DOES A DUAL-TASK PROMOTE BETTER POSTURAL CONTROL IN CHILDREN COMPARED TO A SINGLE TASK?

GRAYDON PAITICH

A thesis submitted in partial fulfillment
of the requirements for the
Master of Science degree in Human Kinetics

Human Kinetics
Faculty of Health Sciences
University of Ottawa

ABSTRACT

Postural control is the skill developed allowing body equilibrium and orientation, allowing for an efficient interaction with the environment. This skill is developed from birth; the first major landmark is the maintenance of an upright stance of a child, followed by the skill to walk freely (Shumway-Cook & Woollacott, 1985). A second important development occurs between the ages of 7-10 years-old when children start to demonstrate adult-like postural control (Riach & Hayes, 1987). While adults and older adults have shown increased automaticity in postural control in a dual-task (DT) (Potvin-Desrochers, Richer, & Lajoie, 2017), children have not yet been studied. The purpose of this experiment was to determine if children aged 6-7, 8-9, and 10-11 years old would demonstrate better postural stability, and greater postural automaticity in a DT condition than in a postural task (PT). To verify this, children were asked to stand still on a force platform in a PT or in a DT condition (PT with concurrent cognitive task). Results showed that older children had better postural stability, as demonstrated by a smaller sway area (7.20 cm^2), reduced sway variability (0.60 cm), and a slower MV of sway (4.70 cm/s) than younger children (12.37 cm^2, 0.78 cm, 6.60 cm/s). Older children also had a higher MPF in the PT (0.24 Hz) than in the DT (0.16 Hz). A wavelet transformation revealed a greater contribution of the ultra-low frequency band in the PT (49.9%) than in the DT (46.8%) across all children. These results demonstrated that older children were more stable than younger children. The smaller contribution to the ultra-low band in the DT may be an indication that children rely less heavily on their visual system in the DT. This research shows that children do not demonstrate automaticity of postural control between the ages of 6-11 years.

Key words: postural control, dual-task, children, automaticity

ACKNOWLEDGEMENTS

I would first like to thank my thesis supervisor, Dr. Yves Lajoie, who has provided me with guidance and support whenever necessary, while he also allowed me to truly explore the opportunity of being an autonomous researcher. I will always remember the first class of his that I attended, and his enthusiasm for the topic of motor control shaped my academic trajectory. I would like to thank him for his continued patience and support towards my academic – and sometimes more than academic – development.

I would also like to acknowledge my thesis committee, Dr. Diane Ste-Marie and Dr. Nicole Paquette. They have both provided me with much insight and guidance concerning my thesis and have helped to shape it for the better.

I would like to thank all the participants who took the time out of their busy schedules to patiently work with me – bringing a child in for a science experiment is not always the easiest thing to do as a parent! The patience of the children who participated in a cooperative and enthusiastic manner is greatly appreciated and commended!

A special thank you goes out to my lab-mates and other graduate student friends for their support and their ability to relate to my situation throughout the thesis writing process.

Last but not least, I would like to thank my fiancé for her unconditional love and support through the development of my project and the long hours spent at the lab. The patience she demonstrated is without parallel, and for which I am eternally grateful.

TABLE OF CONTENT

CHAPTER 1: REVIEW OF LITERATURE

Postural Control

Postural control is necessary for every day activities, whether that be walking around, kicking a soccer ball, or standing still waiting for the bus. There are two primary objectives when it comes to postural control. The first of these objectives is body orientation, which is the alignment of the body in relation to external forces, such as gravity and the available surfaces, and to the internal and external environment (Massion, 1994). The second of these is to maintain equilibrium through the coordination of sensorimotor strategies in response to internal and external disturbances (Massion, 1994). Both of these goals serve to maintain the vertical projection of the body's centre of gravity within its base of support (Massion, 1994; Winter, 1995).

Postural control calls upon three primary systems – the central nervous system (Massion, 1994; Shumway-Cook & Woollacott, 1985), the musculoskeletal system (Massion, 1994), and the sensory systems (Massion, 1994; Winter, 1995). These systems work in harmony to keep the centre of gravity within the base of support which allows for upright stance. Within the sensory systems come the interaction of the visual system, the proprioceptive system, and the vestibular system (Massion, 1994). The visual system is primarily responsible for providing feedback on the environment and the orientation and whole body movement, the proprioceptive system is primarily responsible for providing feedback on the effector system and the environment, and the vestibular system is primarily responsible for providing feedback on the body's orientation and acceleration (Massion, 1994; Winter, 1995; Woollacott & Shumway-Cook, 1990). In all, these systems provide the postural body scheme, which is the internal representation of the body's geometry, dynamics, and orientation in relation to being vertical (Massion, 1994). A disruption in the sensory systems can disrupt the maintenance of upright postural control and the vertical projection of the centre of gravity within the base of support (Winter, 1995).

In order to maintain that projection of the centre of gravity within the base of support – to maintain balance – certain strategies are employed. Among these strategies are the ankle strategy and the hip strategy, which account for a large proportion of the antero-posterior (AP) control and response to small perturbations, in addition to that of the medio-lateral (ML) control and response to larger perturbations to postural control, respectively (Winter, 1995). Within these strategies are imbedded muscular synergies, which are defined as a muscular group activating simultaneously as a response to external or internal perturbations (Woollacott & Shumway-Cook, 1990). Muscular synergies are called upon in response to perturbations and used to control the degrees of freedom of any articulation, but notably are the ankle joint and the hip joint synergies, used in the ankle and hip strategies respectively (Woollacott & Shumway-Cook, 1990).

Postural Control in Children

Whereas healthy adults have fully developed postural strategies, postural control in children is inherently different than in adults – in large part due to an underdeveloped repertoire of balance strategies (Assaiante, Mallau, Viel, Jover, & Schmitz, 2005). One reason for this difference is in the developmental maturity of the sensory systems in children (Assaiante & Amblard, 1995; Shumway-Cook & Woollacott, 1985). Adults have developed the skill necessary to prioritize and re-weight dependence on a given system – for example to re-weight the priority in favor of the vestibular and proprioceptive systems if the visual system is disrupted (Winter, 1995); however, young children (up to 6 years old) lack this skill and are unable to resolve multi-modal sensory conflict (Shumway-Cook & Woollacott, 1985). As a result, children have less flexible and adaptable postural control systems (Shumway-Cook & Woollacott, 1985). Some research has shown that children aged 4-6 years can solve either a visual conflict, or a somatosensory conflict, whereas children aged 7-10 years are able to solve this multi-modal sensory conflict (Shumway-Cook & Woollacott, 1985). These researchers used a moving platform to perturb the somatosensory system, and eye closure to perturb the visual system (Shumway-Cook & Woollacott, 1985). Other research has shown that children aged 10 years demonstrate an increased sensory conflict resolution when faced with a somatosensory conflict compared to that of children aged 7 years, and that children aged 11 years demonstrate similar conflict resolution to adults (Cuisinier, Olivier, Vaugoyeau, Nougier, & Assaiante, 2011). These researchers used vibrations at the ankle to perturb the somatosensory system (Cuisinier et al., 2011). Other research has shown that children develop the skill necessary to resolve a simple visual conflict by the age of 7 years, a simple proprioception conflict by the age of 8 years, and a combination of visual and proprioceptive conflict only by the age of 12 years (Hsu, Kuan, & Young, 2009). These researchers used a foam pad to perturb the proprioceptive system, and eye closure to perturb the visual system (Hsu et al., 2009). Research in this area is inconclusive about the exact age at which there occurs the filly developed sensory conflict resolution, but it would appear that a visual conflict can be resolved between the age of 4 and 7 years, that a proprioceptive conflict can be resolved between the age of 8 and 10 years, and a combined sensory conflict can be resolved between the ages of 7 and 12 years (Cuisinier et al., 2011; Hsu et al., 2009; Shumway-Cook & Woollacott, 1985).

There is also research which supports the gradual mastery of equilibrium constraints via temporal organization of balance control, stating that postural control strategies start with a descending temporal organization (from birth to the skill of upright stance), followed by an ascending temporal organization (from upright stance to 6 years old), to fully develop into a descending temporal organization (from 6 years old to 10 years old) (Assaiante & Amblard, 1995).

Assaiante & Amblard describe how the descending temporal organization is head-centered, and infants rely primarily on their visual system as a frame of reference and have an articulated head-trunk unit, meaning they disassociate their head from the rest of their body. In contrast, they describe how 6-10-year-olds depend more heavily on their vestibular system and have an articulated head-trunk operation, meaning they disassociate their head from their trunk, but do not neglect their trunk. According to Assaiante & Amblard, the ascending temporal organization is surface-centered, which in upright stance translates to foot-centeredness, where young children rely primarily on their proprioceptive receptors as a frame of reference and have an "en bloc" head-trunk operations, meaning their head and their trunk operate as a single unit. They maintain that children older than 10 years old develop the necessary skill to combine multiple sources of information, and maintain a descending temporal organization as they operate with an articulated head and trunk, with more selective control of the degrees of freedom.

