., 2012; Jerger et al., 1988), making it an excellent choice as an experimental tool in dual task paradigms.

*Top-down control of attention* is the capacity to use intentions and goals to guide attention, rather than the constraints of the task, and provides the ability to divide attention between two tasks. *Top-down* implementation and strategies appear to be developed over the course of middle childhood (5-12 years; Gautier & Droit-Volet, 2002; Irwin-Chase & Burns 2000; Manis, Keating & Morrison 1980; Pick & Frankel, 1974; Schiff & Knopf, 1985). It is hypothesized that with age, children combine an increase in processing capacity with an improved efficiency for attention allocation and children are able to allocate attention more efficiently and scale their attention to the complexity of the task (Karatekin, 2004). For example, when performing a combined auditory and visual response task, children 10 years of age were shown to have the ability to manage attentional resources with a similar strategy to adults (Karatekin, 2004). Attention allocation between tasks during the dual task condition was very
similar between children and adults however children’s performances began to deviate from adult-like levels as the cognitive load of the individual tasks increased. Even at age 10, sufficient resources are not always used when higher cognitive loads are required. Beyond the maturity of the central networks, children reach the limits of their data capabilities when using similar strategy to adults (Karatekin 2004).

**1.5 Dual Task Paradigms**

To explore the effects of simultaneous motor and/or cognitive tasks, a dual-task paradigm is used (Shumway-Cook & Woollacott, 2007). More specifically, the use of dual task paradigms allows a researcher to examine two different types of research objectives: attentional demands for a given postural load or motor task (identified as the primary task) may be investigated, while simultaneously exploring the effect of a simultaneous cognitive task on motor performance or motor strategies (Huang & Mercer, 2001). The belief behind attentional demands of simultaneous tasks is that a central processing capacity exists (See Figure 1.7.2; Huang & Mercer, 2001; Shumway-Cook & Woollacott, 2007). When two tasks are performed simultaneously, the central system must divide the total capacity between the tasks at hand. As illustrated in Figure 1.7.2, the performance of the secondary task can provide an indication of the total processing capacity and the attentional demands for the primary task. If the primary task does not require a large portion of the total processing capacity, performance of the secondary task will not be altered. If however, the primary task is more demanding for processing capacity, the performance of the secondary task will decrease as the total capacity is reached (Huang & Mercer, 2001).

The ability to complete activities of daily living requiring cognitive input and division of attention requires management of both focus and task prioritization. Irwin-Chase and Burns
(2000) used a novel approach to control for any changes in dual-task capabilities in children with age (8 and 11 years), by first controlling for each subject’s performance during the single task. By using the level at which 80% accuracy was reached, researchers allowed for control over the difficulty of the single task before the addition of the second task. Difficulty of the single task (a visual detection task) was altered until an 80% accuracy rate was performed; they observed in subsequent trials that any additional increases in difficulty resulted in a lower accuracy rate. Interestingly, once single task performance was equalized between participants, performance differences between age groups during a dual cognitive task scenario, no longer existed. It was suggested that dual task performance improvements typically associated with age were due to an increase in performance of each task separately combined with an increased ability to divide attention between tasks (Irwin-Chase & Burns, 2000). These researchers concluded that the development of attention division is not only due to ongoing central maturation but the increase in automaticity of attentional allocation with age that aids coordination of mental resources.

The attention required for a given task performance depends on the complexity of the task, the motor and/or cognitive processing capabilities of the subject and the environment in which the paradigm is performed (Chen et al., 1996; Lajoie, Teasdale, Bard & Fleury, 1993; Shumway-Cook & Woollacott, 2007, Manis et al., 1980; Stoffregen, Pagulayan, Bardy & Hettinger, 2000). Dual task paradigms have provided evidence of an order for the attentional demands associated with posture, increasing from sitting, to standing, to walking and to more complex obstacle avoidance gait paradigms (Chen et al., 1996; Lajoie et al., 1993). Using an auditory cognitive task, Lajoie and colleagues (1993) found reaction time fastest while seated and slower while standing or walking, especially during single support. They concluded that as the postural demands increase, so do the attentional demands (Lajoie et al., 1993).
The effects of simultaneous tasks in healthy young adults are relatively small, unless the central system is overloaded, however these effects increase in older adults and children (Chen et al., 1996; Lajoie et al., 1993; Shumway-Cook & Woollacott, 2007). Different stages of motor and cognitive development will affect the way in which simultaneous tasks are performed. In children, mature control strategies are not yet established and a reduced overall attentional capacity will decrease their ability to complete simultaneous tasks. Older adult populations may be affected in dual task scenarios by altered or reduced sensory input (Shumway-Cook & Woollacott, 2007). For example, a detriment in obstacle avoidance behaviour has been observed with execution of a simultaneous secondary task in both healthy young and older adults however the detriments were larger for both tasks in older adults (Chen et al., 1996). Dual-task execution comparisons between different aged subject groups can provide insight to the differences in attentional requirements of tasks with different postural loads.

Improvements in postural control have also been found during dual-task paradigms. For example, a visual attention task improved standing postural control by providing a stationary visual focal point for the subject (Stoffregen et al., 2000). Structural interference refers to simultaneous tasks that are competing for the same central pathways (Huang & Mercer, 2001). If structural interference is not present (i.e. performing an auditory cognitive task while walking through the environment), it is assumed that the interference and related performance effects in a dual-task paradigm are capacity related (Huang & Mercer, 2001). Healthy young adults are able to integrate multiple tasks not only due to their mature motor control system, but also to their ability to divide attention and use executive function efficiently and accurately (Lajoie et al., 1993; Shumway-Cook & Woollacott 2007).
Given that children are in the process of establishing their motor control, executive function and attentional systems, their ability to prioritize tasks properly in a traditional dual task setting can be significantly challenged. It is believed that attentional capacity control can be allocated flexibly between tasks, however this behaviour must be learned (Manis et al., 1980). With age, not only do we see maturation in the development of balance control strategies but also an increase in cognitive task performance. This increase in cognitive performance may be due to an improvement in capacity allocation ability and the child’s specific stage of processing (Manis et al., 1980). As the efficiency of attention allocation for a given task increases, its relative capacity requirements decrease. In other words, with practice, the attentional requirements become smaller as a mature attentional allocation strategy is established (Halford, Maybery & Bain, 1986).

1.6 Thesis Objectives and Hypotheses

Postural and balance control studies, locomotion and gait pattern studies as well as cognitive assessments have identified the age of 6-7 years to be a major developmental transition. By this time, many independent motor and executive function skills have reached adult-like performance however they lack the sophistication and tight control seen in mature control systems (Assaiante and Amblard 1995; Assaiante 1998; Guy et al., 2012; Jerger et al., 1988; Schneiberg et al., 2002). It is unknown, however, if and how children at this transitional age are able to integrate a complex motor and cognitive task simultaneously. Therefore, this study aimed to further our general knowledge about the emergence and development of segmental coordination during complex motor and cognitive tasks in middle aged children. A bimanual reaching and balancing task previously demonstrated to be mastered at an adult-like level in this age group while seated (Roncesvalles et al., 2005) was combined with the auditory
Stroop task to expand upon the effects of executive function on a simultaneous motor task. The same group of children completed the same bimanual and cognitive task in three different postural loads (seated, standing and walking) and motor and cognitive performance was compared to healthy young adults.

This paradigm was designed to explore changes in motor control from a dynamic systems theory point of view. As participants increased postural load, the number of degrees of freedom to be controlled also increased, and the effects of a change in complexity of coordination was explored. In order to complete this complex paradigm, executive function and attention control were challenged with increases in postural load. The overall attentional requirements of the task increased with an increase in postural load from sitting to standing to walking as each posture has a unique attentional requirement (Lajoie et al., 1993). Not only did this paradigm challenge the requirements of the posture and manual motor component, but it also challenged the allocating of cognitive resources required to simultaneously perform the executive function task. Prior to this work it was not yet known if, or how, children will compensate task performance (motor, cognitive or both) as their overall attentional capacity is challenged. Changes in motor control, executive function and attention control with increases in postural load were explored using this simple, yet effective experimental paradigm.

The first objective of this work was to clarify if children at this transitional age have the multi-tasking abilities to perform a dual balance and reaching task separately in three different body postures (sitting, standing and walking). The second objective was to characterize the segmental control and cognitive task strategies used by the child participant group in order to complete the paradigm. It was hypothesized that children at this age would be capable of this complex upper body task, however we expected their motor and cognitive strategies would differ
from adults and differ between postures. More specifically, children aged 7 years would use an *egocentric based control strategy* to decrease the degrees of freedom and attempt to simplify the overall task, especially in the walking task where the postural load is the greatest. Response time to the Auditory Stroop task would increase as postural load increased and it was expected that the addition of the cognitive task would result in children slowing down and altering their reaching movement. This change in motor strategy would come as part of a partitioning strategy in order to complete each *part* properly while still completing the entire paradigm successfully.

The **final objective** was to explore two additional more specific motor and cognitive changes across all postures (*No Motor, Seated Reach, Standing Reach, Walking Reach*) within each subject group. It was hypothesized that response time to the Stroop task would increase from the single task performance (*No Motor*) through each increase in postural load. Finally, it was hypothesized that reach time, based on trunk movement, would also increase from the least posturally demanding task (*Seated Reach*), through to the largest (*Walking Reach*).
1.7 Figures

**Figure 2.7.1:** The ontogenetic scheme of balance control organization during development.

*(From: Assaiante & Amblard, 1995)*

**Figure 1.7.2:** Schematic of total processing capacity and the attentional demands of two different tasks. Less processing capacity is available for a secondary task with Primary Task B.

*(From Huang & Mercer, 2001)*
1.8 References


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Chapter 2. How do children complete a seated combined cognitive and motor multi-tasking paradigm?

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**ABSTRACT:** Healthy children (n=12, age 7 years) and young adults (n=11, age 21 years) were asked to perform a bimanual balance and reaching protocol in a seated posture. Subjects balanced a ball on a Frisbee on the non-dominant palm of the hand while reaching with the dominant hand to pick up a toy off the ground. During half of the trials, an auditory Stroop task was administered simultaneous to onset of the participants’ reach. All children (CH) and adults (AD) successfully completed both motor and cognitive tasks when combined: the ball and Frisbee were not dropped and cognitive accuracy rate for both groups was 77%. Angular range of motion (ROM) measures indicated that the trunk, upper arm (UA) and forearm (FA) segments were moving as articulated individual segments in both adults and children (ROM for trunk≠UA≠FA; p<0.001). However, differences between CH and AD upper body segmental control were evident: greater variability existed between trials and between subjects for segmental ROM in CH compared to AD (p<0.001), suggesting that adult-like control is still developing in this age group. Results indicate children aged 7 years can successfully perform a simultaneous upper body motor and cognitive task in a seated posture, however motor performance control is not yet at the same level as adults.

**Keywords:** children, bimanual task, cognitive task, segmental control, dual-task; attention
2.1 Introduction

The ability to multitask, whether performing multiple motor tasks, cognitive tasks or a combination of the two, is crucial for the execution of activities of daily living. The ability to integrate complex motor tasks is a learned behavior, developed throughout childhood (Assaiante, Thomachot, Aurenty & Amblard, 1998; Assaiante, 1998). The dynamic systems theory provides a basic model for infant and child skill acquisition. Coordination and performance of a skilled task requires the interaction between the skill, the task requirements and the environment (Corbetta & Thelen, 1996) For example, in order to maintain balance while learning to stand and eventually walk, infants must learn to negotiate between overall balance control and the destabilizing movements of their body segments.

Development of postural control is thought to originate from a trunk based reference frame (Assaiante et al., 1998; Assaiante 1998). Classic motor developmental literature has reported that seated infants are able to perform articulated head-trunk movements, by first controlling their head and trunk position and then learning to integrate muscle synergies required for their reach (Assaiante, 1998; Assaiante & Amblard, 1995, Bertenthal & VonHofsten, 1998). Posture and reaching are highly intertwined as head and trunk stability is critical to reaching performance (Sveistrup, Schneiber, McKinley, McFadyen & Levin, 2008). This is also apparent during dual motor tasks while seated: young children under the age of 6 years performing bimanual tasks requiring changes in trunk lean, couple movements of their upper arm and forearm to their trunk. This adapted strategy, termed ‘en bloc’ or egocentric control in developmental literature, reduces the degrees of freedom required to maintain balance during the task (Roncesvalles, Schmitz, Zedka, Assaiante & Woollacott, 2005). Infants first use co-activation muscle synergies to stiffen the trunk and arm to counteract forces moving the arm and
hand in the wrong direction (Thelen & Spencer 1998). By the age of 6-7 years, children are able to reorient the position of their upper arm and forearm to the support surface rather than couple movement of their upper extremity to the orientation of their trunk however their performance continues to show high inter-subject variability (Roncosvalles et al. 2005). Measures of variability (standard deviation) can provide insight into how robust segmental control strategies were from trial to trial for each subject. As motor development matures, variability of performance trial to trial decreases indicating a tighter overall control of movement.

In addition to their motor development stage and age, the difficulty of the task to be performed also plays a role in the selection of control strategies used by a child. For example, postural control studies revealed that children age 7-8 years show independent control of the head, pelvis and shoulder while walking on a flat surface, a relatively easy motor task at this stage of development. However, as the difficulty of the motor task increases, the child’s temporal organization regresses to previous stages of balance control. They no longer use an ascending organization but rather switch erroneously between ascending and descending control (Assaiante, Mallau, Viel, Jover & Schmitz, 2005). Assaiante and colleagues (2005) concluded that at certain transitional periods, the control and coordination of segmental onset and timing seems to be the most challenging to the developing central nervous system (CNS).

Simultaneous to motor development, children are in the process of cognitive development, both in terms of attentional resources and dual tasking capabilities. In a dual-task scenario, each task’s demands compete for attentional processing capacities. The decrease in performance of each single task during a dual task performance, expressed as the percentage difference in performance (positive or negative), is known as dual-task cost (DTC). With age, children decrease DTC with simultaneous tasks. In other words, as children age, performance of
single tasks does not decrease as considerably when performed at the same time as another task (Guttentag, 1989).

Irwin-Chase and Burns (2000) used a novel approach in their experimental paradigm in order to control for this change in DTC with age, by first controlling for the subject’s performance during the single task. The researchers increased the difficulty of the single task (a visual detection task) in a stepwise approach until an 80% accuracy rate was performed and any more increases in difficulty produced a lower accuracy rate. Since there was a significant difference between the difficulty levels reached for the criterion accuracy by the two age groups (8 and 11 years old), using the level at which 80% accuracy was reached allowed for control over the difficulty of the single task before the addition of the second task. Once single task performance was equalized between participants, DTC differences between age groups no longer existed. The decrease in DTC, typically associated with age, was simply due to an increase in performance of each task separately combined with an increased ability to divide attention between tasks (Irwin-Chase & Burns, 2000). Irwin-Chase and Burns (2000) concluded that the development of attention division is not only due to ongoing central maturation but the increase in automaticity of attentional allocation with age that aids coordination of mental resources.