In response to this developmental immaturity, children have slightly different postural control strategies than adults do. Research has show the use of different postural strategies, including an open-loop control of posture, as well as an closed-loop control of posture (Hatzitaki, Zlsi, Kollias, & Kioumourtzoglou, 2002; Kirshenbaum, Riach, & Starkes, 2001; Riach & Hayes, 1987; Riach & Starkes, 1993, 1994). An open-loop control is a more ballistic type of motor control, where a motor command is launched, and no adjustments can be made until the motor command has been completed, which can be observed through large and fast postural corrections (Riach & Starkes, 1994). A closed-loop control is a more finely controlled motor command which refers back to an efferent copy of the motor command through the sensory systems to correct trajectory in real-time, which can be observed through shorter and more frequent postural corrections (Riach & Starkes, 1994). Research has shown that between 4 and 9 years old, children's sensory systems mature and they begin utilizing a more closed-loop type of postural control strategy as opposed to a more open-loop type of postural control strategy (Hatzitaki, Zlsi, Kollias, & Kioumourtzoglou, 2002; Kirshenbaum, Riach, & Starkes, 2001; Riach & Hayes, 1987; Riach & Starkes, 1993, 1994). Some researchers have suggested the transition from open-loop control to closed-loop control occurs between children aged 7.5 and 9 years (Kirshenbaum et al., 2001). Further research suggests the closed-loop strategy has been fully developed by the age of 11-13 years (Hatzitaki et al., 2002). In addition to the development of the closed-loop control of posture, children do not fully develop their muscular synergies until they are between the ages of 7-10 (Riach & Hayes, 1987; Shumway-Cook & Woollacott, 1985; Woollacott & Shumway-Cook, 1990). This lack of control over children's muscular synergies results in the development of a postural control strategy involving the over-contraction of muscular groups when threatened, resulting in poorer postural control than adults (Shumway-Cook & Woollacott, 1985). This strategy results in the co-contraction of agonist and antagonist muscles to effect control over the degrees of freedom at a given articulation (Riach & Hayes, 1987; Shumway-Cook & Woollacott, 1985; Woollacott & Shumway-Cook, 1990). This strategy is also known as the freezing of degrees of freedom and can be seen in children and adults if the task is anxiety-inducing (Stins, Roerdink, & Beek, 2011).

Measuring postural control

Postural control has been analyzed by using force platforms which indirectly measure the changes in postural sway through ground reaction forces (Palmieri, Ingersoll, Stone, & Krause, 2002). These ground reaction forces in addition to centre of mass trajectory and centre of mass acceleration measures are converted into centre of pressure (COP) measurements which can be converted into many different parameters (Palmieri et al., 2002). This experiment has focused on two categories of parameters – those related to postural performance, and those related to automaticity of postural control.

Performance

Performance parameters have been well established in literature, so three appropriately representative parameters were chosen. Parameters such as the 95% confidence ellipse (area) to observe the sway area, standard deviation of COP (SD) to determine the variability of sway, and mean velocity of COP (MV) to observe the speed of sway, have been used to determine overall postural stability and control (Doyle, Hsiao-Wecksler, Ragan, & Rosengren, 2007).

Automaticity

More recently measures such as mean power frequency (MPF) have been used to refine the observation of postural control through frequency of postural adjustments (Wulf, McNevin, & Shea, 2001). A high measure of MPF has been linked to automaticity of postural control when considering the constrained action theory, whereas low measure of MPF has been linked to the conscious control of posture.

(Wulf, McNevin, et al., 2001). Even more recently, sample entropy (SampEn) and wavelet measures have been linked to automaticity of postural control (Donker, Roerdink, Greven, & Beek, 2007; Potvin-Desrochers et al., 2017; Quek, Brauer, Clark, & Treleaven, 2014; Richer, 2018). The measure of SampEn gives an indication of the regularity of postural sway. A SampEn measures between 0 and 2, with a result near 0 indicating a regular postural sway, and a measure closer to 2 indicating an irregular postural sway (Donker et al., 2007). A regular postural sway has been linked to a more conscious control of posture whereas a more irregular postural sway has been linked to a more automatic control of posture (Donker et al., 2007; Potvin-Desrochers et al., 2017; Richer, 2018). A discreet wavelet analysis of postural sway decomposes the postural sway into multiple bandwidth frequencies (Chagdes et al., 2009; Quek et al., 2014). These different frequency bands are associated with different structures – the moderate band (1.56 – 6.25 Hz) is associated with the proprioceptive system, the low band (0.39 0 1.56 Hz) is associated with the cerebellum, the very low band (0.10 – 0.39 Hz) is associated with the vestibular system, and the ultra-low band (< 0.10 Hz) is associated with the visual system (Quek et al., 2014). Higher frequency bands have been linked to a more automatic control of posture, particularly in the low and very low bands (Quek et al., 2014; Richer, 2018).

Attention and postural control

Attention is defined as the capacity to process information, and all tasks are considered to require some level of attention (Woollacott & Shumway-Cook, 2002). There are three primary models which can explain the attentional resource management (Schmidt & Lee, 2011). The first is the central-resource capacity theory which assumes there is a finite amount of processing capacity, and if two tasks overwhelm the central processing capacity, one or both tasks will suffer a deterioration of performance (Kahneman, 1973). The second is the multiple resource theory which assumes that there are different mechanisms of attention for different types of tasks, and that performance will only suffer if two tasks compete for the same attentional resources (Wickens, 2002). The third is the fixed-capacity theory which assumes that some levels in the information processing mechanism can only process information serially, which can create a bottleneck, slowing the informational processing speed (Mccann & Johnston, 1992). The role of attention in motor skill performance has been extensively studied, and research demonstrates that performance of a motor skill is enhanced when a participant is asked to hold an external focus of attention as opposed to an internal focus of attention (Wulf, McNevin, et al., 2001; Wulf & Prinz, 2001; Wulf, Shea, & Park, 2001). An external focus of attention occurs when a person brings their attention to the effect of their movement, whereas an internal focus of attention occurs when a person brings their attention to the movement itself, such as when a person is asked to focus on keeping their feet horizontal on an unstable surface (internal focus) compared to being asked to focus on keeping the markers on the platform horizontal (external focus) (Wulf, McNevin, et al., 2001; Wulf, Shea, et al., 2001). Postural control was, at one point, thought to simply be a reflexive process through which no cognitive involvement was hypothesised to be necessary; however, more recent research suggests that postural control does necessitate a certain level of cognitive involvement – or attention (Lajoie, Teasdale, Bard, & Fleury, 1993; Woollacott & Shumway-Cook, 2002). Research in this field often makes use of a dual-task (DT) methodology. A DT methodology involves the completion of two tasks simultaneously – in the case of research of postural control, one of these tasks is static or dynamic equilibrium tasks (Lajoie et al., 1993). The DT methodology is used with the assumption of the central resource capacity theory, and in the case of postural control, the postural task (PT) is one task, and the secondary task is usually a cognitive or a motor task, which is hypothesised to increase the attentional demand to a point where either the PT or the secondary task will suffer in performance (Lajoie et al., 1993).

Recent research has shown that postural control seems to improve during a DT condition with adult populations and older adult populations when compared to a single task (Polskaia & Lajoie, 2016; Polskaia, Richer, Dionne, & Lajoie, 2015; Potvin-Desrochers et al., 2017; Richer, Polskaia, & Lajoie, 2017). These experiments have built on the constrained action hypothesis proposed by Wulf and colleagues which states that an external focus allows the motor system to self-organize and be more automatic and efficient than internal focus which intervenes with movement control (McNevin, Shea, & Wulf, 2003; Wulf, McNevin, et al., 2001; Wulf & Prinz, 2001; Wulf, Shea, et al., 2001). Research has shown that as focus of attention becomes more distant to the postural control, the postural control is improved when compared to an internal focus of attention, and a close external focus of attention (McNevin et al., 2003). Researchers have recently built on the constrained action hypothesis by suggesting that if a distant external focus of attention is more efficient than a proximal external focus, that bringing the focus of attention even further away from the posture through a concurrent cognitive task would yield the best results (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). These experiments utilized a concurrent cognitive task during quiet standing to capture a portion of the limited processing capacity through the cognitive task to allow the postural control to be unconscious and therefore automatic (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). The results of such experiments have shown that when limiting the ability to consciously focus on the postural control, by maximizing the attention on a separate task, postural stability and automaticity of postural control seem to improve (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). In addition, Potvin-Desrochers and colleagues (Potvin-Desrochers et al., 2017) found that a concurrent cognitive task increases the irregularity of postural control as evidenced by an increased SampEn. The coupling of an increased postural stability and complexity suggests that by removing the attention from the postural control task, it can become more automatically controlled than when attention is being directed to focus on the PT itself (Potvin-Desrochers et al., 2017).

This DT paradigm has also been used to examine attentional processes in postural control in children. Experiments conducted with children tend to use the same variables as in adults; however, the results are often different. Most experiments report that children's MV increases when faced with a secondary task (Olivier, Cuisinier, Vaugoyeau, Nougier, & Assaiante, 2007, 2010; Reilly, Donkelaar, Saavedra, & Woollacott, 2008; Schmid, Conforto, Lopez, & D'Alessio,

2007) and these researchers have proposed that this increase in MV indicates that children might have a lower attentional capacity, and they might therefore use different postural strategies than adults. Some experiments have found that children's COP amplitude increases (Olivier et al., 2010; Reilly et al., 2008; Schmid et al., 2007) and these authors propose this increased amplitude is a result of the inability of children to maintain a consistent control over their COP, which may be due to children's underdeveloped sensory systems. The authors suggest the increased COP amplitude might be a result of a more open-loop control when faced with an attentionally difficult task such as a DT, rather than a more closed-loop control in a simple task such as static standing (Olivier et al., 2010; Reilly et al., 2008; Schmid et al., 2007). Other authors have found that children's COP amplitude decreases with a DT paradigm (Blanchard et al., 2005; Schaefer, Krampe, Lindenberger, & Baltes, 2008) and these authors have proposed that children utilise a freezing of degrees of freedom strategy in order to maintain upright posture in the more difficult DT. All of these authors propose that children have a lower attentional capacity and suggest that children revert back to either an open-loop control of posture (Olivier et al., 2010; Reilly et al., 2008; Schmid et al., 2007) or they revert back to a freezing of degrees of freedom by over contracting their muscles to maintain their upright stance even when faced with a difficult task. These experiments also support the earlier works of Shumway-Cook & Woollacott (1985, 1990) and Riach & Hayes (1987) which state that children start to demonstrate adult-like postural control strategies between the ages of 7 and 10 years old. This age range however is not as accurate as it could be, as other studies suggest different turning points anywhere between 6 and 12 years old (Cuisinier et al., 2011; Hatzitaki et al., 2002; Hsu et al., 2009; Kirshenbaum et al., 2001; Riach & Hayes, 1987; Riach & Starkes, 1993, 1994). In addition, no research has yet tried to identify the age at which children start demonstrating automatic control of posture, as has been identified in young and older adults (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer, 2018; Richer et al., 2017).

CHAPTER 2: INTRODUCTION

Introduction

Postural control is the skill developed to allow the maintenance of the centre of gravity within the limits of the base of support, with the two goals of orientation and equilibrium: orientation to allow the human body to best navigate its surrounding environment, and equilibrium to maintain an upright position when faced with internal and external perturbations (Massion, 1994). Postural control uses the sensory systems, the central nervous system, and the musculoskeletal system to utilize various strategies to accomplish the outlined goals (Massion, 1994; Shumway-Cook & Woollacott, 1985; Winter, 1995). From a developmental perspective, and for the purpose of this experiment, the authors have focused on the motor skill of upright stance, keeping the centre of gravity within the limits of the base of support outlined by a bipedal stance. This is a celebrated milestone in developmental motor control researchers and parents alike (Shumway-Cook & Woollacott, 1985).

While postural control has been considered a mostly unconscious process, research has shown that cognitive attention is required in the performance of postural control (Lajoie et al., 1993; Woollacott & Shumway-Cook, 2002). Woollacott & Shumway-Cook (Woollacott & Shumway-Cook, 2002) have defined attention as the capacity to process information. A common method of observing the attentional demands of postural control is the DT methodology. A DT methodology assumes that 1) there is a limited central processing capacity within the central nervous system; 2) each task requires part of that limited capacity, and 3) if both tasks share the same processing capacity, they might exceed the limited processing capacity and a decline in performance will ensue (Kahneman, 1973). These assumptions are in line with the central-resource capacity theory which was adopted as a conceptual framework in this thesis. Recent research has shown that postural control seems improve with adult populations and older adult populations through the use of a DT methodology when compared to a simple PT (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). These authors built on the constrained action hypothesis proposed by Wulf and colleagues which states that an external focus allows the motor system to self-organize and be more automatic and efficient than internal focus which intervenes and interferes with movement control (McNevin et al., 2003; Wulf, McNevin, et al., 2001; Wulf & Prinz, 2001; Wulf, Shea, et al., 2001). They build on this theory suggesting that, if a distal external focus of attention is more efficient than a proximal external focus, then further distancing the focus of attention from the posture would yield the best results (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). These experiments make use of a concurrent cognitive task during quiet standing to encourage the use of the limited processing capacity to address the cognitive task, which would in turn allow the postural control to be unconscious and therefore automatic (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017).

The present experiment focused on the attention allotted to postural control in children in two parts. The first part was focused on the postural stability of children aged 6-7, 8-9, and 10-11 years old, while the second part focused on children's automaticity of postural control. Research has shown that children might not have completely developed the skill necessary to control their muscular synergies (agonist and antagonist) until the age of 7-10 years old, which could lead to a stronger co-contraction of muscles to control the degrees of freedom (Riach & Hayes, 1987; Shumway-Cook & Woollacott, 1985; Woollacott & Shumway-Cook, 1990). As children's systems develop, their postural control strategies develop with them. Research has shown that as children's somatosensory and vestibular systems mature between the ages of 4 and 9 years old, they go from using a more open-loop type of postural control strategy to a more closed-loop type of postural control strategy (Hatzitaki et al., 2002; Kirshenbaum et al., 2001; Riach & Hayes, 1987; Riach & Starkes, 1993, 1994). An open-loop control does not depend on feedback; whereas, a closed-loop control is readjusting through the sensory system's feedback (Collins & Luca, 1993). Children older than 10 years old develop the ability to combine multiple sources of information, and maintain a descending temporal organization (Assaiante & Amblard, 1995). These developments in postural control have been associated to increases in postural stability as children age, however the precision of age is lacking. These developments might also be linked to the development of automaticity in postural control, but this has not been the subject of previous research.

Purpose

The focus of this research was to determine the effect of a DT condition on postural control in children. Children differ from adults since their various sensory systems (visual, proprioceptive, vestibular) are not yet fully developed, which leads to the utilization of different postural control strategies than adults (Shumway-Cook & Woollacott, 1985; Winter, 1995). For this study, children between the ages of 6 and 11 have been recruited and divided into smaller sub-groups (6-7 years, 8-9 years, 10-11 years), to try to bring into focus, a potential turning point in children's postural automaticity. Since research indicates a change in postural strategies – becoming more evidently adult-like – between the ages of 4 and 11 years old (Kirshenbaum et al., 2001; Riach & Hayes, 1987; Riach & Starkes, 1994; Shumway-Cook & Woollacott, 1985), it would be beneficial to determine if children move from a more conscious control of posture to a more automatic control of posture around this age as well.

Objective

It was the goal of this experiment to investigate the control of posture in children. Specifically, the postural stability and automaticity of postural control were investigated in children aged 6-7, 8-9, and 10-11 years old. The postural stability and automaticity of postural control were investigated in a simple PT, as well as through a DT paradigm.. This research provided further insight into the attentional demands of postural control in children, specifically related to automaticity and stability of postural control.

Hypotheses

It was hypothesised that the postural control of older children would be more stable than that of younger children. This hypothesis was expected to be demonstrated through a smaller sway area, SD of COP, and decreased MV in the older children compared to younger children. It was hypothesised that the postural control of older children would be more automatic than that of younger children. This hypothesis was expected to be demonstrated through an increased MPF, a SampEn closer to 1, and a wavelet transformation demonstrating a greater contribution of higher frequency bands. It was hypothesised that children's postural control, regardless of age, would be more stable, and more automatic in the DT condition than in the control condition.

CHAPTER 3: MANUSCRIPT

Does a Dual-Task Promote a Greater Postural Control Skill in Children Compared to a Single Task?

By

Graydon Paitich

To be submitted to Gait and Posture

Introduction

Postural control is the developed skill to maintain the centre of gravity within the limits of the base of support (Massion, 1994). Postural control requires the sensory systems, the central nervous system, and the musculoskeletal system to utilize various strategies to accomplish the goals of upright balance and appropriate orientation (Massion, 1994; Shumway-Cook & Woollacott, 1985; Winter, 1995). Children differ from adults since their sensory systems (visual, proprioceptive, vestibular) are not yet fully developed, which leads to the utilization of different postural control strategies than adults (Shumway-Cook & Woollacott, 1985; Winter, 1995). For example, research has shown that children might not have completely developed the skill necessary to control their muscular synergies (agonist and antagonist) until the age of 7-10 years old, which could lead to a stronger co-contraction of muscles to control the degrees of freedom (Riach & Hayes, 1987; Shumway-Cook & Woollacott, 1985; Woollacott & Shumway-Cook, 1990). Research has shown that as children's somatosensory and vestibular systems mature (between the ages of 4 and 9 years old) they go from utilizing a more open-loop (ballistic) postural control to a more closed-loop (sensory-guided) postural control (Hatzitaki et al., 2002; Kirshenbaum et al., 2001; Riach & Hayes, 1987; Riach & Starkes, 1993, 1994). An open-loop control does not depend on feedback whereas a closed-loop control is constantly readjusting through the sensory system's feedback (Collins & Luca, 1993).

Attention is defined as the capacity to process information (Woollacott & Shumway-Cook, 2002). The present experiment focused on the role of attention in postural control through a dual-task (DT) condition. Proponents of the DT methodology assume that 1) there is a limited central processing capacity within the central nervous system, 2) each task requires part of that limited capacity, and 3) since both tasks share the same processing capacity, they might exceed the limited processing capacity and a decline in performance will ensue (Kahneman, 1973). Past research has shown that postural control seems to improve under DT conditions (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). Research showing this phenomenon build on the constrained action hypothesis proposed by Wulf and colleagues which states that an external focus allows the motor system to self-organize and be more automatic and efficient than an internal focus which intervenes with movement control (McNevin et al., 2003; Wulf, McNevin, et al., 2001; Wulf & Prinz, 2001; Wulf, Shea, et al., 2001). Researchers showing improved postural control under DT conditions build on this theory suggesting that if a distal external focus of attention is more efficient than a proximal external focus, then further removing the focus of attention from posture would yield the best results (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). These authors confirmed this hypothesis in both young and older adults through the use of a DT methodology (Polskaia & Lajoie, 2016; Polskaia et al., 2015; Potvin-Desrochers et al., 2017; Richer et al., 2017). This experiment was focused on observing any changes in postural stability and automaticity through the introduction of a concurrent cognitive task. This has been scarcely studied in children.

Objective

The goal of this experiment was to investigate the control of posture in children aged 6-7, 8-9, and 10-11 years in a PT and a DT condition. Children's postural control was investigated through measures of stability and automaticity.

Hypothesis

It was hypothesised that the postural control of older children would be more automatic than that of younger children. It was hypothesised that the postural control of older children would be more stable than that of younger children. It was hypothesised that children's postural control, regardless of age, would be more stable, and more automatic in the DT condition than in the control.

Methods

Participants

For this experiment, 28 participants were recruited, with eleven participants between the ages of 6-7 years, seven participants between the ages of 8-9 years, and ten participants between the ages of 10-11 years. One participant was not included in the analysis due to their abnormal results (more than ± 3 SD from the average), leaving six participants between the ages of 8-9 and 27 total subjects. Through a G*Power analysis (Faul, Erdfelder, Lang, & Buchner, 2007), it was determined that the minimum total number of participants for finding significance is 24. These participants were recruited through convenience sampling from three sporting organizations, and through word of mouth. Participants completed a brief health questionnaire to ensure no sensory, neuromuscular, or cognitive deficits. A parent/legal guardian signed an informed consent form prior to experimentation, and participants signed an assent form.