Daily activities continuously demand cognitive input and division of attention, for example, walking and talking with friends. The ability to complete this type of task without error requires management of attention and prioritizing tasks so that they may be completed efficiently. The Auditory Stroop task is a simple yet effective task commonly used to assess cognitive load and attention (Guy, Rogers & Cornish, 2012; Jerger, Martin & Pirozzolo, 1988); the auditory version of this executive function task limits the amount of structural interference that a visually based Stroop task might present (i.e. require participants to split their visual attention between
the cognitive Stroop task and the motor reaching task). Based on the rationale of interference, this test asks the subject to identify the pitch (high or low) of the words “high” and “low”; congruent and incongruent auditory cues are randomly issued. The irrelevant dimension (i.e. the word) is processed faster than the relevant dimension (i.e. the pitch) causing interference and increased reaction time for incongruent trials (Guy et al, 2012; Jerger et al., 1988). A cognitive load ‘ceiling effect’ has been revealed in children 6 years of age using this paradigm. Auditory Stroop tests with children age 3-6 years show rapid improvements in reaction time until age 5 at which point, improvements seem to taper. By age 6, most children can integrate both dimensions of the task (pitch and word) and answer congruent and incongruent trials correctly and more quickly than younger children (Guy et al., 2012; Jerger et al., 1988).

In summary, postural and balance control studies as well as cognitive assessments have identified the age of 6-7 years to be a major developmental transition. By this time, many independent motor skills have reached performance levels similar to those seen in adults. For example, children aged 7 can perform both cognitive and balance tasks at adult levels when performed separately. However, it is not known at this time how effectively young children perform these tasks concurrently. Studying how the CNS executes these tasks separately and concurrently will help us elucidate the cognitive resource limits of children at this critical developmental age.

Our study aimed to further our general knowledge about the emergence and development of attentional strategies and segmental coordination during complex motor and cognitive tasks in school aged children. To this end, we assessed whether, by seven years of age, children can integrate a cognitive task requiring executive function, with an upper body motor task in a seated posture accurately. An adult population (aged 18-25 years) was also studied to determine the
similarities and differences between strategies used by the children and mature young adults. It was hypothesized that children would not be able to complete the cognitive task with the same efficiency or accuracy as adults once combined with the motor task. It was also hypothesized that the children would regress in segmental control and make use of an egocentric based control strategy to simplify the overall task and reduce the degrees of freedom to be controlled in order to successfully integrate the motor and cognitive tasks. This motor strategy was hypothesized would be different from the adult articulated strategy. It was anticipated that adults would have less variability in their segmental control strategies (indicative of a more consistent task performance) than children who are still acquiring complex motor skills. Finally, it was hypothesized that in order to complete both the cognitive and motor tasks successfully, and given their attentional limits at this age, children would employ a partitioning strategy as a task simplification tool, and address each task individually rather than simultaneously.

2.2 Methods

2.2.1 Subjects

Twelve healthy children (4 male and 8 female, mean age 7.5 years ± 0.5 years) and eleven healthy adults (5 male and 6 female, mean age 20.4 years ± 1.0 years) participated in this study. All participants were right handed and right footed except for one child participant who was left handed and left footed (Waterloo Footedness Questionnaire, Elias et al., 1998). All subjects, or the guardians of child participants, completed a health questionnaire confirming a lack of medically diagnosed neurological and musculoskeletal deficits. Exclusion criterion included any history of neurological problems, uncorrected hearing or vision problems or previously observed issues related to comprehension or perception. Both child and adults participants came from a wide variety of backgrounds as study advertisements were posted at
various local community and campus centres, as well as advertised via word of mouth on the university campus. Participants were not excluded based on athletic or artistic background. Child participants and their parents were informed of the experimental procedure and written consent (parents and adults) was acquired prior to data collection. This study was approved by the Research Ethics Board (REB # 13JN020).

2.2.2 Experimental Paradigm

To ensure that the participants’ particular stage of motor and cognitive development enabled them to accurately perform these tasks individually, two inclusion criteria were required of each subject. Participants were introduced to the Auditory Stroop task at the beginning of the testing protocol. The auditory Stroop task required participants to identify the pitch (high or low) of the words “high” and “low”. A minimum of 6 correct responses out of 8 while seated (no motor condition) was required of each participant to ensure the cognitive task was understood (i.e. the participant attempted to answer correctly rather than guess) and that the task performance could be compared between the child and adult subject groups. The second inclusion criterion required all participants to perform the reaching and balancing task successfully in a seated posture (seated reach condition), without the auditory task. If the participant was not successful, the results were not included in statistical analyses. All participants included in the protocol outlined here, complied with both inclusionary criterion.

Data collection took place at the University’s Gait Biomechanics Laboratory. Kinematic data was collected at 100 Hz using optoelectric cameras (Optotrak 3020, Northern Digital, Inc., Canada). Two banks of cameras were oriented to view participants from frontal and sagittal planes. Three non-collinear infra-red diodes (IRED markers) were mounted on the head, trunk, pelvis, and left and right foot of each subject. Several anatomical landmarks were digitized for
each segment (e.g. ears, coracoid processes, heels, toes) to create fifteen imaginary markers that anatomically defined the head, trunk, pelvis and foot segments (i.e. Head, Trunk4, Trunk1, Upper arms and Forearms; Winter, Patla, Prince, Ishac & Gielo-Perczak 1998). A small microphone was placed on the subject’s chest and simultaneously collected their auditory response sound waves to the auditory Stroop task at 4000 Hz.

The protocol was explained to the participant (and parent), including the order and number of trials, before any experimental trials commenced. To ensure that child participants maintained focus during the experiment, an age appropriate chart was displayed with their progress and the steps left “To Do”. Participants were asked to perform the bimanual balance and reaching protocol in a seated posture, with chair height adjusted to have both feet firmly on the floor; each subject could reach the ground without shifting his or her pelvis from a seated posture. Subjects attempted to maintain balance of a ball placed on a Frisbee on the palm of their non-dominant hand (NDH). Beginning with the upper arm (UA) kept close to the trunk, the forearm (FA) and palm of the NDH parallel to the floor and the ball on the Frisbee balanced, subjects then reached with the dominant hand (DH) to pick up a small toy off the ground. The toy was placed midway between, and in front of, the participant’s feet, and could easily be reached without moving from the chair. The toy was rectangular in shape and small enough to fit in a child’s hand. Participants were encouraged to begin their movement any time after the researcher provided a ‘start’ prompt. Participants completed the reaching task while simultaneously maintaining balance of the ball on the Frisbee and were only constrained to maintaining a seated posture. Participants were given the opportunity to perform the motor task two or three times before recording began.
Each participant completed twelve experimental trials (see Table 2.7.1). During 6 of the 12 trials, the auditory Stroop task was administered simultaneous to the participant’s reach. On trials deemed “Auditory” trials (AUD condition), a photo sensor laser gate was used to trigger a stored computerized voice as the subject shifted their trunk forward from their upright-seated posture and reached for the toy. The laser trigger was positioned at an appropriate height and position for each participant. In order to randomize the presence of the auditory component by trial, and once again, involve child participants in the experimental procedures, we asked all participants (adult and child) to select from pieces of coloured paper in a small bag. This paper indicated which type trial would be completed next. For example, an orange paper represented a trial with the auditory task; a purple piece represented a trial without the auditory task. This ‘game’ aided with trial randomization, and also assisted with maintaining child participants’ focus and attention during experimental trials.

The investigators did not communicate prioritization constraints between the reaching and/or cognitive tasks to the participants; participants were instructed to complete all tasks as quickly and as accurately as possible. No constraint on answer timing was made to participants (i.e. response could be made before the cue was complete however this was never the case). During the seated auditory trials (no motor condition), feedback on response accuracy was given to ensure participants understood the task properly. No feedback on response accuracy was given during the combined motor and cognitive tasks (seated reach condition). In order to ensure participants’ focus and attention, subjects were told that the investigator was recording their answers for accuracy and time.
2.2.3 Data Analyses

Cognitive performance was assessed by means of accuracy, reaction time and answer timing relative to toy pickup. Analog signal of the auditory cue and subjects’ responses were processed using a customized LabView program (KinAnalysis) and to determine absolute reaction time to the auditory cue. Analog signal recordings from the microphone were band pass filtered at 700-1000 Hz. Onset of the auditory stimulus and the participant’s response was identified using visual inspection by a primary researcher and verified by a second researcher (percent agreement between the two researchers was 96%). Reaction time was calculated as the difference in seconds between the start of the auditory cue and the participant’s response, thus controlling for participants who responded to the cue before the cue was completed. Accuracy was recorded by a research assistant during the protocol, as to whether the participant had correctly identified the pitch of the auditory Stroop cue. A mean accuracy rate was determined for each subject within congruent and incongruent trials and then collapsed across subject types (Child, Adult) for each task (no motor, seated reach).

Kinematic data was collected for the seated reach condition and was processed (Visual 3-D, C-Motion Inc., Germantown MD) to calculate segmental velocity, absolute segmental angles and the variability of these measures across the six trials collected for each experimental condition (auditory cue present: AUD; no auditory cue present: NoAUD). Kinematic data was interpolated for small gaps in marker position (maximum 200 ms); when substantial data was missing (> 20 frames), the trial was omitted from analysis. Trials for each condition (AUD, noAUD) were analyzed and averaged for each subject and group means and standard errors (SE) were calculated. A three dimensional (3D) trunk centre of mass (COM) position was estimated using the Winter model (Winter et al., 1998) and a 3D Trunk COM velocity vector was created.
for the entire trial. As outlined by Roncesvalles and colleagues (2005) the analysis of segmental movements began with the onset of reach (RCH). For this protocol, reach onset was defined as the time point when the trunk COM velocity vector increased beyond 5% of the trial’s maximum trunk velocity (see Figure 2.7.1A). A 3D velocity vector allowed for the ability to account for any twisting as well as forward lean during the reach.

Kinematic data analyses of the upper body included calculating the absolute angle relative to the right horizontal of the trunk, and UA and FA of the arm balancing the Frisbee (NDH). A two dimensional trunk absolute angle was calculated relative to right horizontal and maximum forward trunk lean for each trial was used at the end point of the reach (MAX, see Figure 2.7.1B). The absolute angles of the UA and FA balancing the Frisbee and the trunk segment were calculated and the angular displacement (from RCH to MAX) in each trial was determined for all three segments and collapsed for each subject across auditory conditions (AUD and noAUD). Finally group means and SE were calculated across auditory conditions. Angular ROM variability was calculated as the standard deviation of segmental angular displacement for each subject during the seated reach and was collapsed across subject groups (child and adult) and auditory condition (AUD and noAUD).

2.2.4 Statistical Analyses

The mean reaction time was calculated for each subject in each motor condition (no motor and seated reach). A general linear model was used to investigate the effect of subject group (Child, Adult) on reaction time for each motor condition (no motor, seated reach). The mean angular ROM of each segment (trunk, UA, and FA) within an auditory condition (AUD or NoAUD) for both subject groups (Child, Adult) was calculated. A two-way analysis of variance (ANOVA) was conducted to investigate the effect of age group and auditory cue on the angular
ROM of each segment (trunk, UA, FA). To explore whether segments were moving through the same ROM, which would indicate the use of an egocentric based control, paired t-tests were used to compare the mean angular ROM of the trunk, UA and FA segments within each age group (Child, Adult), a Tukey’s adjustment was made to account for multiple t-tests. A general linear model was used to investigate the effect of age group (Child, Adult) and segment (trunk, UA, FA) on variability. Finally, to determine whether the presence of an auditory cue affected segmental ROM, the difference in Angular ROM between auditory conditions (Mean ROM for NoAUD subtracted from Mean ROM for AUD) was calculated. An independent sample t-test was then used to determine if this difference value was different from 0; if no statistical difference was present it would indicate that there was no difference in ROM values between the cognitive load conditions.

2.3 Results

2.3.1 Auditory Stroop Task

As illustrated in Figure 2.7.2, reaction time (RT) for children averaged 2.96 seconds (S.E. = 0.27) and 1.32 seconds for adults (S.E. = 0.31) during the single task (no motor condition). A univariate linear model showed that children took longer to respond than adults to the auditory Stroop task in the no motor condition (F(1,21) = 16.239, P<0.001). To investigate whether a practice effect was present, the analyses were repeated a second time using only the last 3 trials for each subject in the no motor condition. Interesting, the trend was the exact same with children having significantly longer reaction times (Children = 3.203 seconds (S.E. = 0.478) and Adults = 1.588 seconds (S.E. = 0.516) seconds; F(1,11)=5.265 P=0.042). Reaction time during the seated reach was 1.67 seconds (S.E. = 0.11) for children and 1.36 seconds for adults (S.E. =
Again, a univariate linear model showed that children took longer to respond than adults (Seated Reach: F(1,28) = 4.782, P = 0.037).

There was no effect of congruency on reaction time. Both subject groups reached the minimum of 6 of 8 answers correct during the no motor condition to continue on to the seated reach protocol. A summary of subject’s accuracy rate to the auditory Stroop condition during the seated reach condition can be found in Table 2.7.2. While seated, both subject groups reached an overall accuracy rate of 77.1% correct. Both children and adults answered congruent cues more correctly than incongruent. Children and adults also used the exact same strategy for answer timing: 20% of answers to the Stroop task came during toy pickup, and 80% occurred after toy pickup.

2.3.2 Seated Reach Motor Task

Representative traces of the absolute angle of the trunk, upper arm and forearm during the reaching task are illustrated in Figure 2.7.3 for one child and one adult. If the ball did not drop from the Frisbee it was considered a successful trial. In general all participants were successful at this balancing motor task though on a few trials the children did drop the ball (<5% of all trials) when they were bored; these trials were discarded and recollected after a brief break. Figure 2.7.4 displays the angular displacement of the trunk, UA and FA segments for children and adults from RCH to MAX. A two-way ANOVA (Age group X Auditory condition) revealed no effect of age group or auditory condition for the mean trunk ROM (Adults (Mean ± SE)=15.34 ± 0.96º, Children=16.36 ± 0.95º, F(1,33)=0.578, p=0.453). This confirms that despite the fact that seat height was different (to ensure feet were flat on the ground during reaching trials), the amount of trunk motion during the reaching task was the same for children and adults. There was, however, a main effect of age for the UA angular ROM (Mean ROM ± SE; Adults =
38.42 ± 2.27º, Children = 31.63 ± 2.24º; F(1,33)= 4.532, p<0.05) and FA angular ROM (Mean ROM ± SE; Adults = 6.98 ±0.82º, Children = 10.04 ± 0.80º; F(1,33)= 7.137, p<0.05).

As illustrated in Figure 2.7.5, children had a mean variability of 1.94º for the trunk, 10.12º for the UA and 4.07º for the FA. A univariate linear model revealed children were significantly more variable in their angular displacement of the trunk (Adult= 1.03º, F(1,30)= 9.814, p = 0.004), UA (Adult = 4.52 º, F(1,30) = 20.933, p<0.001) and FA (Adult =1.86 º, F(1,30) = 19.331, p<0.001) than adults.