Apparatus

The present experiment used an AMTI force platform (ORG-6-1000, Watertown, MA, USA) to measure centre of pressure (COP) data by collecting the projection of ground-reaction forces at a sampling frequency of 500Hz. This experiment also used a computer screen and a PowerPoint presentation for the implementation of the cognitive task.

Dependent variables

Dependent variables included measures of postural performance and postural automaticity. Postural performance measures included the 95% confidence ellipse area (area), the standard deviation of COP (SD), and mean velocity of sway (MV). Postural automaticity measures included the mean power frequency (MPF), the sample entropy (SampEn), and the wavelet transform (wavelet). SampEn is a measure of regularity of sway – the less regular sway is, the more automatic it could be. Wavelet gives an indication of structures used through frequency bandwidth. A moderate frequency band (1.56 – 6.25 Hz) is linked to the use of the proprioceptive system, a low frequency band (0.39 – 1.56 Hz) is linked to the use of the cerebellum, a very low frequency band (0.10 – 0.39 Hz) is linked to the use of the vestibular system, and an ultra-low frequency band (<0.10 Hz) is linked to the use of the visual system.

Procedure

This experiment had three conditions outlined below.

Postural task control: The PT had participants stand still with their feet 2 cm apart and arms relaxed by their sides, while staring at a target 2m in front of them. Participants were standing on the force platform and were instructed to "stand as still as possible while looking at the shape on the screen".

Cognitive task control: The cognitive task was a memory test performed while seated. The memory test involved showing participants a series of shapes through a PowerPoint presentation on a screen 2m in front of them. Participants were instructed to "count how many (specific shapes) you see, in your head, without counting on your fingers or moving your mouth, and tell me your answer at the end". Correct answers were counted as a manipulation check, and if participants answered outside ± 3 from the actual answer, the trial was repeated.

Dual-task: The DT consisted of completing both the cognitive task and the PT simultaneously. Participants were instructed to "Stand as still as possible while counting the number of (shapes) you see, in your head, without counting on your fingers or moving your mouth, and tell me your answer at the end". During the DT condition, participants who answered outside ± 3 from the actual answer was repeated.

Each participant performed a block of 8 trials for each condition. The order of performing the conditions was counterbalanced across participants. Participants were encouraged to take as much rest time as they needed between trials and conditions – a 30 second break and a 3-minute break was suggested between trials and conditions respectively. Each trial lasted 70 seconds.

Data analysis

From the collected COP data, we measured various postural control indicators. We measured area, SD in the antero-posterior (AP) and medio-lateral (ML) directions, MV in AP and ML directions, MPF in AP and ML directions, SampEn in AP and ML directions, and wavelet in AP and ML directions. MATLAB software was used to calculate all variables. Cognitive task results were measured as a control for the attention invested during a DT.

Statistical Analysis

All measures were analyzed for correlations. Since there was only a correlation between area and SD, a MANOVA was not performed. Each measure except area (which has no direction) was analyzed in both directions (ML and AP) by means of a two-way 2 Condition by 3 Group ANOVA. If Mauchly's test of sphericity was violated, a Greenhouse-Geisser correction was performed. Statistical significance was set at $p < .05$. When necessary, Newman-Keuls post-hoc analysis was performed to establish the location of significance with an adjusted p-value when multiple comparisons were performed.

Results

Measures of Performance

Area

The 2 Condition by 3 Group ANOVA yielded a significant main effect of age ($F_{2, 24} = 9.50$, $p < 0.01$, $\eta^2 = 0.44$). Post-hoc analyses revealed that the 6-7-year-old group produced a significantly larger area (12.37 ± 4.66 cm^2) compared to the 8-9-year-old group (6.81 ± 2.28 cm^2) and the 10-11-year-old group (7.20 ± 3.33 cm^2). No statistical difference was found between the PT and the DT. No statistically significant interactions between age and condition were found.

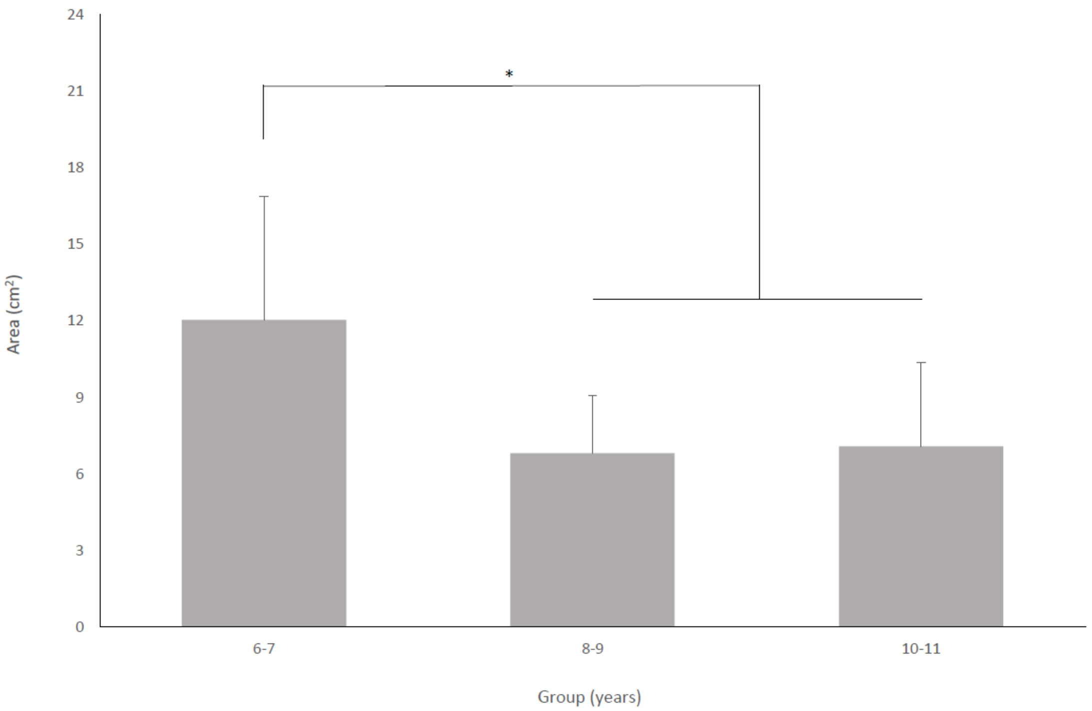


Figure 1. Area (cm^2) across age groups (6-7, 8-9, 10-11 years)

SD

The ANOVA yielded a significant main effect of age ($F_{2, 24} = 7.01$, $p < 0.01$, $\eta^2 = 0.40$). Post-hoc analyses revealed that the 6-7-year-old group produced a significantly larger SD (0.78 ± 0.17 cm) compared to the 8-9-year-old group (0.61 ± 0.15 cm) and the 10-11-year-old group (0.60 ± 0.15 cm). No statistical difference was found between the PT and the DT. No statistical difference was found between the ML direction and the AP direction. No statistically significant interactions between age, condition and direction were found.

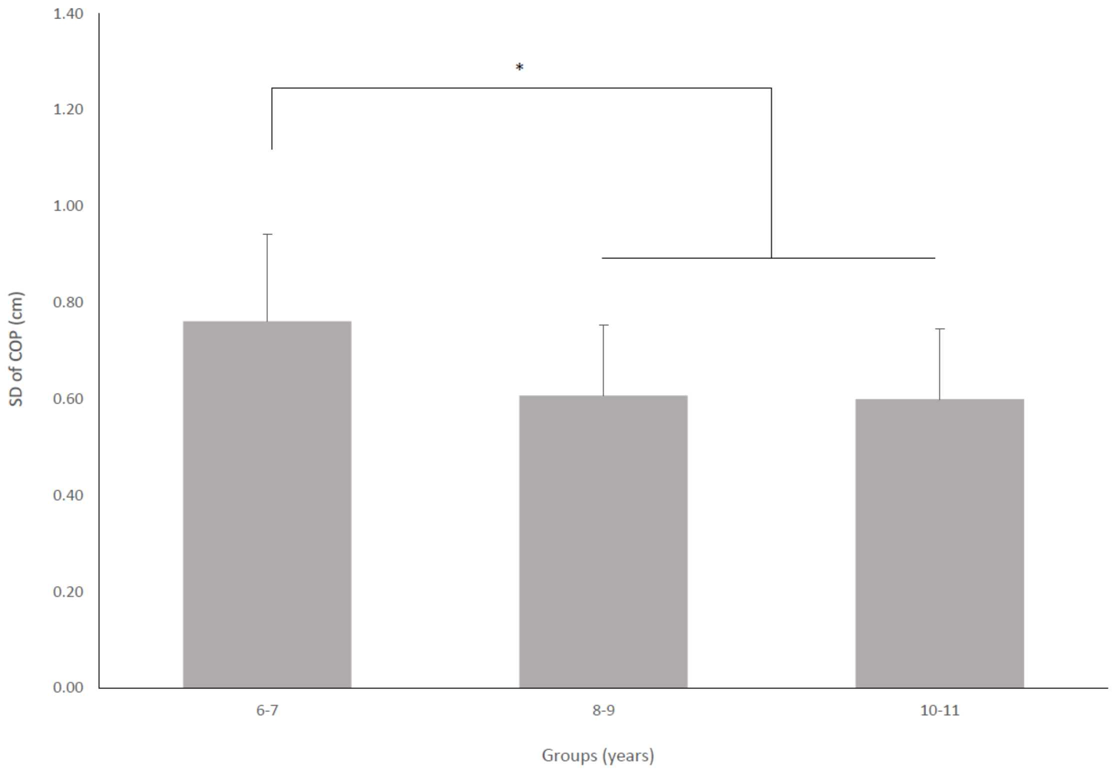


Figure 2. SD of COP (cm) across age groups (6-7, 8-9, 10-11 years)

MV

The ANOVA yielded a significant main effect of age ($F_{2, 24} = 7.76$, $p < 0.01$, $\eta^2 = 0.39$). Post-hoc analyses revealed that the 6-7-year-old group and the 8-9-year-old group produced significantly faster MV (6.60 ± 0.59 cm/s; 6.21 ± 1.01 cm/s) compared to 10-11-year-old group (4.70 ± 1.13 cm/s). The ANOVA yielded a significant main effect of direction ($F_{1,\,24} = 26.72$, $p < 0.01$, $\eta^2 = 0.53$). Post-hoc analyses revealed that the ML direction produced significantly slower MV (5.71 ± 0.90 cm/s) compared to the AP direction (5.96 ± 0.92 cm/s). No statistical difference was found between the PT and the DT. No statistically significant interactions between age, condition and direction were found.

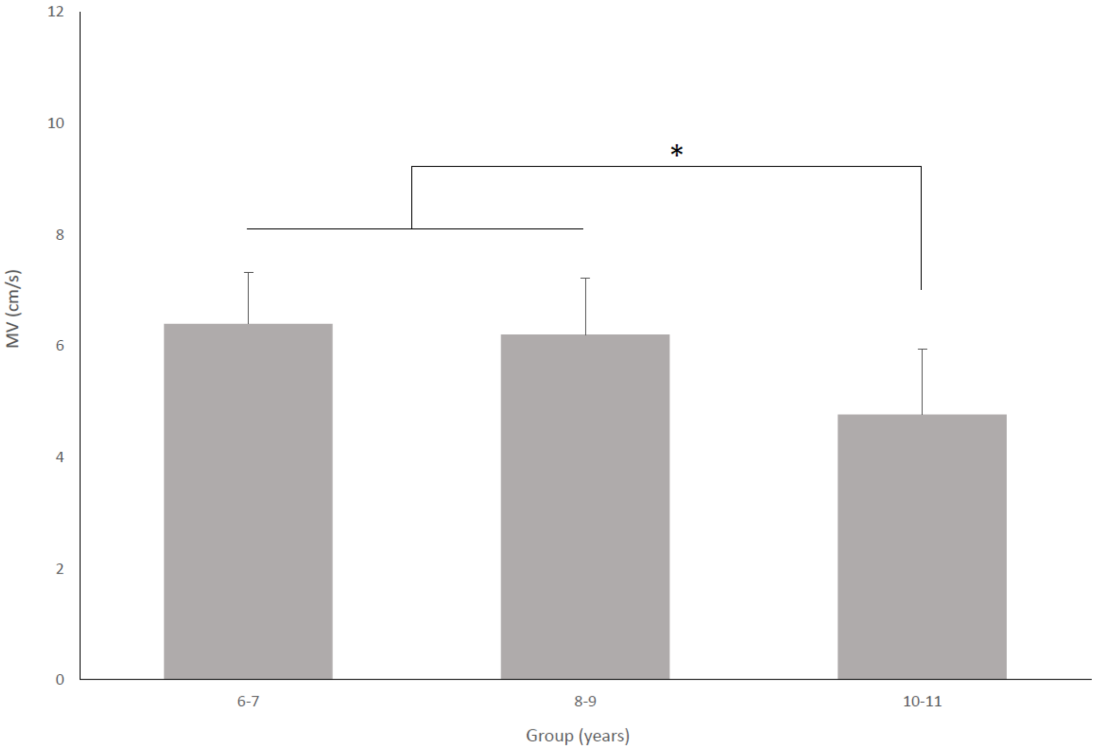


Figure 3. MV (cm/s) across age groups (6-7, 8-9, 10-11 years)

Measures of Automaticity

MPF

The ANOVA yielded a significant main effect of direction ($F_{1,\,24} = 11.31$, $p < 0.01$, $\eta^2 = 0.61$). Post-hoc analyses revealed that the ML direction produced a significantly higher MPF (0.34 ± 0.30 Hz) compared to the AP direction (0.16 ± 0.16 Hz). The ANOVA yielded a trend towards a significant interaction between age, condition, and direction ($F_{2,\,24} = 3.26$, $p < 0.06$, $\eta^2 = 0.24$). This trend shows the 6-7-year-old group and the 8-9-year-old group had a lower MPF in the PT (0.18 ± 0.12 Hz ; 0.19 ± 0.08 Hz) than in the DT (0.32 ± 0.31 Hz ; 0.43 ± 0.59 Hz) whereas the 10-11-year-old group had a higher MPF in the PT (0.24 ± 0.17 Hz) than in the DT (0.16 ± 0.10 Hz). This trend was exacerbated in the 8-9-year-old group's ML direction (0.68 ± 1.06 Hz). No statistical difference was found between the PT and the DT.

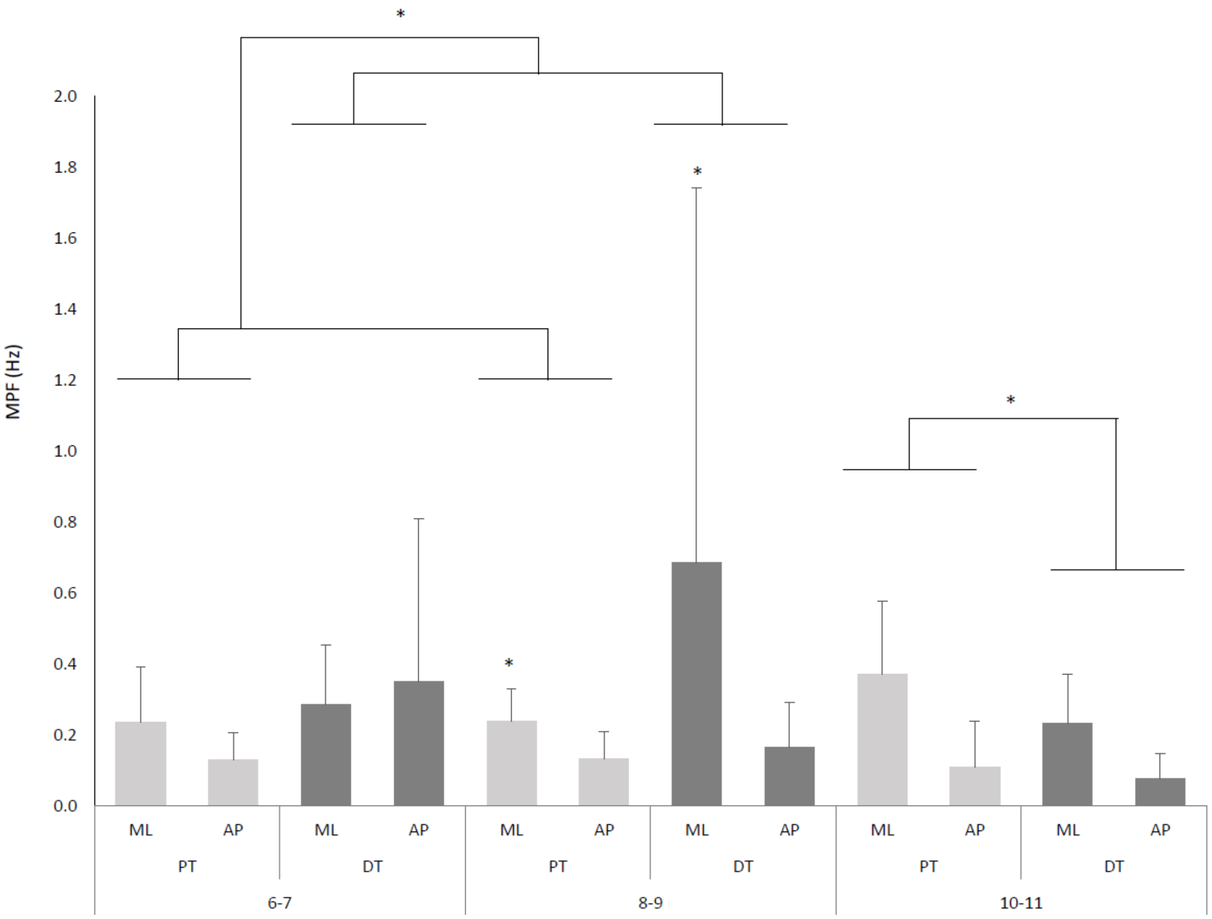


Figure 4. MPF (Hz) in each direction (ML & AP) across age groups (6-7, 8-9, 10-11 years) and conditions (PT & DT)

SampEn

The ANOVA yielded a significant main effect of direction ($F_{1,\ 24} = 4.86$, $p < 0.05$, $\eta^2 = 0.17$). Post-hoc analyses revealed that the ML direction produced significantly smaller measures (0.079 ± 0.22) compared to the AP direction (0.087 ± 0.23). No statistical difference was found between the 6-7-year-old group, the 8-9-year-old group and the 10-11-year-old group. No statistical difference was found between the PT and the DT. No statistically significant interactions between age, condition and direction were found. The main effect of direction was not influenced by age or condition.

Wavelet

The ANOVA yielded a significant main effect of energy band utilization ($F_{3,72} = 722.03$, $p < 0.001$, $\eta^2 = 0.97$). Post-hoc analyses revealed that contribution towards each of the energy bands were significantly different than all others. The contribution towards the medium band was statistically significantly smaller (0.82 ± 1.11 %) compared to the contribution towards the low band (9.13 ± 3.81 %), which had a statistically significantly smaller contribution than towards the very-low band (39.78 ± 5.97 %), which also had a statistically significantly smaller contribution than towards the ultra-low band (48.34 ± 8.27 %).