2.3.3 Effect of Cognitive task on Motor Performance

Figure 2.7.6(A-C) illustrates the mean difference for each subject between the angular displacement during AUD and noAUD trials. A mean difference of 0 (depicted on the y-axis) would be representative of the same ROM for both AUD and noAUD conditions. Mean differences between the angular displacement of trunk, UA and FA during the AUD and noAUD conditions (AUD-noAUD) for adults and children were compared to 0 using an independent samples t-test. No significant differences were observed between AUD-noAUD and 0 for the Trunk (Adults (mean difference ± SE) = -0.29 ± 0.43º, t (9)= -0.682, p=0.512; Children = -0.37 ± 0.62º, t(7) = -0.588, p=0.575), Upper Arm (Adults= -1.53 ± 1.53º, t(9)=-0.996, p=0.345; Children = 4.19 ± 2.03º, t(7)=2.067, p = 0.078), and Forearm (Adult = 0.17 ± 0.46º, t(9)=0.369, p=0.721; Children = 0.05 ± 1.17º, t(7) = 0.039, p= 0.97). Since there was no evidence of an effect of simultaneous cognitive task, paired t-tests (trunk-UA, UA-FA, trunk-FA, see Table 2.7.3) for each subject group were performed collapsed across auditory conditions. Results of these tests revealed the trunk, UA and FA segments of both adults and children completed a unique angular ROM indicating articulated control of the upper body.
2.4 Discussion

Past research has confirmed the ability of children age 7 years to complete, independently, a seated bimanual task (Roncesvalles et al., 2005) and an auditory Stroop task (Guy et al., 2012) accurately and efficiently similar to strategies used by adults. It was our goal to combine these tasks to elucidate strategies that children use to attempt motor and cognitive tasks simultaneously, a daily challenge faced by children in this age group. The results of this study highlight the adaptability of children age 7 years to perform novel motor and cognitive tasks simultaneously using strategies appropriate for their motor skill and attentional capacity.

2.4.1 Children adopted a similar overall strategy to adults

There was no effect of the auditory cue on trunk, upper arm or forearm angular ROM for adults or children. One of the main goals of this work was to compare how children at this transitional period differ (if at all) from the motor performance of adults for the same balance and reaching task. Similar to adults, children used the same motor strategy with and without the presence of a simultaneous cognitive task. However, adults used an articulated motor plan with significantly shorter response times to the auditory cue compared to the children. Implementation of the articulated motor strategy for the children was, in part, an attempt to simplify the level of control required for the entire paradigm. The children’s strategy contained some adult-like qualities (articulated movement of the trunk, and UA and FA balancing the Frisbee) however their level of segmental control (i.e. ROM variability) and response time to the cognitive task does not match adult behavior. No priority was made to the participants between the cognitive and motor tasks, however the results suggest that children first ensured their motor plan was set and did not change their strategy whether the Stroop task was present or not. Although not a traditional partitioning strategy that has been observed in middle aged children (Vallis &
McFadyen, 2005), setting up a motor plan irrelevant to a cognitive addition seems to have been employed as a task simplification tool, providing the child with the ability to perform both tasks successfully. However, in using this motor plan, a greater proportion of their attentional capacity was required, and the cognitive task reaction time was compromised.

### 2.4.2 Children require more attentional resources for the same task

It was hypothesized that children age 7 would not be able to complete the cognitive task with the same efficiency or accuracy as adults once combined with the motor task. Our results revealed that children in this age group are capable of an auditory Stroop task with the same accuracy and timing strategies as adults, however when combined with a motor condition, children required more time to react to the auditory Stroop task. All children met the cognitive inclusion criteria however we hypothesize that the combined task required more attentional resources for children. This hypothesis is founded not only on the increased reaction time while seated, but also due to their continued development and maturation of attention division (Irwin-Chase & Burns 2000).

Children learned the task and were able to match the adult group in terms of accuracy and answer timing, however their reaction time to the Stroop cue was significantly longer, suggesting an increase in their cognitive processing time. Relative to their toy pickup, children used the same answer timing strategy as adults and even answered during their toy pickup. In order for children to match an adult-like accuracy level, the attentional requirements appeared to be greater than adults for the same task as children required a longer answering time to reach this same accuracy level. It is important to note the importance of instructions, especially with a child population. The instructions provided for the cognitive task were “to answer as quickly and
accurately as possible” and so it was assumed that children would take enough time to come to the correct answer.

### 2.4.3 Children did not require an egocentric based strategy

It was expected that children age 7 would regress in segmental control and make use of an egocentric based strategy when the motor and cognitive tasks were performed simultaneously. In an attempt to simplify the overall task and reduce the degrees of freedom to be controlled, it was thought regressing to an egocentric strategy would allow the children to successfully integrate the motor and cognitive tasks. This type of regression in postural control has been seen in children in this age group when a simple motor task (e.g. straight walking) becomes more complex (e.g. obstacle avoidance; Assaiante et al., 2005). A true egocentric strategy would have been demonstrated if two or more segments moved through the same ROM at the same time, therefore reducing the control of degrees of freedom from multiple segments to, effectively, one segment.

Given previous developmental literature displaying the trunk to be the first segment to be controlled independently (Assaiante & Amblard, 1995; Assaiante et al., 1998), it was thought that with the addition of the cognitive task, children would prioritize the position of their trunk over maintaining the position of the forearm relative to gravity (to prevent the ball from falling) however this was not the case. We conclude from our results that children instead adopted a pseudo-articulated segmental control, rather than a completely egocentric based control strategy that did not change with the addition of the cognitive task. The trunk, and UA and FA segments balancing the Frisbee each completed an independent angular ROM for both children and adults. However, children decreased upper arm angular ROM and increased forearm angular ROM compared to adults. Children are attempting to account for the load on their hand, and are
successful, but their motor strategy is not yet the same as the adults and the degree of control from trial to trial (i.e. angular ROM variability) is significantly different than adults.

2.4.4 Segmental Control is still developing at 7 years old

Healthy adults are not only capable of articulated control of their upper body, maintaining forearm position relative to gravity rather than their trunk position, they also have tight control over their body position changes. We did not see large discrepancies between trials for the control of individual body segments or even between adult subjects. Using standard deviation as an index of performance consistency, it is clear that children demonstrate higher variability in motor task performance, however based on these findings it is unknown at this time if this variability generated by the central nervous system is detrimental or beneficial. Perhaps, in the process of development and specifically the acquisition of complex motor skills, it is of upmost importance for children to learn how to produce flexible yet precise behaviour and thus for children who are still acquiring complex motor skills this degree of variability is advantageous and an important part of the developmental process. Children are still learning to control their segments relative to an environmental reference frame, and do not appear to have the same level of consistent control (Roncessvalles et al., 2005). An increase in balance control comes with age and experience and eventually allows for more precise upper body and cognitive performance coordination (Roncessvalles et al., 2005; Karatekin, 2004). When beginning to walk, the trunk is the first reference frame used by children in balance control (Assaiante & Amblard, 1995; Assaiante et al., 1998). Typically developing children aged seven years are capable of using a segmental control system based on gravity (Assaiante, 1998), however we hypothesized that the challenge of dividing attention between the Stroop task and the motor task would have required children to regress back to a more immature, egocentric based segmental control strategy.
(Assaiante et al. 2005). Children in the current paradigm were able to adapt to our challenging motor task and select a motor strategy that provided success in the task (i.e. the ball was not dropped) which was also appropriate to their attentional capacities.

### 2.4.5 Children are developing the ability to divide attention

*Top-down control of attention* is the capacity to use intentions and goals to guide attention rather than simply the constraints of the task and provides the ability to divide attention between two tasks. Top-down implementation and strategies are developed over the course of middle childhood (5-12 years; Pick & Frankel 1974; Schiff & Knopf 1985; Manis, Keating & Morrison 1980; Gautier & Droit-Volet 2002; Irwin-Chase & Burns 2000). Several hypotheses relating top-down control to limited attentional resources exist. It is thought that with age, children combine an increase in processing capacity with an improved efficiency for attention allocation (Karatekin, 2004). This paradigm confirms that children age 7 years have the ability to implement a *top-down* strategy for attention however, this system is not yet fully mature. With age, children can allocate attention more efficiently and scale their attention to the complexity of the task (Karatekin, 2004).

For example, Karatekin (2004) asked children age 10 years, to perform a combined attention and motor response to visual stimuli. While children 10 years of age have the ability to manage attentional resources with a similar strategy to adults, their system is not yet fully mature (Karatekin, 2004). In Karatekin’s paradigm (2004), children attended to instructions properly and their attentional allocation between tasks during the dual task condition was very similar to adult strategies however their performance began to deviate from adult-like levels as the cognitive load of the individual tasks increased. Even at age 10, sufficient resources are not always used when higher cognitive loads are required (Karatekin, 2004). Specific to this paradigm, children...
were able to implement a *top-down* control over attention shown through their ability to divide their attention between tasks appropriately in order to be successful (ball rarely dropped, accuracy rate similar to adults). Beyond the maturity of the central networks, Karatekin (2004) stated children reach the limits of their data capabilities when using similar strategy to adults. Children in our paradigm attempted the same cognitive strategies as adults however their motor task performance was not able to reach the same level of control. To perform the same dual task strategy requires more attentional resources for children in comparison to adults and children are not yet able to allocate their attention properly to the demands of the dual task paradigm at the same level of control as adults.

2.4.6 Controlling for between subject group differences

Like Irwin-Chase and Burns (2000), attempts were made to keep the individual tasks the same across participants in order to account for the overall difficulty of the task. By requiring participants to reach a 75% accuracy rate for the cognitive task, we were able assess whether or not participants understood the auditory Stroop task properly to move onto the experimental trials. Chair height was adjusted so that each participant’s feet were firmly planted on the ground and able to reach the ground with their dominant hand without moving their pelvis from the chair seat. This was confirmed through the angular ROM of the trunk during the reach: no difference between age groups existed. Given that the physical constraints of the motor task were identical between subjects, differences in motor and/or cognitive strategies would be more likely to be due to discrepancies in attentional resources and resource allocation than the attentional demands of the tasks themselves (Irwin-Chase & Burns, 2000).
2.4.7 Limitations to the current protocol and future research directions

Our combined bimanual seated task and auditory Stroop task was within the attentional capacity of children age 7, and they were able to quickly adapt their abilities to be successful at the task. We acknowledge that a further challenge to the postural system (through a standing or gait task) would be a better test of the true limits of the attentional capacity at seven years of age. We also acknowledge that perhaps the type of cognitive task chosen (auditory or visual) and its presentation (discrete or continuous) may have interesting effects on the results in a child population.

2.5 Conclusion

The results of this study provide evidence that children age 7 are capable of completing a simultaneous cognitive and upper-body motor task in a seated posture using a similar strategy as healthy young adults. Children are quickly able to adapt their current attentional resource capacities to the task and effectively divide their attention between tasks in order to be successful in both tasks. Children did not change their motor strategy with the addition of the cognitive task however different from adults, this strategy was used as simplification tool rather than completing both tasks simultaneously in a more adult like manner. We conclude that using a mature control strategy (i.e. similar to the strategy used by adult subject)s for both cognitive and motor performance required more of the children’s’ available attentional capacity as overall cognitive efficiency and motor control declined. Children age 7 years are approaching behavior similar to adults and can create and implement adult motor and cognitive strategies for a seated, multi-task paradigm, however when their attentional capacity is challenged, they are forced to simplify both independent tasks in order to complete the overall task.
2.6 Tables

Table 2.6.1. Summary of trial designation for all participants (Child and Adult). No Motor trials included the auditory Stroop cue without a reaching task. Seated Reach trials refer to trials including the balance and reaching task. All No Motor trials were completed prior to Seated Reach trials. Presence of an auditory cue within Seated Reach trials was randomized.

<table>
<thead>
<tr>
<th></th>
<th>Auditory (AUD)</th>
<th>No Auditory (No AUD)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Motor</td>
<td>8</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Seated Reach</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>6</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 2.6.2. Summary of accuracy results to the auditory Stroop task during the seated reach. Accuracy rate provided as a percentage of answers given correctly. 20% of answers came during toy pickup while 80% of answers came after for both subject groups.

<table>
<thead>
<tr>
<th>Accuracy (% correct)</th>
<th>Overall</th>
<th>Congruent Cue</th>
<th>Incongruent Cue</th>
<th>Answer During Toy Pickup</th>
<th>Answer After Toy Pickup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children</td>
<td>77.1</td>
<td>84.2</td>
<td>68.8</td>
<td>85.7</td>
<td>75.0</td>
</tr>
<tr>
<td>Adults</td>
<td>77.1</td>
<td>88.2</td>
<td>66.7</td>
<td>85.7</td>
<td>75.0</td>
</tr>
</tbody>
</table>

Table 2.6.3. Comparison of segmental angular ROM during seated reach. The mean difference between segmental angular ROM for 3 pairs of segments and standard error is provided in degrees. Paired t-tests confirmed that no segments completed the same angular ROM in either subject group.

<table>
<thead>
<tr>
<th></th>
<th>Adults</th>
<th>Children</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (°) ± SE</td>
<td>t-test</td>
</tr>
<tr>
<td>Trunk - Upper Arm</td>
<td>-23.09 ± 1.82</td>
<td>-12.719, p&lt;.001</td>
</tr>
<tr>
<td>Upper Arm - Forearm</td>
<td>31.44 ± 1.34</td>
<td>23.462, p&lt;.001</td>
</tr>
<tr>
<td>Trunk - Forearm</td>
<td>8.35 ± 4.32</td>
<td>8.215, p&lt;.001</td>
</tr>
</tbody>
</table>
2.7 Figures

A. Reach Onset (RCH) =
Trunk COM velocity > 5% of

B. Maximum Trunk Flexion (MAX)

Absolute angular range of motion (ROM) = RCH to MAX

Figure 2.7.1. The experimental setup. A. Reach onset (RCH), the point in time where trunk center of mass velocity exceeded 5% of maximum. B. Maximum trunk flexion (MAX) relative to the right horizontal was deemed the end of the reach. Absolute angular range of motion (ROM; relative to right horizontal) for the trunk, and upper arm and forearm balancing the Frisbee was determined from RCH to MAX for each trial.
Figure 2.7.2. Absolute reaction time (seconds) to the auditory Stroop task during no motor and seated reach trials with an auditory component (AUD). As no differences ($p>0.05$) were observed between congruent and incongruent conditions in children and adults, all auditory reaction time data was collapsed for the single task (no motor) and multi-task (seated reach) conditions. Reaction time for children was significantly longer than adults in each condition ($p<0.05$).

Figure 2.7.3. Representative trace of the absolute angle (relative to right horizontal) of the trunk, and upper arm and forearm balancing the Frisbee during the seated reach for one child and one adult.
Figure 2.7.4. Angular displacement (change in absolute segmental angle relative to right horizontal) for the trunk, and upper arm and forearm balancing the Frisbee, from onset of reach (RCH) to maximum trunk flexion (MAX) in children and adults. Note that there are no age differences for trunk segment but significant differences ($p<0.05$) were apparent for the control of upper arm (UA) and forearm (FA) segments between the adults and children. Paired t-tests confirmed that all three segments completed a unique angular range of motion ($p<0.01$) within each age group.

Figure 2.7.5. Variability (standard deviation) of angular displacement (change in absolute segmental angle relative to right horizontal) of the trunk, and upper arm (UA) and forearm (FA) balancing the Frisbee, from onset of reach (RCH) to maximum trunk flexion (MAX) in children and adults. Children were significantly more variable in their segmental control than adults for all three segments ($p<0.01$). Error bars are not included due to the nature of this outcome measure.
Figure 2.7.6. Bland-Altman plot of (A) the trunk; (B) the upper arm (UA) and; (C) the forearm (FA) balancing the Frisbee for adults and children during the seated reach. The X axis displays the mean segmental angular displacement (º) from onset of reach (RCH) to maximum trunk flexion (MAX). The Y axis displays the difference in angular displacement between AUD and Non-Auditory (noAUD) conditions; a value of 0 represents no difference in angular displacement between auditory conditions. Each symbol represents the mean of a single subject, 95% confidence intervals for each age group are displayed. No significant differences ($p>0.05$) were found between the mean difference ($AUD$-$noAUD$) and 0 for any segment in either age group confirming that the auditory condition did not affect the motor strategy for either group.
2.8 References


Chapter 3. Children age 7 complete a cognitive and motor multi-task paradigm differently than adults while standing and during gait.