The ANOVA yielded a significant interaction between group and direction ($F_{2,\ 24} = 7.87$, $p < 0.01$, $\eta^2 = 0.40$). Post-hoc analyses revealed that the ML direction produced a statistically significantly smaller average contribution towards ultra-low to medium bands (23.70 ± 5.11 %) compared to the AP direction (24.20 ± 3.56 %) only in the 8-9-year-old group. Post-hoc analyses also revealed that the 8-9-year-old group produced a statistically significantly smaller average contribution than the 6-7-year-old group and the 10-11-year-old group in both ML (24.87 ± 4.45 % ; 24.79 ± 4.45 %) and AP (24.73 ± 6.13 % ; 24.81 ± 5.02 %) directions. A larger proportion of energy was diverted to higher frequencies than to those associated with postural control.

The ANOVA yielded a trend towards a significant interaction between condition and band contribution ($F_{3,72} = 2.64$, $p < 0.10$, $\eta^2 = 0.10$). Post-hoc analyses revealed that both conditions showed similar contributions for the medium band, the low band, and the very-low band, but that the PT demonstrated a statistically significantly greater contribution towards the ultra-low band (49.87 ± 7.22 %) compared to the DT (46.80 ± 9.31 %). Regardless of age and direction, in the DT condition, children showed a lower contribution to the ultra-low band than in the PT.

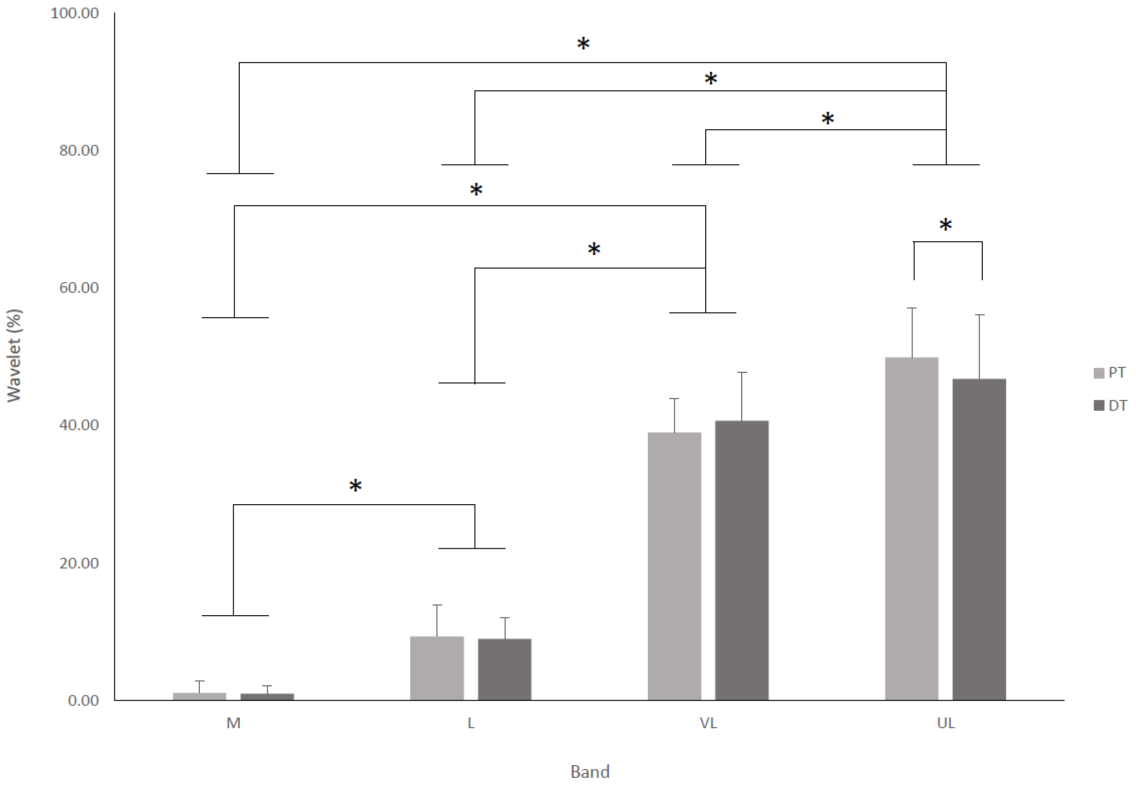


Figure 5. Wavelet band contribution (%) in each condition (PT & DT) across band frequencies (M, L, VL, UL)

Discussion

The objective of this experiment was to determine the postural stability and automaticity in children in a DT condition. The first hypothesis was supported by our results, the second hypothesis was not supported by our results and the third hypothesis was not conclusively supported by our results.

The results supported the first hypothesis since area is larger (Figure 1), SD is higher (Figure 2), and MV is slower (Figure 3) in 6-7-year-olds compared to 8-9-year-olds and 10-11-year-olds. Most literature indicates that older children have more stable posture control than younger children through smaller measures of COP radius or displacement (Figura, Cama, Capranica, Guidetti, & Pulejo, 1991; Mickle, Munro, & Steele, 2011; Rival, Ceyte, & Olivier, 2005), and slower measures of COP speed (Figura et al., 1991; Rival et al., 2005). Research shows that as children get older, their sensory systems (visual, proprioceptive, vestibular) mature and they tend to use different postural control strategies, such as transitioning from an open-loop control of posture to a closed-loop control of posture at some point between 6-8 years old (Assaiante, 2011; Kirshenbaum et al., 2001; Riach & Starkes, 1993, 1994). This maturation of the sensory systems is hypothesized to play an important part in the postural control of children as displayed by an increased postural stability and was supported by the results of this experiment.

The second hypothesis was not supported by the results. Older children did not show a higher MPF, a less regular SampEn, or a higher wavelet band frequency. The MPF results did trend towards a significant age, condition and direction interaction. The 10-11-year-olds decreased their MPF from the PT to the DT, whereas the 8-9-year-olds significantly increased their MPF from the PT to the DT (Figure 4). Results showed that 6-7-year-olds sway large (area & SD) and sway fast (MV). This was exacerbated in the DT condition, as evidenced by the increased frequency of postural adjustment to account for potentially swaying too often near the edge of their base of support (Riach & Starkes, 1993). Conversely, 8-9-year-olds swayed smaller (area & SD of COP) and at a higher frequency (MPF) in the DT condition, demonstrating either an increased automatic control, or an increased muscular co-contraction at the ankle (Woollacott & Shumway-Cook, 1990). The SampEn results did not support automaticity of older children, as they revealed no main effect of age. The 10-11-year-olds had a smaller area and SD, demonstrating a greater skill level, necessary to maintain equilibrium, as evidenced by a slower MV. This skill level was further demonstrated by a decreased MPF in the DT compared to the PT (Figure 4). This could mean that the 10-11-year-olds were more stable in the DT condition, but not necessarily more automatic.

The third hypothesis was not supported by our results. As previously mentioned, MPF was higher in a DT condition than in a PT condition for 6-7-year-olds and for 8-9-year-olds, but not for 10-11-year-olds (Figure 4). SampEn results showed no influence of condition. Wavelet measures showed a statistically significant band frequency and condition interaction. Results demonstrated that all children reported a higher percentage of usage of the ultra-low frequency band in the PT than in the DT (Figure 5). Since the ultra-low band is associated with the visual system, children could have relied less heavily on their visual system in the DT compared to the PT. This result gives no clear indication into the automaticity of the postural control, since no other systems were statistically significantly more utilized. This result does, however, provide some insight into the control strategies used by children in postural control.

Conclusion

In summary, our hypothesis that older children are more stable than younger children was confirmed; our hypothesis that older children would have a more automatic control of posture was rejected, and our hypothesis that a DT condition would illicit a more automatic postural response was not confirmed. Our results help to support the research conducted by Kirshenbaum (2001), and Riach and colleagues (1994) suggesting that older children move from a ballistic control of posture to a sensory-guided control of posture, but may not have enough experience with this new strategy to allow it to be fully automated. It would be important to conduct further research focusing on automaticity measures with older children and adolescents (ex. 12-15 years old). Automaticity studies in children could help enlighten the debate as to whether it could be a detriment to learning for children to be asked to sit still, to stand still, or to stand and move freely.

Bibliography

Assaiante, C. (2011). Action and representation of action during childhood and adolescence: A funtional approach. *Neurophysiologie Clinique*, *42*, 43–51. https://doi.org/10.1016/j.neucli.2011.09.002

Assaiante, C., & Amblard, B. (1995). An ontogenetic model for the sensorimotor organization of balance control in humans. *Human Movement Science*, *14*(1), 13–43. https://doi.org/10.1016/0167-9457(94)00048-J

Assaiante, C., Mallau, S., Viel, S., Jover, M., & Schmitz, C. (2005). Development of postural control in healthy children: A functional approach. *Neural Plasticity*, *12*(2–3), 109–118. https://doi.org/10.1155/NP.2005.109

Blanchard, Y., Carey, S., Coffey, J., Cohen, A., Harris, T., Michlik, S., & Pellecchia, G. L. (2005). The influence of concurrent cognitive tasks on postural sway in children. *Pediatric Physical Therapy*, *17*(3), 189–193. https://doi.org/10.1097/01.PEP.0000176578.57147.5d

Chagdes, J. R., Rietdyk, S., Haddad, J. M., Zelaznik, H. N., Raman, A., Rhea, C. K., & Silver, T. A. (2009). Multiple timescales in postural dynamics associated with vision and a secondary task are revealed by wavelet analysis. *Experimental Brain Research*, *197*(3), 297–310. https://doi.org/10.1007/s00221-009-1915-1

Collins, J. J., & Luca, C. J. De. (1993). Open-loop and closed-loop control of posture : A random-walk analysis of center-of-pressure trajectories. *Experimental Brain Research*, *95*, 308–318.