ABSTRACT: Healthy children (7 years) and adults (21 years) completed a simultaneous balancing, reaching and cognitive task while standing and during gait. Cognitive accuracy rate for children and adults was similar for both postures however response latency was greater for children than adults. While standing, trunk, upper-arm and forearm segments moved as individual segments in adults, however articulated control of the upper-arm and forearm in children was not evident. Both adults and children showed evidence of articulated segmental control during gait. Gait velocity was significantly slower for children however there was no effect of age on step length. Children age 7 can perform a simultaneous motor and cognitive task but their performance strategies do not yet match young adults.

KEY WORDS: dual-task, segmental control, cognitive task, posture, gait
3.1 Introduction

On a daily basis, we are constantly challenged to execute more than one task at a time. The ability to perform or integrate more complex simultaneous tasks is a learned behaviour over the course of childhood (Reed, 1989; Shumway-Cook & Woollacott, 2007). Infant and child skill acquisition has been modelled using a dynamic systems theory approach: learning a skill requires an interaction between the skill, its requirements and the environment in which it is performed (Corbetta & Thelan, 1996). Task development, therefore, is comprised of multiple components that must interact for accurate performance to be achieved (Thelan, Ulrich & Jensen, 1989). The development of postural control is believed to originate from a trunk based reference frame (Assaiante 1998; Assaiante, Thomachot, Aurenty & Amblard, 1998). Interestingly, to simplify a new or more challenging task, infants instinctively co-activate the muscles of the trunk and arm to counteract experimentally applied forces that move the arm and hand in the wrong direction (Thelan & Spencer, 1998). The number of segments being coordinated, known as the degrees of freedom of a given movement, is commonly reduced in younger children by linking segments together and simplifying the coordination required to execute a given motor task (Assaiante, 1998; Assaiante & Amblard, 1995; Thelan & Spencer, 1998). This adapted control strategy is commonly termed ‘en bloc’ or ‘egocentric control’ in developmental literature and the degrees of freedom to be coordinated are dependent upon the task performed and the child’s current motor capabilities (Assaiante, 1998; Assaiante & Amblard, 1995; Thelan, Ulrich & Jenson, 1989).

Until approximately age 6, operation of the head and trunk segments, while standing and walking, is said to be ‘en bloc’ (Assaiante & Amblard, 1995). Similarly, young children performing seated bimanual reaching tasks that require changes in trunk lean, couple movements of their upper arm and forearm to their trunk. This ‘en bloc’ control strategy effectively reduces
the degrees of freedom required to be controlled to maintain balance during the task (Roncsevalles, Schmitz, Sedka, Assaiante & Woollacott, 2005). By seven years of age, during standing posture (Assaiante & Amblard, 1995), locomotion (Assaiante, 1998) and seated bimanual tasks (Hinton & Vallis, 2015; Roncsevalles, Schmitz, Sedka, Assaiante & Woollacott, 2005), the head, trunk and arm segments are controlled in an articulated manner: gradually the child is able to use their head independent from the position of their trunk and uncouple movements of the trunk and arm (Roncsevalles, Schmitz, Sedka, Assaiante & Woollacott, 2005). However, as the difficulty of the motor task increases, the child’s temporal organization may regress to previous stages of balance control (Assaiante, Mallau, Viel, Jover & Schmitz, 2005; Woollacott, Shumway-Cook & Williams, 1989). Variability measures (i.e. trial to trial for each subject) can provide insight into the resiliency of a child’s segmental control strategies for a given task. Over the course of motor development, performance variability typically decreases, indicating a ‘tighter’ overall control of movement (Shumway-Cook & Woollacott, 2007).

We are often required to perform motor and cognitive tasks concurrently as we go about our daily lives. Executive function (EF) refers to higher levels of cognitive function which facilitate voluntary attention processes. Information from the body’s cortical sensory systems is processed using EF to produce cognitive and behavioral responses responsible for executing goal directed actions (Sheridan & Housdorf, 2007; Yogev-Seligmann, Hausdorff & Giladi, 2008). The Stroop task (generally provided in a visual or auditory form as an executive function task) is an ideal cognitive task to use to address research questions about the influence of EF on a simultaneous motor task. The auditory version of the Stroop task is a superior option when visual gaze information from the environment is required to complete the motor task: this avoids potential structural interference that may occur with a visual Stroop task (Huang & Mercer 2001;
MacLeod, 1991). The use of the auditory Stroop task in previous work has revealed its reliability as a consistent and accurate measure of EF in both adults (Kahneman & Chajczyk, 1983; Morgan & Brandt, 1989) and children (Guy, Rogers & Cornish, 2012; Jerger, Martin & Pirozzolo, 1988), making it an excellent choice as an experimental tool in dual task paradigms. Children can integrate both dimensions of the Stroop task (pitch and word) by age 6, answering correctly and more quickly than younger children (Guy, Rogers & Cornish, 2012; Jerger, Martin and Pirozzolo, 1988) and with a similar accuracy rate to adults (Hinton & Vallis, 2015).

How do we integrate more than one task at once? There are several theories outlining rationale for simultaneous task performance however the work outlined here is based on the capacity-sharing theory. This theory suggests that individuals have a limited information processing capacity (i.e. attention) based on age and cognitive and/or motor development (Yoge-Seligmann, Hausdorff & Giladi, 2008). In a dual-task scenario, the demands of each task compete for attentional processing capacities (Shumway-Cook & Woollacott, 2007; Yoge-Seligmann, Hausdorff & Giladi, 2008). Based on this theory, adults have the ability to allocate attention voluntarily between simultaneous tasks (Yoge-Seligmann, Hausdorff & Giladi, 2008). The ability to complete this type of task without error requires management of attention and the prioritization of tasks so that both may be completed efficiently. The development of attention division is not only due to ongoing central maturation but the increase in automaticity of attentional allocation with age that aids in the coordination of mental resources (Irwin-Chase & Burns, 2000).

Six to seven years of age has been identified as major developmental transition for posture, balance and executive function. The main objective of the current work was to compare the motor and cognitive strategies used by children age 7 to those used by young adults for the
same task: a simultaneous balancing and reaching task combined with an executive function task in a standing posture and during gait. It was hypothesized that children would not be able to complete the cognitive task with the same accuracy or with the same efficiency as adults, in terms of response latency, once combined with the motor task (Hypothesis 1). In order for children to complete the motor task successfully, children were expected to use an egocentric based control strategy rather than a matured, articulated control of body segments expected of the adult group (Hypothesis 2). As children at this age are still acquiring balance control associated with complex motor skills, we expected adults to have less variability in their segmental motor control compared to the child subject group (Hypothesis 3). Finally, compared to adults, children were expected to have a slower absolute gait velocity (in m/s) during the reaching task, with a shorter absolute step length (in meters; Hypothesis 4).

3.2 Methods

3.2.1 Subjects

Participants in this paradigm were part of a larger study (Hinton & Vallis, 2015). Twenty-two participants completed the multi-task paradigm (Children: n=12, 4 male and 8 female, mean age 7.5±0.5 years; Adults: n=10, 4 male and 6 female, mean age 20.4±1.0 years). All but one participant (left handed and footed) were right handed and right footed (Waterloo Footedness Questionnaire, Elias, Bryden and Bulman-Fleming, 1998). A health questionnaire was completed confirming a lack of medically diagnosed neurological and musculoskeletal deficits. All participants met the exclusion criteria: no history of neurological problems, uncorrected hearing or vision problems or previously observed issues related to comprehension or perception. Past and current involvement in athletics (i.e. recreational or otherwise) and/or artistic endeavors was recorded in our questionnaires, but was not considered as either an inclusion or exclusion
criterion. The experimental procedure was explained to child participants and their parents using a graphical illustration, and written consent (parents and adults) was acquired prior to data collection. This study was approved by the Research Ethics Board (REB # 13JN020).

3.2.2 Equipment

Kinematic data was collected at 100 Hz using optoelectric cameras (Optotrac 3020, Northern Digital, Inc., Canada) to view participants from the frontal and sagittal plane. Three non-collinear infra-red diodes (IRED markers) were mounted on the head, trunk, pelvis, and left and right foot of each subject. Anatomical landmarks (e.g. ears, coracoid processes, heels, toes) were digitized to define the head, trunk, pelvis and foot segments (i.e. Head, Trunk4, Trunk1, Upper arms and Forearms; Winter, Patla, Prince, Ishac & Gielo-Perczak, 1998). Analog auditory response waves to the auditory Stroop task were collected and digitized (4000 Hz; ODAU unit, NDI, Inc Waterloo, ON) via a small microphone placed on the subject’s chest.

3.2.3 Pre-testing protocol:

A cognitive inclusion criterion was first presented to verify that participants’ understood the task instructions and ensure that each child’s cognitive development was adequate for successful completion of the Stroop task. Participants identified the pre-recorded pitch (high or low) of the words “high” and “low”. All participants completed a minimum of 6 correct responses out of 8 while seated (no motor condition). Next, the experimental task protocols (Task 1: Standing Reach, Task 2: Walking Reach) were explained to the participant. To help child participants maintain focus during the experiment, an age appropriate graphical illustration of the experimental protocol steps was displayed with the children marking their progress at each step completion.
3.2.4 Experimental Task 1: Standing Reach Condition

Presentation of Task 1 and Task 2 were randomized between participants within each group (Child, Adult). Participants performed a bimanual balance and reaching protocol in a standing posture, with both feet firmly on the floor (Standing Reach condition, Figure 3.7.1A and B). A Frisbee with a ball on top was first placed on the palm of their non-dominant hand (NDH). With the upper arm (UA) kept close to the trunk, the forearm (FA) and palm of the NDH parallel to the floor and the ball on the Frisbee balanced, subjects reached with the dominant hand (DH) to pick up a small toy off the ground. Participants stood comfortably and the toy was placed midway between, and in front of, the participant’s feet, easily reachable without moving their feet. The toy was a rectangular block small enough to fit in a child’s hand. The reaching task was completed while simultaneously maintaining balance of the ball on the Frisbee. The only constraint was to maintain the original foot position while reaching. Participants were given the opportunity to perform the Standing Reach three times before recording began. Each participant then completed 12 experimental trials of the standing reach.

3.2.5 Experimental Task 2: Walking Reach Condition

Participants were asked to walk 5 meters towards a toy on the ground, reach to pick it up off the ground with their dominant hand (DH), and then continue to walk straight 5 meters past the toy’s original position (See Figure 3.7.1C). At the same time, participants were asked to perform the same balance and reach task outlined for Task 1). Participants were not constrained to a reaching or balancing strategy. Participants performed the Walking Reach three times before recording began to ensure their gait pattern was as close to normal as possible. Twelve experimental trials of the Walking Reach were completed for a total of 32 trials (8 trials pre-protocol, 12 Standing Reach trials, 12 Walking Reach trials).
3.2.6 Auditory Stroop Task

The auditory Stroop task was administered to coincide with the participant’s reach during 6 of 12 trials within each experimental task. The presence of the auditory component was randomized by trial: all participants (adult and child) selected from pieces of coloured paper in a small bag indicating which type trial would be completed next. During “Auditory” trials (AUD condition), a photo sensor laser gate triggered a stored computerized voice as the subject shifted their trunk forward from their upright-standing posture to reach.

3.2.7 Task Prioritization

Investigators did not indicate prioritization between the reaching or cognitive tasks to the participants. Instructions were to “Complete all tasks as best you can. Try to answer as quickly as possible with the right answer”. Feedback on response accuracy was provided during the No Motor condition to ensure participants understood the task properly. During the experimental tasks, participants were told the investigator was recording their answers for accuracy and time however no feedback on response accuracy was given.

3.2.8 Data Analyses

Cognitive performance was assessed with answer accuracy and response time (RT; Hypothesis I). Analog signal of the auditory cue and subjects’ responses were processed (customized LabView program: KinAnalysis) to determine absolute RT to the auditory cue. Analog signal recordings from the microphone were dual, band-pass filtered with a Butterworth filter at 700-1000 Hz. Onset of the auditory stimulus and participant’s response were identified via visual inspection by a primary researcher and verified by a second researcher (percent agreement between the two researchers was 96%). RT was calculated as the difference (in
seconds) between the start of the auditory cue and the start of the participant’s response. A mean RT and standard error (SE) was determined for each subject for each posture (No Motor, Standing Reach, Walking Reach) and then collapsed across subject types (Child, Adult) and group means and SE were calculated. A research assistant recorded accuracy of pitch identification. Accuracy rate for each subject group was determined as the percentage correct of total trials within congruent and incongruent trial types within the Standing Reach and Walking Reach tasks.

Kinematic data was processed using Visual 3-D Software (C-Motion Inc., Germantown MD) and interpolated for small gaps in marker position (maximum 200 ms). A trial was omitted from analysis when > 20 frames were missing during the participant’s reach. A three dimensional (3D) trunk centre of mass (COM) position was estimated using the Winter model (Winter, Patla, Prince, Ishac & Gielo-Perczak, 1998) and a 3D Trunk COM velocity vector was created for the entire trial. Analysis of segmental movements began with the onset of reach (RCH), the time point when the trunk COM velocity vector increased beyond 5% of the trial’s maximum trunk velocity (see Figure 3.7.1A; Roncesvalles, Schmitz, Sedka, Assaiante & Woollacott, 2005).

Trunk absolute angle (relative to right horizontal) was calculated for the entire trial, with maximum forward trunk lean for each trial used at the end point of the reach (MAX, see Figure 3.7.1B; Roncesvalles, Schmitz, Sedka, Assaiante & Woollacott, 2005). Absolute angles of trunk and UA and FA balancing the Frisbee were calculated for the entire trial and angular displacement from RCH to MAX in each trial was determined for all three segments (Hypothesis 2). Angular ROM measures were collapsed for each subject across auditory conditions (AUD and noAUD) and then into groups (Child, Adult). Angular ROM variability was considered as the
coefficient of variation (CV) of the change in absolute angle for each segment (*Hypothesis 3*). CV was calculated as the standard deviation (SD) of angular displacements for a given segment divided by its mean angular displacement. Mean CV for each subject within auditory conditions (AUD and noAUD) was collapsed across subject groups (Child, Adult) and group means and SE were calculated.

Heel contacts were determined as time point when the distance between the Pelvis COM (Trunk4: Winter, Patla, Prince, Ishac & Gielo-Perczak, 1998) and heel marker (right and left) was maximized (Zeni, Richards & Higginson, 2008). Step length was defined as the difference between right and left heel markers at heel contact in the direction of progression (see Figure 3.7.1C; *Hypothesis 4*). Gait velocity was determined from the 3D velocity vector of the trunk COM to account for any twisting or turning while walking forwards. Step length and gait velocity were normalized to pelvis COM height from the floor. By normalizing to leg length, it was possible to compare participants of different heights to each other without anthropometrics as a factor. Step length and gait velocity were then classified as pre-, during or post- toy pickup using the RCH onset and end point of the reach (MAX) time points. Subject means and SE for gait parameters were collapsed across subject groups (child and adult) and auditory condition (AUD and noAUD).