Cuisinier, R., Olivier, I., Vaugoyeau, M., Nougier, V., & Assaiante, C. (2011). Reweighting of sensory inputs to control quiet standing in children from 7 to 11 and in adults. *PLoS ONE*, *6*(5). https://doi.org/10.1371/journal.pone.0019697

Donker, S. F., Roerdink, M., Greven, A. J., & Beek, P. J. (2007). Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Experimental Brain Research*, *181*(1), 1–11. https://doi.org/10.1007/s00221-007-0905-4

Doyle, R. J., Hsiao-Wecksler, E. T., Ragan, B. G., & Rosengren, K. S. (2007). Generalizability of center of pressure measures of quiet standing. *Gait and Posture*, *25*(2), 166–171. https://doi.org/10.1016/j.gaitpost.2006.03.004

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Figura, F., Cama, G., Capranica, L., Guidetti, L., & Pulejo, C. (1991). Asessment of static balance in children. *Journal of Sports Medicine and Physical Fitness*, *31*(2), 233–242.

Hatzitaki, V., Zlsi, V., Kollias, I., & Kioumourtzoglou, E. (2002). Perceptual-motor contributions to static and dynamic balance control in children. *Journal of Motor Behavior*, *34*(2), 161–170. https://doi.org/10.1097/01.PEP.0000072447.53166.9D

Hsu, Y. S., Kuan, C. C., & Young, Y. H. (2009). Assessing the development of balance function in children using stabilometry. *International Journal of Pediatric Otorhinolaryngology*, *73*(5), 737–740. https://doi.org/10.1016/j.ijporl.2009.01.016

Kahneman, D. (1973). Attention and effort. *Englewood Cliffs, NJ*. https://doi.org/10.2307/1421603

Kirshenbaum, N., Riach, C. L., & Starkes, J. L. (2001). Non-linear development of postural control and strategy use in young children: A longitudinal study. *Experimental Brain Research*, *140*(4), 420–431. https://doi.org/10.1007/s002210100835

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1993). Attentional demands for static and dynamic equilibrium. *Experimental Brain Research*, *97*(1), 139–144. https://doi.org/10.1007/BF00228824

Massion, J. (1994). Postural control system. *Current Opinion in Neurobiology*, *4*(6), 877–887. https://doi.org/10.1016/0959-4388(94)90137-6

Mccann, R. S., & Johnston, J. C. (1992). Locus of the single-channel bottleneck in dual-task interference. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(2), 471–484.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research*, *67*(1), 22–29. https://doi.org/10.1519/JSC.0b013e31823f275c

McNevin, N. H., & Wulf, G. (2002). Attentional focus on supra-postural tasks affects postural control. *Human Movement Science*, *21*(2), 187–202. https://doi.org/10.1016/S0167-9457(02)00095-7

Mickle, K. J., Munro, B. J., & Steele, J. R. (2011). Gender and age affect balance performance in primary school-aged children. *Journal of Science and Medicine in Sport*, *14*(3), 243–248. https://doi.org/10.1016/j.jsams.2010.11.002

Olivier, I., Cuisinier, R., Vaugoyeau, M., Nougier, V., & Assaiante, C. (2007). Dual-task study of cognitive and postural interference in 7-year-olds and adults. *NeuroReport*, *18*(8), 817–

821. https://doi.org/10.1097/WNR.0b013e3280e129e1

Olivier, I., Cuisinier, R., Vaugoyeau, M., Nougier, V., & Assaiante, C. (2010). Age-related differences in cognitive and postural dual-task performance. *Gait and Posture*, *32*(4), 494–499. https://doi.org/10.1016/j.gaitpost.2010.07.008

Olivier, I., Palluel, E., & Nougier, V. (2008). Effects of attentional focus on postural sway in children and adults. *Experimental Brain Research*, *185*(2), 341–345. https://doi.org/10.1007/s00221-008-1271-6

Palmieri, R. M., Ingersoll, C. D., Stone, M. B., & Krause, B. A. (2002). Center-of-pressure parameters used in the assessment of postural control. *Journal of Sport Rehabilitation*, *11*(1), 51–66. https://doi.org/10.1123/jsr.11.1.51

Polskaia, N., & Lajoie, Y. (2016). Reducing postural sway by concurrently performing challenging cognitive tasks. *Human Movement Science*, *46*, 177–183. https://doi.org/10.1016/j.humov.2015.12.013

Polskaia, N., Richer, N., Dionne, E., & Lajoie, Y. (2015). Continuous cognitive task promotes greater postural stability than an internal or external focus of attention. *Gait and Posture*, *41*(2), 454–458. https://doi.org/10.1016/j.gaitpost.2014.11.009

Potvin-Desrochers, A., Richer, N., & Lajoie, Y. (2017). Cognitive tasks promote automatization of postural control in young and older adults. *Gait and Posture, 57*(April), 40–45. https://doi.org/10.1016/j.gaitpost.2017.05.019

Quek, J., Brauer, S. G., Clark, R., & Treleaven, J. (2014). New insights into neck-pain-related postural control using measures of signal frequency and complexity in older adults. *Gait* *and Posture*, *39*(4), 1069–1073. https://doi.org/10.1016/j.gaitpost.2014.01.009

Reilly, D. S., Donkelaar, P. Van, Saavedra, S., & Woollacott, M. H. (2008). Executive function of attention. *Journal of Motor Behavior*, *40*(2), 90–102. https://doi.org/10.3200/JMBR.40.2.90-102.Interaction

Riach, C. L., & Hayes, K. C. (1987). Maturation of postural sway in young children. *Developmental Medicine and Child Neurology*, *29*, 650–658. https://doi.org/10.1111/j.1469-8749.1987.tb08507.x

Riach, C., & Starkes, J. (1993). Stability limits of quiet standing postural control in children and adults. *Gait & Posture*, *1*(2), 105–111. https://doi.org/10.1016/0966-6362(93)90021-R

Riach, C., & Starkes, J. (1994). Velocity of centre of pressure excursions as an indicator of postural control systems in children. *Gait and Posture, 2*(3), 167–172. https://doi.org/10.1016/0966-6362(94)90004-3

Richer, N. (2018). Postural Mechanisms in Young and Older Adults. (PhD). University of Ottawa. Ottawa. Canada.

Richer, N., Polskaia, N., & Lajoie, Y. (2017). Continuous Cognitive Task Promotes Greater Postural Stability than an Internal or External Focus of Attention in Older Adults. *Experimental Aging Research*, *43*(1), 21–33. https://doi.org/10.1080/0361073X.2017.1258214

Rival, C., Ceyte, H., & Olivier, I. (2005). Developmental changes of static standing balance in children. *Neuroscience Letters*, *376*(2), 133–136. https://doi.org/10.1016/j.neulet.2004.11.042

Schaefer, S., Krampe, R. T., Lindenberger, U., & Baltes, P. B. (2008). Age differences between children and young adults in the dynamics of dual-task prioritization: Body (balance) versus mind (memory). *Developmental Psychology*, *44*(3), 747–757. https://doi.org/10.1037/0012-1649.44.3.747

Schmid, M., Conforto, S., Lopez, L., & D'Alessio, T. (2007). Cognitive load affects postural control in children. *Experimental Brain Research*, *179*(3), 375–385. https://doi.org/10.1007/s00221-006-0795-x

Shumway-Cook, A., & Woollacott, M. H. (1985). The growth of stability. *Journal of Motor Behavior*, *17*(2), 131–147. https://doi.org/10.1080/00222895.1985.10735341

Stins, J. F., Michielsen, M. E., Roerdink, M., & Beek, P. J. (2009). Sway regularity reflects attentional involvement in postural control: Effects of expertise, vision and cognition. *Gait and Posture, 30*(1), 106–109. https://doi.org/10.1016/j.gaitpost.2009.04.001

Stins, J. F., Roerdink, M., & Beek, P. J. (2011). To freeze or not to freeze? Affective and cognitive perturbations have markedly different effects on postural control. *Human Movement Science, 30*(2), 190–202. https://doi.org/10.1016/j.humov.2010.05.013

Wickens, C. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*(2), 159–177.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait and Posture*, *3*(4), 193–214. https://doi.org/10.1016/0966-6362(96)82849-9

Wolff, D. R., Rose, J., Jones, V. K., Bloch, D. A., Oehlert, J. W., & Gamble, J. G. (1998). Postural balance measurements for children and adolescents. *Journal of Orthopaedic*

Research, *16*(2), 271–275. https://doi.org/10.1002/jor.1100160215

Woollacott, M. H., & Shumway-Cook, A. (1990). Changes in posture control across the life span--a systems approach. *Physical Therapy*, *70*(12), 799–807.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait and Posture*, *16*(1), 1–14. https://doi.org/10.1016/S0966-6362(01)00156-4

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Research in Psychology*, *54*(4), 1143–1154. https://doi.org/10.1080/0272498014300011

Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review*, *8*(4), 648–60. https://doi.org/10.3758/BF03196201

Wulf, G., Shea, C., & Park, J.-H. (2001). Attention and motor performance: Preferences for and advantages of an external focus. *Research Quarterly for Exercise and Sport*, *72*(4), 335–344. https://doi.org/10.1080/02701367.2001.10608970

Wulf, G., Töllner, T., & Shea, C. H. (2007). Attentional focus effects as a function of task Difficulty. *Research Quarterly for Exercise and Sport*, *78*(4), 257–264. https://doi.org/10.5641/193250307X13082490461183

CHAPTER 4: GENERAL DISCUSSION

Whereas research has shown that younger and older adults have a more automatic control of posture when faced with a DT condition (Polskaia & Lajoie, 2016; Potvin-Desrochers et al., 2017; Richer, 2018; Richer et al., 2017), this has not been studied in children in previous literature. The focus of this experiment was to measure the postural control of children through variables derived from the COP displacements, with a particular attention given to signs of postural automaticity. The first part of the objective of this experiment was to determine the postural stability in children aged 6-7 years old, 8-9 years old, and 10-11 years old, in a PT condition compared to a DT condition. The second part of the objective of this experiment was to determine the postural automaticity in children aged 6-7 years old, 8-9 years old, and 10-11 years old, in a PT condition compared to a DT condition. The first hypothesis was that older children would have a more stable postural control than younger children in all conditions, and this hypothesis was supported by our results. The second hypothesis was that older children would have a more automatic control of posture in all conditions, and this hypothesis was not supported by our results. The third hypothesis was that the DT condition would cause all children to show a more automatic control of posture, and this hypothesis was not supported by our results.