### 3.2.9 Statistical Analyses

Statistical analyses were completed in SPSS Software (Version 22). When data from both subject groups and both postures was combined, Levene’s homogeneity of variance assumption was violated. As a result, all subsequent statistical analyses were completed within the different postures (i.e. Standing Reach and Walking Reach separated). This allowed all results to be compared between subject groups (Child, Adult) for each posture.
The effect of subject group (Child, Adult) on RT was investigated with a one-way analysis of variance (ANOVA) within each task (Standing Reach, Walking Reach; Hypothesis 1). Pearson Chi Square tests were performed on accuracy rates to the cognitive task since a normal distribution of these responses is not possible. This statistical test was used to determine if significant relationships existed between Subject Group or Congruency, and Accuracy within the Standing Reach and Walking Reach tasks (Hypothesis 1).

The effect of subject group and auditory cue on the angular ROM of each segment (Trunk, UA, FA) was then explored for the Standing Reach and Walking Reach tasks separately (2-way ANOVA; Hypothesis 2). To determine if segments were completing the same ROM, paired t-tests compared the mean angular ROM of the Trunk, UA and FA segments within each age group and task (Child, Adult; Standing Reach and Walking Reach; Hypothesis 2).

A one-way ANOVA was used to investigate the effect of age group (Child, Adult) on the CV of each segment’s angular ROM (trunk, UA, FA; Standing Reach and Walking Reach; Hypothesis 3). Paired t-tests compared the CV of the trunk, UA and FA segments within each age group (Child, Adult; Hypothesis 3). A multivariate ANOVA (MANOVA) was used to determine the overall effect of age group and auditory condition on normalized gait velocity across the entire gait trial. Then, a one-way ANOVA was conducted to further explore the effect of age group (Child and Adult) on normalized gait velocity and step length within each trial phase (pre-, during, post-toy pickup; Hypothesis 4). Finally, paired t-tests were used to compare normalized step length between trial phases (Hypothesis 4). Bonferroni corrections were completed for all multiple paired t-tests. The null hypothesis for all statistical tests was rejected when the p-value was less than 0.05.
3.3 Results

The results of all ANOVA, MANOVA and paired t-tests are summarized in Table 3.6.1 and Table 3.6.2.

3.3.1 Auditory Stroop Task

RT for children was significantly greater for children than adults in each posture (See Table 3.6.1 and Table 3.6.3). There was no significant relationship between subject group (Child, Adult) and accuracy rate during the experimental tasks (% of trials correct; Standing Reach: \( \chi^2(1)=0.009, p=0.923 \); Walking Reach: \( \chi^2(1)=1.676, p=0.195 \)). Similarly there was no significant relation between congruency and accuracy for children (Standing Reach: \( \chi^2(1)=0.180, p=0.671 \); Walking Reach, \( \chi^2(1)=0.825, p=0.364 \)) or adults (Standing Reach: \( \chi^2(1)=0.237, p=0.626 \); Walking Reach, \( \chi^2(1)=1.339, p=0.247 \)).

3.3.2 Angular Range of Motion: Standing Reach

A two-way ANOVA revealed no main effect of auditory condition (AUD vs noAUD) on angular ROM for the Trunk, Upper Arm or Forearm \((p>0.05, \text{see Table 3.6.1 and Figure 3.7.2A})\). There was a main effect of group (Child, Adult) on the mean trunk ROM and forearm ROM (see Table 3.6.1 and Figure 3.7.2A). Paired t-tests (Table 3.6.2 and Figure 3.7.2B) indicated a unique ROM between the Trunk and UA, and Trunk and FA in both subject groups. Between the UA and FA of adults, articulated control was indicated by a significantly different ROM for each segment, however no differences were found between the UA and FA ROM for children indicating that these segments moved together for this standing reach task.

A main effect of group (Child, Adult) was significant for Trunk ROM CV (Table 3.6.1). Paired t-tests (Table 3.6.2 and Figure 3.7.3) indicated significantly different CV between Trunk and UA, and Trunk and FA segments in both age groups. Between the UA and FA CV in
adults, CV values were not significantly different \((p > 0.05)\), however they were shown to be statistically different in children.

3.3.3 Angular Range of Motion: Walking Reach

There was no effect of auditory condition \((AUD \text{ vs } noAUD)\) or subject group \((Child, Adult)\) on angular ROM for the Trunk, UA or FA \((p > 0.05)\). The trunk, UA and FA of both subject groups went through a unique ROM, indicating articulated segmental control (Table 3.6.2 and Figure 3.7.4).

A main effect of age \((Child, Adult)\) was significant for Trunk ROM CV. Paired t-tests indicated significant differences for CV between Trunk and UA, and Trunk and FA segments in both age groups. Between the upper arm and forearm CV in adults, CV values were not significantly different \((p > 0.05)\), however they were shown to be statistically different in children (see Table 3.6.2 and Figure 3.7.5).

3.3.4 Walking Reach Gait Velocity and Step Length

A MANOVA revealed a main effect of subject group \((Child, Adult)\) on normalized gait velocity across the entire trial however no effect of auditory condition was apparent \((p > 0.05)\), see Table 3.6.1 and Figure 3.7.6). Taking into account all three trial phases (Pre-, During and Post-Toy Pickup) children displayed significantly greater normalized gait velocity than adults. A one-way ANOVA for subject group further revealed that the main effect of age was significant for pre-toy pickup and post-toy pickup normalized gait velocity (See Table 3.6.1 and Table 3.6.4). There was no significant effect of age group \((Child, Adult)\) on normalized step length in any of the three trial phases (Pre-, During- and Post-Toy Pickup; \(p > 0.05\)). Paired t-tests between Pre-Pickup and During Pickup normalized step lengths and During Pickup and Post-Pickup
normalized step lengths revealed Pre- and Post-toy pickup normalized step lengths to be significantly greater than step lengths during-toy pickup in each age group (Table 3.6.2 and 3.6.4).

3.4 Discussion

The objective of this study was to compare the motor and cognitive strategies used by children (age 7) and young adults for a simultaneous balancing and reaching task combined with cognitive task requiring executive function. The ability of children at this transitional age to incorporate a cognitive task with a complex motor task was first assessed, and then compared to the motor and cognitive task execution by adults for the same paradigm. Given the intricate nature of the paradigm, we were very interested to see how children at this age adapt their motor control patterns and cognitive responses under two different postural load conditions. Not only were children able to adjust to the complexity of the paradigm and accurately perform all tasks simultaneously (i.e. the Frisbee and ball were not dropped), their cognitive accuracy rate was not significantly different from adults. However, there were significant differences in both motor and cognitive task execution between subject groups.

3.4.1 Auditory Stroop task performance

Children and adults reached the same overall accuracy rate during Standing Reach and Walking Reach for the auditory Stroop task, confirming not only that this executive function task was appropriate for children age 7, but also that could be completed to the same performance level as a healthy young adult. Somewhat surprisingly, both subject groups produced similar motor actions regardless of the presence of the auditory cue (AUD vs noAUD trials): there was no significant effect of the AUD condition on the angular ROM of the trunk, UA or FA in children or adults in each posture. Adults possessed adequate attentional resources to complete
the reaching and balancing task and cognitive task simultaneously. All postural tasks are
attentionally demanding, however in adults the effects of dividing attention tend to be small,
unless the postural system is overloaded however these effects increase in older adults and
children (Chen et al., 1996; Lajoie, Teasdale, Bard & Fleury, 1993; Shumway-Cook &
Woollacott, 2007). Different stages of motor and cognitive development will affect the way in
which simultaneous tasks are performed. In children, mature control strategies are not yet
established and a reduced overall attentional capacity will decrease their ability to complete
simultaneous tasks. Older adult populations may be affected in dual task scenarios by altered or
reduced sensory input (Shumway-Cook & Woollacott, 2007). As expected, our young adult
participants were able to integrate the tasks and implement an articulated control of the upper
body segments during both tasks due to their mature motor control system (Lajoie, Teasdale,

Conversely, although children did not show an effect of auditory condition on their motor
performance, a significantly longer RT suggests that their attentional resource capacity may have
been approached with this complex task. The attentional demands of posture and segmental
coordination are relatively greater for younger children compared to adults (Shumway-Cook &
Woollacott, 2007). During the Standing Reach task, children seemed to first decide on motor
task execution, and once completed successfully, went on to complete the Stroop task accurately.
This plan of action required a longer RT however children were just as accurate on the overall
cognitive task as adults. While at a critical transitional period in motor development and
attention allocation children (age 7) are still able to adapt and complete this complex paradigm
with the attentional resources at their disposal.
3.4.2 Seven years of age highlighted as a transition in motor development

The transitional motor development stage was highlighted in the children’s segmental control system while standing and during gait. By age 7, children have been shown to use articulated control of segments during basic gait tasks and seated bimanual tasks (Assaiante & Amblard, 1995; Roncesvalles, Schmitz, Zedka, Assaiante & Woollacott, 2005). However, with an increase in postural load from seated to standing, and the addition of an auditory executive function task, children adapted to using an egocentric based control of the arm balancing the Frisbee (e.g. Fig 3.7.2: the UA and FA move through the same range of motion during the Standing Reach). By reducing the degrees of freedom to be controlled and moving the entire arm as one segment, children were able to simplify one portion of the multi-task paradigm and in doing so, complete the entire paradigm accurately. This adaptation and regression in balance control strategy is believed to allow the child to fine tune their behavior to the complex task (Woollacoot, Shumway-Cook & Williams, 1989). In order to complete the overall task, without the same attentional resources as adults, children altered some aspects of the task to perform others at a more mature level.

Previous work has highlighted increases in postural control attentional demands from standing to walking (Lajoie, Teasdale, Bard & Fleury, 1993). Similar to more complex obstacle avoidance tasks while walking, it was expected that children at this age, when challenged with an upper body task while walking, would also revert to an egocentric based control of their body (Assaiante, 1998). This type of behavior was, surprisingly, not seen. This observation was especially interesting given that children moved both arm segments through the same angular range of motion while standing, but not during the walking reach task (Figure 3.7.4: Trunk, UA and FA move through unique ROM). One possible reason for this discrepancy is a change in the
base of support used for each posture. During the *Standing Reach*, participants were asked not to move their feet from a shoulder-width stance while reaching for the toy on the ground. However, while walking, no instruction was provided to foot position during toy reach. It was observed, anecdotally, that participants were more likely to use a staggered foot base of support while reaching for the toy during the *Walking Reach* task. This reaching strategy would, effectively, increase the base of support during the *Walking Reach* task compared to the *Standing Reach* task.

In the future, it would be interesting to quantify the location of the centre of mass and its position relative to the base of support during a reaching protocol. In addition, dynamic stability measures have not been well researched in children; this modelling approach might provide an interesting research direction in developmental research. Unfortunately, this type of data analysis, was not possible with the marker setup used for the current experimental paradigm.

Another possibility for the discrepancy in balance control strategy used between postures may be attributed to a change in attentional focus from the upper body task (primary focus during the *Standing Reach*) to an external focus (Schaefer, Jagenow, Verrel & Lindenberfer, 2015; Wulf, McNevin & Shea, 2001; Wulf & Prinz, 2001). The *Constrained Action Hypothesis* (Wulf, McNevin & Shea, 2001) explains how the location of attention focus (i.e. internal vs external) can affect posture or performance of a motor task. Although no prioritization constraints were provided to participants, perhaps during the *Walking Reach* task, children focused on the gait task and the completion of the upper body task occurred without active focus in a mature, articulated fashion. Evidence of the benefits of an external focus have been shown previously in a study involving children age 7 completing cognitive tasks of different difficulties while walking (Schaefer, Jagenow, Verrel & Lindinberger, 2015). An increase in gait performance was accomplished with an easier cognitive task in both child and adult subject
groups. However, Schaefer and colleagues (2015) observed a “U” shaped pattern of gait related effects in children that were not observed in their adult participants: a more challenging cognitive task caused detrimental effects on gait, perhaps due to exceeding the children’s overall attentional capacity. For the current study, it is possible that instead of primarily focusing on the effect of balancing and reaching simultaneously, which may have interfered with the performance of the gait task (as in the Standing Reach task), the children used the gait task as an external focal point. Regardless, children at age 7 are not only in the process of complex motor skill development, but also have the ability to divide their attention properly between tasks.

Previous work has shown that when challenged in a dual task scenario, children decrease gait velocity from gait without the addition of a secondary task (Boonyong, Siu, van Donkellar, Chou & Woollacott, 2012; Huang, Mercer & Thorpe, 2003). This temporal adjustment allows children to accommodate for a decreased overall attentional capacity and facilitates the successful integration of both tasks. Even though basic gait at this age is a highly practiced skill, balance control of gait at age 7 requires attentional resources that are not required for young adults (Abbruzzese et al., 2014; Boonyong, Siu, van Donkellar, Chou & Woollacott, 2012). The addition of simultaneous tasks can alter gait control and efficiency significantly in the child group since this task since motor control patterns are not yet completely mature. Given the manner in which gait was normalized in this paradigm, a significantly greater normalized gait velocity for children is indicative of a slower absolute velocity (in m/s). In order to complete this challenging paradigm, children were required to use a significantly slower absolute gait velocity (m/s) than adults, even when their body size is taken into account. A decreased step length in children has been previously reported during dual task paradigms (Huang, Mercer & Thorpe, 2003; Boonyong, Siu, van Donkellar, Chou & Woollacott, 2012), but was not observed in the
current paradigm. The change in overall gait velocity is then suggested to come from the step
cadence (steps/min). By decreasing absolute gait velocity (compared to adults) may have
allowed children more time to take in their surroundings as they approached the toy on the
ground. It could have also provided a more stable hip and trunk to perform the upper body task.
Given the overall complexity of the task during the Walking Reach task, reductions in absolute
gait velocity in children could also be attributed to a decrease in the amount of attention being
directed to gait. (Abbruzzese et al., 2014). These results suggest children age 7 are working with
a decreased overall attentional capacity compared to adults and thus less attention can be
provided to gait execution. If control of a given task performance is not yet fully mature, the
addition of another simultaneous task has the potential to interfere with the quality of
performance of all tasks (Abbruzzese et al., 2014).

3.4.3 Increased variability present in children’s motor performance

Variability refers to the ability to perform the same task more than once with the same
level of control (Shumway-Cook & Woollacott, 2007). In adults, temporally synchronized and
coordinated control of segmental movement through space is expected, even with a challenging
multi-segment task, given their mature motor control and attention division capabilities (Lajoie,
Teasdale, Bard & Fleury, 1993). Variability can also indicate if tasks in a dual-task scenario are
being performed in a fully integrated manner (Abbruzzese et al., 2014). Children age 7 are
continuing to establish internal models for motor task execution and experiment with segmental
balance control (Woollacott, Shumway-Cook & Williams, 1989). Within this developmental
period, we did not expect a consistent repeatable motor pattern from trial to trial. We
hypothesized an increase in CV illustrating a general increase in children’s’ overall segmental
control variability. Since trunk balance control is first developed in infancy, we expected
children to have the greatest control over trunk ROM and movement. However, due to the constraints of the reaching task, both age groups were required to move their trunk through a large ROM. Given the size of this segment and its influence on COM position, it is not surprising that children did not have the same level of control as adults over their trunk. Greater variability in UA and FA ROM was expected as this complex paradigm required coordinated control of multiple arm segments. In children, the ability to produce adaptive behaviours and achieve task accuracy is also dependent on the postural component of the task (Reed, 1989). Children were more variable in the use of their trunk in a more challenging standing posture compared to a seated bimanual task (Hinton & Vallis, 2015; Roncesvalles, Schmitz, Zedka, Assaiante & Woollacott, 2005). Since the balancing task was novel to both subject groups, this could account for why both adults and children had greater variability in the UA and FA segments compared to the trunk. The variability present in both age groups for this task confirms its complexity across age groups.

3.5 Conclusion

This complex paradigm challenged participants to divide their attention and complete an upper body motor task during upright stance, and during gait, while simultaneously completing an executive function task. By age seven, children are capable of completing a complex motor and cognitive task paradigm successfully. Children performed similar cognitive strategies to adults however their motor behavior was not at the same level of maturity or control. In order to successfully integrate all tasks, children altered cognitive performance, overall control and gait velocity. It appears that children do not yet have adequate attentional capacity to complete a balancing, reaching and simultaneous executive function task at the same level of balance control.
and attention division as adults. Children compensated their cognitive performance in order to successfully complete the motor task with the same cognitive accuracy rate as adults.
3.6 Tables

**Table 3.6.1: Summary of ANOVA and MANOVA statistical tests.** The main effect of age group was tested for all variables listed. The main effect of auditory condition was tested for angular range of motion and normalized gait velocity MANOVA. When data from both subject groups and both postures was combined, Levene’s homogeneity of variance assumption was violated. As a result, statistical analysis were completed with the postures (*Standing Reach* and *Walking Reach*) separated.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Posture/Phase</th>
<th>Segment/Phase</th>
<th>Main effect of Age</th>
<th>Main effect of Auditory Condition</th>
<th>Figure/Table</th>
</tr>
</thead>
<tbody>
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<td><strong>Response Time</strong></td>
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<td></td>
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<td></td>
<td>Standing Reach</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Walking Reach</td>
<td></td>
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</tr>
<tr>
<td><strong>Angular Range of Motion</strong></td>
<td>Standing Reach</td>
<td>Trunk</td>
<td>F(1,34)=5.063, p=0.032</td>
<td>NS; p&gt;0.05</td>
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<tr>
<td></td>
<td></td>
<td>Upper Arm</td>
<td>NS; p&gt;0.05</td>
<td>NS; p&gt;0.05</td>
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<tr>
<td></td>
<td></td>
<td>Forearm</td>
<td>F(1,34)=6.697, p=0.015</td>
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<tr>
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<td>Trunk</td>
<td>NS; p&gt;0.05</td>
<td>NS; p&gt;0.05</td>
<td>Figure 3.7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper Arm</td>
<td>NS; p&gt;0.05</td>
<td>NS; p&gt;0.05</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Forearm</td>
<td>NS; p&gt;0.05</td>
<td>NS; p&gt;0.05</td>
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<td><strong>Coefficient of Variation</strong></td>
<td>Standing Reach</td>
<td>Trunk</td>
<td>F(1,16)=9.793, p=0.008</td>
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<td>Forearm</td>
<td>NS; p&gt;0.05</td>
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<td>Walking Reach</td>
<td>Trunk</td>
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<td>Upper Arm</td>
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<td></td>
<td>Forearm</td>
<td>NS; p&gt;0.05</td>
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<td><strong>Normalized Gait Velocity (MANOVA)</strong></td>
<td>Walking Reach</td>
<td>Pre Toy Pickup</td>
<td>Pillai’s Trace = 0.539, F(3,24)=9.357, p&lt;0.001</td>
<td>NS; p&gt;0.05</td>
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<td>Post Toy Pickup</td>
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<td><strong>Normalized Gait Velocity (ANOVA)</strong></td>
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<td>Pre Toy Pickup</td>
<td>F(1,29)=8.171, p=0.008</td>
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<td>During Toy Pickup</td>
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<td>NS; p&gt;0.05</td>
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<td>Post Toy Pickup</td>
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<td><strong>Normalized Step Length</strong></td>
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<td>NS; p&gt;0.05</td>
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<tr>
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<td></td>
<td>During Toy Pickup</td>
<td>NS; p&gt;0.05</td>
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<td></td>
<td>Post Toy Pickup</td>
<td>NS; p&gt;0.05</td>
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Table 3.6.2: Summary of paired t-test statistical tests. Paired t-tests were performed between all segment and/or phase pairs listed.

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<th>Variable</th>
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<th>Age Group</th>
<th>Segment/Phase Pair</th>
<th>T-test</th>
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<td>Trunk-UA</td>
<td>UA-FA</td>
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<td>Figure 3.7.2</td>
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<td></td>
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<td>UA-FA</td>
<td>NS; p&gt;0.05</td>
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<tr>
<td></td>
<td>Adult</td>
<td>Trunk-FA</td>
<td>Trunk-UA</td>
<td>t(16)=15.116, p&lt;0.001</td>
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<td>Trunk-UA</td>
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<td>UA-FA</td>
<td>t(8)=3.982, p=0.012</td>
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<td>Trunk-FA</td>
<td>Trunk-UA</td>
<td>t(7)=3.988, p=0.015</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trunk-UA</td>
<td>t(8)=4.138, p=0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UA-FA</td>
<td>NS; p&gt;0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking Reach</td>
<td>Child</td>
<td>Trunk-UA</td>
<td>UA-FA</td>
<td>t(6)=4.558, p=0.012</td>
<td>Figure 3.7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trunk-FA</td>
<td>t(6)=7.280, p&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>Trunk-UA</td>
<td>t(9)=-3.780, p=0.012</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UA-FA</td>
<td>NS; p&gt;0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trunk-FA</td>
<td>t(9)=-5.260, p=0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Normalized Step Length</strong></td>
<td>Walking Reach</td>
<td>Pre-During Pickup</td>
<td>t(7)=3.302, p=0.039</td>
<td>Table 3.6.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Child</td>
<td>During-Post Pickup</td>
<td>t(7)=-4.110, p=0.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-During Pickup</td>
<td>t(8)=4.959, p=0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>During-Post Pickup</td>
<td>t(8)=-4.836, p=0.003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.6.3: Auditory Stroop results. Children’s response time was significantly greater than adults in each posture (* indicates \( p<0.05 \)). There was no significant difference in accuracy rate between Children and Adults in each posture. Note that during the inclusionary posture (the No Motor task, where only the auditory cue was performed with no reach) children took significantly longer (2.638 ±0.191 seconds) than adults (1.351 ± 0.257 seconds) to answer the auditory cue.

<table>
<thead>
<tr>
<th>Posture</th>
<th>Subject Group</th>
<th>Mean Response Time (seconds ± SE)</th>
<th>Accuracy Rate (% Trials Correct)</th>
<th>Chi Square P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>Congruent Cue</td>
<td>Incongruent Cue</td>
</tr>
<tr>
<td>Standing</td>
<td>Child</td>
<td>2.485 ± 0.228</td>
<td>83.3</td>
<td>80.0</td>
</tr>
<tr>
<td>Reach</td>
<td>Adult</td>
<td>1.301 ± 0.231</td>
<td>{ * }</td>
<td>84.4</td>
</tr>
<tr>
<td>Walking</td>
<td>Child</td>
<td>3.329 ± 0.585</td>
<td>73.9</td>
<td>78.4</td>
</tr>
<tr>
<td>Reach</td>
<td>Adult</td>
<td>1.325 ± 0.720</td>
<td>{ * }</td>
<td>83.3</td>
</tr>
</tbody>
</table>

Table 3.6.4: Normalized gait velocity and step length during Task 2: Walking Reach across auditory conditions. Gait velocity and step length were normalized to pelvis centre of mass height for each participant.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Normalized Gait Velocity (s(^{-1})) (mean±S.E.)</th>
<th>Normalized Step Length (mean±S.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children</td>
<td>Adults</td>
</tr>
<tr>
<td>Pre-toy pickup</td>
<td>1.287±0.04</td>
<td>1.124±0.04</td>
</tr>
<tr>
<td>During</td>
<td>0.533±0.08</td>
<td>0.566±0.07</td>
</tr>
<tr>
<td>Post-toy pickup</td>
<td>1.276±0.03</td>
<td>1.085±0.03</td>
</tr>
</tbody>
</table>
3.7 Figures

A. Reach Onset (RCH) = Trunk COM velocity > 5% of maximum

B. Maximum Trunk Flexion (MAX)

3D Trunk COM Velocity

Absolute angular range of motion (ROM) = RCH to MAX

C. Walking Reach Paradigm

Direction of progression

SL

Toy

Pre-toy pickup

RCH to MAX

Post-toy pickup

Figure 3.7.1: A. Reach Onset (RCH) was determined as the point in time where the trunk centre of mass 3D velocity exceeded 5% of its maximum. B. Maximum Trunk Flexion (MAX) relative to right horizontal was deemed the end of the reach. All angular range of motion measures were taken from RCH to MAX time points. C. Walking Reach Paradigm Setup. Note the direction of progression from left to right. The auditory cue was initiated by a photo sensor laser gate indicated by the dotted rectangle. Step length (SL: Heel to Heel in the direction of progression) and gait velocity were normalized to the height of each subject’s pelvis centre of mass.
A. Within each auditory condition, statistical analyses indicated no main effect for auditory condition on ROM ($p>0.05$). B. When collapsed across auditory conditions, a main effect of age group was present for the Trunk and Forearm segments ($p<0.05$). Paired t-tests revealed that each if the trunk, upper arm and forearm segments completed a unique ROM in Adults. The trunk completed a unique ROM from the upper arm and forearm in children, however there was no significant difference in ROM between the upper arm and forearm ($p>0.05$).

**Figure 3.7.2:** Angular range of motion (ROM) during the Standing Reach. A. Within each auditory condition, statistical analyses indicated no main effect for auditory condition on ROM ($p>0.05$). B. When collapsed across auditory conditions, a main effect of age group was present for the Trunk and Forearm segments ($p<0.05$). Paired t-tests revealed that each if the trunk, upper arm and forearm segments completed a unique ROM in Adults. The trunk completed a unique ROM from the upper arm and forearm in children, however there was no significant difference in ROM between the upper arm and forearm ($p>0.05$).
Figure 3.7.3: Coefficient of variation (CV) of angular range of motion during the *Standing Reach*. A high CV value indicates a greater amount of variability relative to the mean range of motion for each segment. A main effect of age was present for just the trunk segment ($p<0.05$). Upper arm and forearm CV were significantly greater than trunk CV in both age groups ($p>0.05$).

Figure 3.7.4: Angular range of motion (ROM) during the *Walking Reach* across auditory conditions. There was no effect of auditory condition on ROM in either group. Paired t-tests revealed the trunk, upper arm and forearm completed a unique ROM in each age group, with the trunk segment demonstrating, as expected, the greatest ROM for the reach followed by the upper arm and finally the forearm.
Figure 3.7.5: Coefficient of variation (CV) of angular range of motion during the Walking Reach. A high CV value indicates a greater amount of variability relative to the mean range of motion for each segment. A main effect of age was present for just the trunk segment ($p<0.05$). Upper arm and forearm CV were significantly greater than trunk CV for both age groups ($p>0.05$).

Figure 3.7.6: Normalized gait velocity during Walking Reach. Gait velocity was normalized to each participant’s pelvis centre of mass height. Children had a significantly greater normalized velocity than adults in the pre- and post-pickup phases of the trial.
3.8 References


Reed, E. S. (1989). Changing theories of postural development. In M. H. Woollacott, & A. Shumway-Cook (Eds.), *Development of posture and gait across the lifespan* (pp. 3-24). Columbia, South Carolina: University of South Carolina Press.


Chapter 4. Linking all three postures

To address the final objective of the thesis, two outcome measures were used to quantify a cognitive and motor effect of increasing postural load from the *No Motor condition*, through *Seated* and *Standing Reach* to the *Walking Reach*. It was hypothesized that Response Time (RT) to the cognitive task would increase for children from the single task performance (*No Motor*) through to the *Walking Reach* task as the attentional requirements of the task increased with each increase in postural load. Finally, it was expected that reach initiation time would increase from the least posturally demanding task (*Seated Reach*), through to the greatest (*Walking Reach*) as a simplification tool for children to the overall complex paradigm.

4.1 Methods

Please refer to the Methods sections of *Chapter 2* and *Chapter 3* for a detailed description of marker placement, and motor and cognitive task instructions for participants. In brief, the response time outcome measure was calculated using the same method as outlined in *Chapter 2* and *Chapter 3*: the analog signal collected from the microphone placed on the participant’s chest was digitized and a visual inspection method was used to determine cue and response onset. A mean and standard error (SE) of the mean response time was calculated for each subject for each posture (*No Motor, Seated Reach, Standing Reach, Walking Reach*), and then averaged across subject groups (*Child, Adult*).

A detailed description of how the time points for Reach Initiation (RCH) and maximum trunk flexion (MAX) were determined can be found in the Methods sections of *Chapter 2* and *Chapter 3* (See Figure 2.7.1 and Figure 3.7.1). In brief, the duration of time (in seconds) from RCH to MAX for each reaching posture (*Seated Reach, Standing Reach, Walking Reach*) was
determined for each trial and a mean and SE for each subject was calculated. Mean RCH times were averaged across subject groups (Child, Adult) within each posture.

Finally, the difference between mean RT and mean RCH time in seconds (RT-RCH) was determined for each subject within each reaching posture (Seated Reach, Standing Reach, Walking Reach). A mean difference and SE were calculated for each subject group within each posture. A difference of 0 between these measures would indicate that the same response time for the cognitive and motor tasks was performed.

4.2 Statistical Analyses

Statistical analyses were completed in SPSS Software (Version 22). When data from all subject groups and both postures was combined, Levene’s homogeneity of variance assumption was violated. As a result, statistical analysis were completed with the subject groups separated (Child, Adult) separated. This allowed all results to be compared across postures (No Motor, Seated Reach, Standing Reach, Walking Reach).

A one-way analysis of variance (ANOVA) was used to compare the effect of Posture (No Motor, Seated Reach, Standing Reach, Walking Reach) on Response Time (RT) within each subject group (Child, Adult). A one-way ANOVA was used to compare the effect of Posture (No Motor, Seated Reach, Standing Reach, Walking Reach) on Reach Time within each subject group (Child, Adult). RCH times were then split up between postures and the effect of age group within each posture was calculated using a one-way ANOVA. An independent samples t-test was used to compare the difference between RT and RCH (RT-RCH measure) to 0 for each subject group (Child, Adult) within each posture (Seated Reach, Standing Reach, Walking Reach). A significant difference from zero would suggest one task was being performed significantly more quickly than the other.
4.3 Results

Mean and standard deviation values for individual subjects for RT and RCH time are presented for each posture are presented in Figure 4.5.1 (RT: A to D) and Figure 4.5.2 (RCH: A to C) for descriptive purposes. If a subject had large gaps in their marker data or a technical error in the microphone recording, their data was not included in these descriptive figures.

ANOVA results are summarized in Table 4.4.1. There was no significant effect of posture on RT in either age group (See Figure 4.5.3). There was no significant effect of posture on RCH Time within the child subject group (See Figure 4.5.4). A significant main effect of posture was present within the adult subject group. Tukey’s post-hoc test revealed Seated Reach Time to be significantly greater than Standing Reach Time ($p<0.05$) and Walking Reach Time ($p<0.05$). There was no significant difference between Standing Reach Time and Walking Reach Time ($p>0.05$). There were no significant effects of age group on Reach Time within each posture ($p>0.05$). The difference between RT and RCH time was not significantly different from 0 for either subject group in any of the postures, see Figure 4.5.5 and Table 4.4.2.
4.4 Tables

Table 4.4.1: Summary of ANOVA statistical tests. The main effect of posture was tested for response time and reach time. Statistical analyses were completed in SPSS Software (Version 22). When data from all subject groups and both postures was combined, Levene’s homogeneity of variance assumption was violated.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Age Group/Posture</th>
<th>Main effect of Posture</th>
<th>Figure/Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Time</td>
<td>Child</td>
<td>F(3,47)=1.443, <em>p</em>=0.245</td>
<td>Figure 4.5.3</td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>F(3,47)=0.207, <em>p</em>=0.891</td>
<td></td>
</tr>
<tr>
<td>Reach Time</td>
<td>Child</td>
<td>F(2,21)=1.127, <em>p</em>=0.345</td>
<td>Figure 4.5.4</td>
</tr>
<tr>
<td></td>
<td>Adult</td>
<td>F(2,28)=9.607, <em>p</em>=0.001</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4.2: Difference between response time (RT) and reach time (RCH) within each posture. There was no significant difference between the mean difference (RT-RCH) and 0 for any posture in either subject group indicating RT and RCH were completed in the same amount of time.

<table>
<thead>
<tr>
<th>Subject Group</th>
<th>Posture</th>
<th>Mean Difference (RT-RCH, secs) ± S.E.</th>
<th>Independent T-Test (Compared to 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children</td>
<td>Seated Reach</td>
<td>0.156±1.11</td>
<td>t(6)=0.14, <em>p</em>=0.893</td>
</tr>
<tr>
<td></td>
<td>Standing Reach</td>
<td>0.261±1.21</td>
<td>t(6)=0.217, <em>p</em>=0.835</td>
</tr>
<tr>
<td></td>
<td>Walking Reach</td>
<td>0.653±0.415</td>
<td>t(2)=1.573, <em>p</em>=0.256</td>
</tr>
<tr>
<td>Adults</td>
<td>Seated Reach</td>
<td>-0.192±0.170</td>
<td>t(5)=−1.125, <em>p</em>=0.312</td>
</tr>
<tr>
<td></td>
<td>Standing Reach</td>
<td>0.060±0.189</td>
<td>t(5)=0.317, <em>p</em>=0.764</td>
</tr>
<tr>
<td></td>
<td>Walking Reach</td>
<td>0.103±0.174</td>
<td>t(5)=0.595, <em>p</em>=0.578</td>
</tr>
</tbody>
</table>
4.5 Figures

A

B.
C.

D.

**Figure 4.5.1** Individual Response Time to the auditory Stroop task (CH= child, YA= young adult). A. No Motor; B. Seated Reach; C. Standing Reach; D. Walking Reach. If a subject had large gaps in their marker data or a technical error in the microphone recording, their data was not included in these descriptive figures.
A.

B.
C.

Figure 4.5.2 Individual Reach Time (CH=child, YA= young adult) A. Seated Reach; B. Standing Reach; C. Walking Reach. If a subject had large gaps in their marker data or a technical error in the microphone recording, their data was not included in these descriptive figures.
Figure 4.5.3 Response time (RT) in seconds within each posture for children and adults. There was no effect of posture on RT in either subject group ($p > 0.05$).
Figure 4.5.4 Reach Time (RCH) in seconds within each posture for children and adults. There was no effect of posture on RCH in children ($p>0.05$). Seated RCH time was significantly longer than Standing or Walking in adults ($p<0.05$).
Figure 4.5.5 Difference between Response Time and Reach Time (RT-RCH) for children and adults within each posture (mean ± SE). Independent t-tests revealed no significant difference between the mean difference and 0 for either group in any posture, however note that SE is observed to be larger for child subjects indicating a greater variability between the child participants.
Chapter 5. General Discussion

From the *Dynamic Systems Theory* (DST), we know that, rather than a pre-set series of “hard wired” events, motor control is emergent. A child learns to coordinate their own body, their muscles and joints, and balance control, for a given task within the surrounding environment. In this way, the DST characterizes task performance as self-organizing: infants and children are able to scale their stability and control parameters to the development level of their interacting subsystems (Gabbard, 2011). Each subsystem (i.e. motor, biological) develops at different rates to produce varying skill levels at each stage of motor development. Subsequently, each factor then contributes to the variability observed at transitional periods when disruptions in movements, learning and control are present (Thelen & Spencer, 1998).

The overall objective of this thesis was to examine how children acquire the ability to integrate motor and cognitive tasks. The age of 6-7 years has been identified as a major developmental transition, in terms of postural, gait, executive function and attention. At this transitional developmental stage, many individual tasks are performed in a similar approach to adults however, the strategies used by children to integrate and perform multiple tasks at once was unknown prior to this work. With the current series of studies, we aimed to further our general knowledge about the emergence and development of segmental coordination during three complex motor and cognitive tasks in middle aged children. To this end, children age 7 years and healthy young adults were asked to perform a bimanual task while also responding to an auditory executive function task. We decided upon a bimanual reaching and balancing task as they are typically performed at adult-like levels in this age group while seated (Roncesvalles, Schmitz, Zedka, Assaiante & Woollacott, 2005). We expanded on this previously completed work by adding the auditory Stroop task, to observe the effects of executive function on a
simultaneous motor task. We hoped to highlight how different postural load conditions influence motor and cognitive outcome measures by studying the same group of children and adults performing the same motor and cognitive task. Differences in motor control, executive function and attention control due to increases in postural load (i.e. seated, standing walking) were explored using this simple, yet effective, experimental paradigm.

The first manuscript (Chapter 2) provided evidence that children age 7 are capable of completing a simultaneous cognitive and upper-body motor task in a seated posture using a similar strategy as healthy young adults. Children adapted their current attentional resource capacities to the task and effectively divided their attention between tasks in order to be successful in the overall paradigm. Both children and adults did not change their motor strategy with the addition of the cognitive task, however this strategy appeared to be used by children as simplification tool; this simplified the control required but meant that the children did not complete both tasks simultaneously in a more adult like manner. Since we observed declines in overall cognitive efficiency and motor control performance, it was determined that using a mature motor strategy similar to the strategy used by adult subjects for both cognitive performance and balance control required more of the children’s available attentional capacity. We concluded that children age 7 years are approaching adult-like behavior: children can create and implement adult motor and cognitive strategies for a seated, multi-task paradigm. However when their attentional capacity is challenged, they are forced to increase response time and decrease control (i.e. increase variability trial to trial) in order to complete the overall paradigm.

The second manuscript (Chapter 3) challenged participants to divide their attention and complete an upper body motor task while standing and during gait, while simultaneously answering an auditory executive function task. By age seven, children are capable of completing
a complex motor and cognitive task paradigm successfully both while standing and during gait. Children were able to perform similar cognitive accuracy rates to adults however their motor behavior was not at exactly the same level of maturity or control as the adults, shown through a significant increase in trunk variability. In order to successfully integrate all tasks, children increase cognitive response time, increased trial-to-trial variability and reduced gait velocity. From this study, we concluded that children do not yet have adequate attentional capacity to complete a balancing, reaching and simultaneous executive function task at the same level as adults. Children compensated by reducing cognitive performance (i.e. increased response latency time) in order to successfully complete the motor task with the same cognitive accuracy rate as adults.

The hierarchy of postural control demands (i.e. seated, standing, and walking) provided an interesting paradigm to examine how attentional load influences a progressively more demanding motor control task. To this end, two measures (Response Time - RT and Reach Time - RCH time) that applied to all three postures were further investigated (Chapter 4) to clarify if attentional load differences between postures were present for each age group (Children, Adults) and if so, identifying where these differences lied.

Somewhat surprisingly, there were no differences in RT or RCH time between postures for the children studied (aged 7 years). Based on the attentional capacity theory (Figure 1.7.2), performance detriments were expected when the total capacity is exceeded by the individual capacities required by each individual task (Huang & Mercer, 2001). Our results suggest that the cognitive task required a larger portion of overall attentional capacity in children at this age compared to adults, as their response time was longer in each posture (See Figures 2.6.2, and Table 3.7.1). The children’s overall attentional capacity was not exceeded, however, as they were
able to complete both tasks successfully and answer the Stroop task with similar accuracy rates to adults in all postures (See Table 2.7.2 and Table 3.7.1). Since there were no significant differences between age groups for each posture, within this capacity model it is suggested that the motor task required a similar amount of attentional capacity in both age groups.

There was an effect of posture on reach time in adults, as seated reach time was significantly longer than standing or walking. Since the seated reach was always presented first, this result could simply be due to a practice effect as there were no differences in reach time between standing and walking postures for adults. This suggested practice effect may not have been seen in children due to anthropometrics of the trunk. Because of the constraints of task, children were required to move their trunk, the largest segment of their body, through a large range of motion. Ongoing balance control of this segment, displayed through the main effect of age on variability of the trunk while walking and during gait (Figures 3.7.3 and 3.7.5), introduced an added complexity to the task that was not apparent in the adult group. Coupled with the suggested reduced attentional capacity in children at this age, the overall multi-task paradigm challenged this age group across all postures and a practice effect was not observed.

The large variability present in both RT and RCH time across postures in the Child group coincides well with the Dynamic Systems Theory. Within this theory, variability characterizes a transitional period when individuals are optimizing their movements or responses (Thelen & Spencer, 1998). Descriptively, this variability was present in the individual data presented in Figures 4.5.1 and 4.5.2 for the children. From the small variability trial-to-trial, we can see that young adults have an established motor control and attentional system. Children, on the other hand, demonstrate a wide range of variability between participants. There are some children who have an amount of variability comparable to their adult counterparts, suggesting that they are
closer to a more mature control system than some of their peers. Other children have a large amount of trial-to-trial variability, indicating an immature, explorative stage in motor and attentional control. This is especially interesting regarding the overall conclusions that can be drawn from this thesis work; our child participants were all extremely close in age (i.e. all within one year). Through high subject-to-subject and trial-to-trial variability within each participant was observed, this thesis has been able to pinpoint that 7 years of age is a stage of continuing development, maturation and balance control.

From the outcome measures we have explored, it is not possible to expand upon prioritization differences (i.e. posture or cognitive task prioritization) between age groups. There were no significant differences between RT and RCH time in either group (RT-RCH = 0, p>0.05), suggesting that both tasks were performed as accurately and as quickly as possible, as we requested of them during experimental trials. Instructions to the participant are of extreme importance during a dual-task paradigm, especially with a group of children. It is possible that the same paradigm, with explicit prioritization between tasks, would be able to expand on whether children at this age are capable of properly prioritizing one task over the other in a complex multi-task situation.

5.1 Limitations and Future Directions

With any research program, there are limitations to the paradigm and its conclusions. For example, the relevance of our chosen cognitive task to tasks of daily living in children/adults may be questioned. There are numerous cognitive tasks used in the literature today which assess different parts of cognitive function (i.e. executive function, working memory). The auditory Stroop task was chosen because it has been well used in the literature and shown to be reliant with both adults (Kahneman & Chajczyk, 1983; Morgan & Brandt, 1989) and children (Guy,
It can be expected that a different cognitive task (e.g. a continuous backwards counting task) might change the way in which the motor task was performed in either subject group.

The motor task in our paradigm was likely a relatively novel paradigm to both groups. It is possible then that the behaviour we observed in our young adult group was unpracticed or “immature” in nature, if this was their first time performing the motor task. We are confident that our results and conclusions (i.e. comparisons made between groups) are still relevant and important due to the low variability observed between participants in the young adult group. If the task was novel, and more difficult that we had planned, a large variability from trial-to-trial and from participant-to-participant would have been expected even in these young adult “control” subjects.

In more recent motor control literature pertaining to the development of head-trunk coordination, the anchoring index measure has been used to determine if a movement is ‘en bloc’ or articulated. This measure has been used to examine sensorimotor organization in the control of two body segments in relation to each other (e.g. head vs trunk) for balance and locomotor tasks (e.g. Assaiante and Amblard, 1993 and 1995) as well as during reaching tasks (Sveistrup, Schneiberg, McKinley, McFadyen & Levin, 2008). For this thesis, we chose not to use this outcome measure as we felt it could be harder to interpret as opposed to the range of motion measure that we used in Chapter 2 and Chapter 3. In doing so, we have carefully worded our findings and conclusions and have not used the term ‘en bloc’ to describe any movements as this term is typically associated with a negative anchoring index. We feel that our use of a range of motion outcome measure answers our research questions properly and is more quickly interpreted by a range of audiences.
As research continues to explore motor and postural control and task performance, children provide an excellent study population. By examining the ways in which typically developing children learn to sit, stand, walk and perform simultaneous tasks we may better understand the way in which motor and skills are lost with age, injury or cognitive declines. If motor skills emerge based on a certain level of balance control in childhood, perhaps we can better prepare older adults with motor or cognitive declines with better research based rehabilitation. It may be possible that the patterns of behaviour we see in typically developing children can be applied at the opposite end of the spectrum, providing a functional link across the lifespan for future research purposes.

5.2 References


Chapter 6. Conclusions

This thesis set out to fill the gap between our understanding of the establishment of mature of motor control and attention during individual task performance and their integration for simultaneous multi-task situations. From the novel research presented here, we have illustrated evidence that children age 7 were able to adapt well and perform our complex paradigm. At this age, children are able to complete each task properly with their given motor and attentional capacities. This thesis deepens our knowledge about how children integrate more than one task at once, and how their control strategies compare to those used by young adults. Children scale their motor and executive function capabilities in order to complete a complex task successfully. In doing so, their response time and variability of control of motor synergies was significantly greater than adults. This variability, already shown to be a strong outcome measure in past developmental motor control research, adds important knowledge to the scientific literature. It provides further evidence that children at this transitional age are exploring their capabilities and searching for optimal control strategies over body kinematics. Children appear to make the best use possible of their developing system to perform daily tasks in an appropriate manner, establishing more mature motor control patterns, fine tuning their ability to perform tasks involving high levels of executive function and improving their ability to integrate more than one task. Children in this interesting stage of development are adaptable to their environment, and when challenged, are able to perform tasks properly, even if they have not yet established a mature motor control and attentional capacity.
Chapter 7. Appendices

7.1 University of Guelph Gait Biomechanics Laboratory Preliminary Health Questionnaire

(Completed On-line)

Thank you for volunteering your child for the Balance and Walking study at the University of Guelph. Any information obtained from this survey will be kept confidential and will be used strictly for research and teaching purposes and will not be re-distributed.

Please fill out this form for your child to the best of your abilities. Please ensure you click "submit" after the final question.

Subject codes will be used in data analysis, your child's name therefore, will not be used. However, for the purpose of preliminary identification, please fill in your child's initials below in order to properly link your responses. ______________

**Question 1.** What is your child's sex?

**Question 2.** What is your child's date of birth?

**Question 3.** What is your child's handedness?

For example: Hand they write with, hand they are more likely to throw a ball with.

**Choices:** Right Hand Always, Right Hand Usually, Equal, Left Hand Usually, Left Hand Always

**Question 4.** If your child was to kick a soccer ball, which foot would they use?

**Choices:** Right Always, Left Always, Unsure.

*If Unsure, the following questions are asked:

**Footedness Questionnaire**

We will use this questionnaire to determine your child's footedness. Please answer the following questions for your child to the best of your ability.

**Question A.** Which foot would your child use to kick a stationary ball at a target straight in front of them?

**Choices:** Right Foot Always, Right Foot Usually, Equal, Left Foot Usually, Left Foot Always, Unsure

**Question B.** If your child had to stand on one foot, which foot would it be?

**Choices:** Right Foot Always, Right Foot Usually, Equal, Left Foot Usually, Left Foot Always, Unsure
Question C. Which foot would your child use to smooth sand at the beach?

Choices: Right Foot Always, Right Foot Usually, Equal, Left Foot Usually, Left Foot Always, Unsure

Question D. If your child was to step up onto a chair, which foot would be placed on the chair first?

Choices: Right Foot Always, Right Foot Usually, Equal, Left Foot Usually, Left Foot Always, Unsure

Question E. Which foot would your child use to stomp out a fast moving bug?

Choices: Right Foot Always, Right Foot Usually, Equal, Left Foot Usually, Left Foot Always, Unsure

Question F. If your child was to hop on one foot, which foot would they use?

Choices: Right Foot Always, Right Foot Usually, Equal, Left Foot Usually, Left Foot Always, Unsure

Preliminary Health Questionnaire Part 2

Question 5. Has your child every been diagnosed with any perceptual problems? (E.g. "lazy eye", "cross eyes", tipping head or body to read)

If Yes please specify in Question 6. If No, please proceed to Question 7.

Question 6. If Yes, please list the perceptual problem with which they have been diagnosed. For example, please let us know if your child has ever been diagnosed with a “lazy eye”, glaucoma, or any other eye problem that may interfere with their vision.

Question 7. Has your child ever been diagnosed with a hearing problem? (E.g. multiple ear infections, use of a hearing aid)

If Yes, please specify in Question 8. If No, please proceed to Question 9.

Question 8. If you answered 'Yes' to Question 7, please specify your child's possible hearing impairments.

For example, please let us know if your child has been diagnosed with multiple ear infections, uses a hearing aid, or requires special assistance to hear properly.

Question 9. Does your child normally wear corrective eye wear (i.e. eye glasses, eye patch)?

If Yes, please specify in Question 10. If No, please proceed to Question 11.

Question 10. If you answered 'Yes' to Question 9, please specify your child's corrective eye wear.

For example, please let us know if your child wears glasses, contact lenses, or an eye patch in order to complete normal day-to-day tasks.

Question 11. Has your child ever had a fracture (i.e. broken bones)?

If Yes, please specify in Question 12. If No, please proceed to Question 13.
**Question 12.** If you answered 'Yes' to Question 11, please specify your child's fracture(s) (i.e. broken bones)

Please let us know the date (month and year) of your child's fracture(s).

**Question 13.** Is your child currently taking any medication?

If Yes, please specify in Question 14. If No, please press submit to complete Health Questionnaire.

**Question 14.** If you answered 'Yes' to Question 13, please provide the names of the medications your child is currently taking.

Thankyou for completing the Preliminary Health Questionnaire. Please press submit below.
CONSENT TO PARTICIPATE IN RESEARCH

Reaching The Limits Of Cognitive Resources: Coping Strategies Used During A Multi-Task Paradigm

You are asked to participate in a research study conducted by Dorelle Hinton (student), Sarah Mitchell-Ewart (student) and Dr. Lori Ann Vallis (Faculty supervisor) from the Human Health and Nutritional Sciences Department at the University of Guelph. This study will contribute to Miss Hinton’s Master’s of Science thesis and Miss Mitchell-Ewart’s Bachelor of Science Honours Research Project. Funding for this project has been provided by the Discovery Grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) awarded to Dr. Vallis.

If you have any questions or concerns about the research, please feel free to contact Dr. Lori Vallis (Faculty Supervisor) at (519)-824-4120 ext 54589.

PURPOSE OF THE STUDY

The proposed study will attempt to determine whether children aged 7-12 years old and young adults (18-25 years old) are able to separate the position of their forearm from the position of their trunk (i.e. keep forearm horizontal regardless of orientation of their trunk). Specific walking parameters and body orientation will be measured in the study, such as your forearm orientation in relation to your trunk.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:

**SETUP:**
Before coming into the lab, please read over this information so that you are clear on how your time in the lab will be spent. Your participation only requires a single, 90 minute visit to the Gait Biomechanics Laboratory. Once you arrive, we will ask you to change into a loose fitting t-shirt and shorts or yoga style pants and their own running shoes for the testing session. Markers that are used to track your movements during the experiment will be mounted on your head, chest, pelvis, right and left shoulders, elbows, wrists and feet. Using these markers, your body segments will be digitalized onto a computer and we can analyze your movements through space, however no images will be recorded. In total, you child will be asked to complete 10 seated trials, 12 standing trials and 12 walking trials.

**SEATED TRIALS:**
You will be asked to complete 10 seated trials as confirmation of your motor development. Each subject will balance a soft ball on a Frisbee in their non-dominant hand, and sitting in a chair, will be asked to pick a toy up off the ground. If you are able to complete this task without losing balance of the Frisbee, you will continue with the next two tasks.

**STANDING TRIALS:**
You will be asked to complete two different standing trials, 6 times for a total of 12 standing trials. The first type of standing task will require you to balance a soft ball on a Frisbee in your non-dominant hand while standing and then Frisbee in hand, pick up a toy off the ground with your dominant hand. The second type of standing task will require you to perform a listening task while standing, with the ball and Frisbee in your non-dominant hand and then pick the toy up off the ground. The listening task will require you to determine the pitch (high or low) of spoken words “high” and “low”; the pitch of these words may match the spoken word (i.e. “high” spoken in a high pitch voice) or may be mismatched (“high” spoken in a low pitch voice). You will be asked to only indicate the pitch of the voice and not the word spoken. We will provide practice opportunities so that you understand the task we are asking you to complete. The order of the two types of standing trials (with or without the listening task) will be randomly assigned.

**WALKING TRIALS:**
You will be asked to complete two different walking trails, 6 times for a total of 12 walking trials. The first type of walking task will require you to balance a soft ball on a Frisbee in your non-dominant hand while walking, and then Frisbee in hand, pick up a toy off the ground with their dominant hand. The second type of walking task will require you perform the same listening task as the standing trials. The order of the two types of walking trials will be randomly assigned.

**POTENTIAL RISKS AND DISCOMFORTS**
During the laboratory trials there will be a minimal risk of encountering a trip or fall during the walking tasks. To ensure your safety at all times, trained individuals will be present to act as spotters should an issue arise. You will be encouraged to perform to the best of your abilities during the trials but if at anytime you feel unsafe or unstable we will encourage you to stop and steady yourself and perhaps take a rest break.

You can withdraw from the experiment at anytime without penalty even after you have given consent to participate. Your safety is important to us. Should you choose to withdraw from the study you may opt to have your data removed from the study as well.

**POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY**
Our studies will investigate at what age children transition in balance and global postural control and begin to show selective control upper body segments. Current research on balance strategies in children characterizes a major transition in stability control between 7 and 8 years of age. Prior to this study, there has been little research performed to upper body segment control and balance while walking in school aged children. By investigating these control strategies in children, we will be able to compare this information to balance strategies used in adults. From this comparison we will be able to determine the milestones of balance control development. In the future, this information may inform treatment strategies for children with developmental locomotor disabilities or with acquired neurological impairments.

**PAYMENT FOR PARTICIPATION**
We appreciate your participation in this study. As you will be asked to travel to the University of Guelph Gait laboratory for your testing session, your parking costs will be paid for by the laboratory on your laboratory session date. A small token of appreciation ($5 cash) will be given as a thank-you for your participation in the study, even if you choose not to complete the study protocol.

CONFIDENTIALITY

Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study.

For the purposes of comparison and accurate reporting of our findings subject codes will be used in all data analysis; your name will not be used.

Any information obtained from these records will be kept confidential in the laboratory and secured in a locked cabinet. This information will be used strictly for research and teaching purposes only. The data collected during your test sessions will be stored electronically on a password protected computer.

PARTICIPATION AND WITHDRAWAL

You can choose whether you will be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don’t want to answer and you may still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through the University of Guelph Research Ethics Board. If you have questions regarding your rights as a research participant, contact:

Director, Research Ethics
University of Guelph
437 University Centre
Guelph, ON  N1G 2W1

Telephone: (519) 824-4120, ext. 56606
E-mail: sauld@uoguelph.ca
Fax: (519) 821-5236

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I have read the information provided for the study “Reaching The Limits Of Cognitive Resources: Coping Strategies Used By Children During A Multi-Task Paradigm” as described herein. My questions have been answered to my satisfaction, and I agree for my child to participate in this study. I have been given a copy of this form.

____________________________________
Name of Participant (please print)

______________________________________

Name of Legal Representative (if applicable)

______________________________________

Signature of Participant or Legal Representative __________________________ Date

SIGNATURE OF WITNESS

Name of Witness (please print)

______________________________________

Signature of Witness __________________________ Date
7.3 Participant Consent Form (Child)

PARENTAL INFORMATION CONSENT FOR CHILD TO PARTICIPATE IN RESEARCH

Reaching The Limits Of Cognitive Resources: Control Strategies Used During A Multi-Task Paradigm

Your child is asked to participate in a research study conducted by Dorelle Hinton (student), Sarah Mitchell-Ewart (student) and Dr. Lori Ann Vallis (Faculty supervisor) from the Human Health and Nutritional Sciences Department at the University of Guelph. This study will contribute to Miss Hinton’s Master’s of Science thesis and Miss Mitchell-Ewart’s Bachelor of Science Honours Research Project. Funding for this project has been provided by the Discovery Grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) awarded to Dr. Vallis.

If you have any questions or concerns about the research, please feel free to contact Dr. Lori Vallis (Faculty Supervisor) at (519)-824-4120 ext 54589.

PURPOSE OF THE STUDY

The proposed study will attempt to determine whether children aged 7-12 years old are able to separate the position of their forearm from the position of their trunk (i.e. keep forearm horizontal regardless of orientation of their trunk). Specific walking parameters and body orientation will be measured in the study, such as your child’s forearm orientation in relation to their trunk.

PROCEDURES

If you volunteer your child to participate in this study, we would ask you to do the following things:

**SETUP:**
Before coming into the lab with your child, please read over this information so that you are clear on how your time in the lab will be spent. Your participation only requires a single, 90 minute visit to the Gait Biomechanics Laboratory. Once you arrive, we will ask your son or daughter to change into a loose fitting t-shirt and shorts or yoga style pants and their own running shoes for the testing session. Markers that are used to track your child’s movements during the experiment will be mounted on the child’s head, chest, pelvis, right and left shoulders, elbows, wrists and feet. Using these markers, your child’s body segments will be digitalized onto a computer and we can analyze your child’s movement through space, however no image of your child will be recorded. In total, your child will be asked to complete 10 seated trials, 12 standing trials and 12 walking trials.

**SEATED TRIALS:**
Your child will be asked to complete 10 seated trials as confirmation of their motor development. Each child will balance a soft ball on a Frisbee in their non-dominant hand, and sitting in a chair, will be asked to pick a toy up off the ground. If the child is able to complete this task without losing balance of
the Frisbee, they will continue with the next two tasks. It is critical that we determine that your child has reached this developmental stage in balance control, as chronological age is not necessarily representative of their motor development at this transitional age.

**STANDING TRIALS:**

Your child will be asked to complete two different standing trials, 6 times for a total of 12 standing trials. The first type of standing task will require your child to balance a soft ball on a Frisbee in their non-dominant hand while standing and then Frisbee in hand, pick up a toy off the ground with their dominant hand. The second type of standing task will require your child to perform a listening task while standing, with the ball and Frisbee in their non-dominant hand and then pick the toy up off the ground. The listening task will require your child to determine the pitch (high or low) of spoken words “high” and “low”; the pitch of these words may match the spoken word (i.e. “high” spoken in a high pitch voice) or may be mis-matched (“high” spoken in a low pitch voice). Your child will be asked to only indicate the pitch of the voice and not the word spoken. We will provide practice opportunities so that they understand the task we are asking them to complete. The order of the two types of standing trials (with or without the listening task) will be randomly assigned. To make the experience fun for your child we will ask them to help us determine the order of the walking trials (with the listening task or without the listening task) by choosing coloured blocks out of a bin; one colour will indicate a combined walking-reaching task + listening task; another colour will indicate that we would like them to perform just the walking-reaching task.

**WALKING TRIALS:**

Your child will be asked to complete two different walking trails, 6 times for a total of 12 walking trials. The first type of walking task will require your child to balance a soft ball on a Frisbee in their non-dominant hand while walking, and then Frisbee in hand, pick up a toy off the ground with their dominant hand. The second type of walking task will require the child to perform the same listening task as in the standing task while walking towards the toy, with the ball and Frisbee in their non-dominant hand, and then pick the toy up off the ground. The same process (choosing coloured blocks) will be used to keep your child engaged in the process during the walking trials.

**POTENTIAL RISKS AND DISCOMFORTS**

During the laboratory trials there will be a minimal risk of your child encountering a trip or fall during the walking tasks. To ensure the safety of your child at all times, trained individuals will be present to act as spotters should an issue arise. Your child will be encouraged to perform to the best of their abilities during the trials but if at anytime they feel unsafe or unstable we will encourage them to stop and steady themselves and perhaps take a rest break.

Your child can withdraw from the experiment at anytime without penalty even after you have given consent to participate. Your child’s safety is important to us. Should you or your child choose to withdraw from the study you may opt to have your child’s data removed from the study as well.

**POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY**

Our studies will investigate at what age children transition in balance and global postural control and begin to show selective control upper body segments. Current research on balance strategies in children characterizes a major transition in stability control between 7 and 8 years of age. Prior to this study, there has been little research performed to upper body segment control and balance while walking in school aged children. By investigating these control strategies in children, we will be able to compare this information to balance strategies used in adults. From this comparison we will be able to determine
the milestones of balance control development. In the future, this information may inform treatment strategies for children with developmental locomotor disabilities or with acquired neurological impairments.

**PAYMENT FOR PARTICIPATION**

We appreciate your child’s participation in this study. As you will be asked to travel to the University of Guelph Gait laboratory for your child’s testing session, your parking costs will be paid for by the laboratory on your child’s laboratory session date. A small token gift card for a local activity (e.g. swim pass, bowling game or gift card for ice cream shop) will be given to your child as a thank-you for their participation in the study, even if they choose to not complete the study protocol.

**CONFIDENTIALITY**

Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study.

For the purposes of comparison and accurate reporting of our findings subject codes will be used in all data analysis; your child’s name will not be used.

Any information obtained from these records will be kept confidential in the laboratory and secured in a locked cabinet. This information will be used strictly for research and teaching purposes only. The data collected during your child’s test sessions will be stored electronically on a password protected computer.

**PARTICIPATION AND WITHDRAWAL**

You can choose whether your child will be in this study or not. If you volunteer your child to be in this study, you may withdraw your child at any time without consequences of any kind. You may exercise the option of removing your child’s data from the study. You may also refuse to answer any questions you don’t want to answer and your child may still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

**RIGHTS OF RESEARCH PARTICIPANTS**

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through the University of Guelph Research Ethics Board. If you have questions regarding your rights as a research participant, contact:

Director, Research Ethics
University of Guelph
437 University Centre
Guelph, ON  N1G 2W1

Telephone: (519) 824-4120, ext. 56606
E-mail: sauld@uoguelph.ca
Fax: (519) 821-5236

**SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE**

I have read the information provided for the study “Reaching The Limits Of Cognitive Resources: Coping Strategies Used By Children During A Multi-Task Paradigm” as described herein. My
questions have been answered to my satisfaction, and I agree for my child to participate in this study. I have been given a copy of this form.

____________________________________
Name of Participant (please print)

____________________________________
Name of Legal Representative (if applicable)

____________________________________
Signature of Participant or Legal Representative  Date

SIGNATURE OF WITNESS

____________________________________
Name of Witness (please print)

____________________________________
Signature of Witness  Date