Postural control in children

When considering postural control, there are many aspects to consider. Some important systems to consider are the musculoskeletal system, the sensory system, and the central nervous system (Massion, 1994; Winter, 1995). Previous research conducted with children has concluded that musculoskeletal components of postural control such as height, weight, and foot size, are correlated to age (Riach & Hayes, 1987; Riach & Starkes, 1993, 1994). For this reason, this thesis did not focus on the musculoskeletal components of postural control. The sensory systems in children, and the development of such systems have also been studied in children (Assaiante & Amblard, 1995). Research has shown that the sensory systems develop throughout childhood, but that children appear to be most dependent on their vestibular system in infancy, followed by either a dependence on their proprioceptive or visual system in the early stages of upright stance, to the integration of all three systems in the later stages of upright stance (Assaiante & Amblard, 1995). The mechanism of postural control which has been less studied in children is that of the central nervous system, which would play an important part in the automaticity of postural control, as seen through the management of attentional resources (Kahneman, 1973; Wickens, 2002). Automaticity has, to date only been observed in one study in children. In this experiment, children's (11-13 years old) expertise was measured using SampEn. In this experiment, Stins, Michielsen, Roerdink & Beek (2009) compared non-dancers to dancers, and proposed the measure of SampEn would give an indication of expertise and attentional demand. The authors found that dancers showed a higher SampEn which is an indication of a more irregular sway pattern, confirming that experts (dancers) might show a higher irregularity of sway than non-experts (non-dancers) (Stins et al., 2009). They also found that when faced with a DT, SampEn data showed higher results than in a single-task experiment for dancers with their eyes closed, and for non-dancers with their eyes open (Stins et al., 2009). The authors suggest this may be an indication of a ceiling effect of the benefits of removing the attention from postural sway in an easier condition (eyes open) for dancers, but this same condition was appropriate in difficulty for the non-dancers, who showed increased regularity with their eyes closed, which might be an indication of a regression, and increased PT prioritization in non-dancers (Stins et al., 2009). These results are in line with Wulf, Töllner & Shea (2007) which suggest that children can enhance their motor performance only if the task was difficult enough. The results shown by Sins and colleagues (Stins et al., 2009) suggests that some children may show an increased automaticity of postural control when faced with a DT condition. This thesis sought to build on these results, by measuring for automaticity, at ages where children start developing postural control strategies resembling mature, adult-like strategies.

Postural stability in older children

The first hypothesis was supported by results of this experiment. This experiment demonstrated that children aged 6-7 years and 8-9 years had a larger sway area and a higher SD of COP than children aged 10-11 years. In addition, children aged 6-7 years demonstrated a faster MV compared to those aged 8-9 and 10-11 years. These results supported the hypothesis that older children have better postural stability than younger children. These results are in accordance with previous literature (Figura, Cama, Capranica, Guidetti, & Pulejo, 1991; Mickle, Munro, & Steele, 2011; Olivier et al., 2010; Reilly et al., 2008; Riach & Hayes, 1987; Rival, Ceyte, & Olivier, 2005; Shumway-Cook & Woollacott, 1985; Wolff et al., 1998; Woollacott & Shumway-Cook, 1990). Of particular interest are the authors who have conducted experiments with children of a similar age range or age categories as presented in this experiment (Figura et al., 1991; Mickle et al., 2011; Rival et al., 2005). Figura and colleagues (1991) showed that 10-year-olds had statistically significantly more stable postural control than 6-year-olds, but not of 8-year-olds, as evidenced by a slower mean speed of COP displacement and a smaller mean radius of COP displacements. Rival and colleagues (2005) demonstrated that 10-year-olds had statistically significantly more stable posture than 8-year-olds, as evidenced by a smaller range of COP and a slower speed of COP. They also demonstrated that 10-year-olds did not have a statistically significantly smaller range of COP than 6-year-olds, but they did have a statistically significantly slower speed of COP than 6-year-olds (Rival et al., 2005). Mickle and colleagues (2011) demonstrated that 10-year-old children had a more stable postural control than 8-year-olds as demonstrated by a smaller sway path.

Previous research clearly shows that older children generally have a more stable postural control than younger children, with slight variations in measures, and this experiment complements the previous research.

Research has demonstrated that the maturation of children's sensory systems (visual, vestibular, proprioceptive) occurs over time, and that they develop different postural control strategies as a result of this immaturity (Assaiante & Amblard, 1995; Kirshenbaum et al., 2001; Riach & Starkes, 1994). An important transition is from an open-loop control of posture to a closed-loop control of posture which appears to occur at some point between 6-8 years old (Assaiante, 2011; Kirshenbaum et al., 2001; Riach & Starkes, 1993, 1994). It has been demonstrated in research that this maturation of sensory systems plays an important part in the postural control of children as displayed by an increased postural stability through measures of MV (Figura et al., 1991; Kirshenbaum et al., 2001; Riach & Starkes, 1994; Rival et al., 2005). The postural performance results in this experiment might help to explain why there is some discrepancy when comparing age groups, but that 10-year-olds generally have a more stable postural control than their younger counterparts. Whereas 10-11-year-olds had a smaller area (Figure 1), SD (Figure 2), than the 6-7-year-olds and the 8-9-year-olds, they only had a smaller MV than the 6-7-year-olds (Figure 3).

Postural automaticity in older children

The second hypothesis was not supported by the results of this experiment. This experiment demonstrated no significant main effect of age on MPF, SampEn, or wavelet band utilization. The results did indicate a trend towards the significant interaction of age, condition, and direction (Figure 4). This trend indicated that children aged 10-11 years had a decreased MPF in the DT condition compared to the PT condition, whereas children aged 6-7 and 8-9 years demonstrated an increased MPF in the DT condition compared to the PT condition. The results of this experiment show that the MPF is higher in the DT condition for 6-7- and 8-9-year-olds, and particularly for that of the 8-9-year-olds in the ML direction. An increased MPF has been hypothesised to represent an increased automaticity in postural control, particularly when combined with a decreased sway amplitude and SD of COP (McNevin & Wulf, 2002). Our results demonstrate that sway area and SD of COP are smaller in 8-9-year-olds and 10-11-year-olds than in 6-7-year-olds, but that there is no main effect of age in the MPF. These results could suggest a freezing strategy, however sway area and SD of COP measures should prove to be smaller if the freezing strategy is employed (Stins et al., 2011), which was not the case in this experiment.

Another possible strategy of postural control used could be the ballistic (open-loop) or the sensory-guided (closed-loop) control. One measure which has previously been used to help determine whether a child is utilizing an open-loop control of posture or a closed-loop control of posture is the MV (Kirshenbaum et al., 2001; Riach & Starkes, 1994). These authors propose that a decrease in MV is an indication of a maturation of the sensory system which allows for a more sensory-guided (closed-loop) control of posture (Kirshenbaum et al., 2001; Riach & Starkes, 1994). When observing the MV results from this experiment, it is shown that 10-11-year-olds have a significantly slower MV than 6-7- and 8-9-year-olds, which is in line with the previous literature suggesting 8-years old was a turning point for the maturation of the sensory system (Kirshenbaum et al., 2001; Riach & Starkes, 1994).

Taking all these measurements into consideration, it was observed that 6-7-year-olds sway large (area & SD of COP) and sway fast, which was exacerbated in the DT condition, as evidenced by the increased frequency of postural adjustment (Figure 4). This increase in MPF in conjunction with an increased sway area and SD of COP demonstrates that they often sway near the edge of their base of support. The 8-9-year-olds followed the anticipated measures of having a smaller sway (area & SD of COP) as well as an increased frequency of postural adjustment in the DT condition, demonstrating either an increased automatic control, or a restrictive control of posture through increased muscular co-activation. The SampEn results reveal that it is more likely to have been contributed by an increased muscular co-contraction than an increased automaticity, as the SampEn results show no effect from age. The 10-11-year-olds had a smaller sway (area & SD of COP) and were demonstrated to have a greater skill in the maintenance of their COG within the centre of their base of support as evidenced by a slower MV, which is exacerbated in the DT condition as evidenced by a smaller MPF. This could mean that the 10-11-year-olds are more stable in the DT condition, but our SampEn results suggested that their control is not more automatic. Instead it is likely that our results helped to supported the research conducted by Kirshenbaum, Riach and colleagues (Kirshenbaum et al., 2001; Riach & Starkes, 1994) suggesting that older children move from a ballistic control of posture to a sensory-guided control of posture, but may not have enough experience with this new strategy to allow it to be fully automated.

Postural automaticity as a result of dual-task conditions

The third hypothesis was not conclusively supported by the results of this experiment. This experiment made use of the MPF, SampEn, and wavelet transformation to create a more complete picture of automaticity. As previously mentioned, children aged 10-11 years old demonstrated a decreased MPF in the DT compared to the PT, but children aged 6-7 and 8-9 demonstrated an increased MPF in the DT compared to the PT (Figure 4). This could suggest a decreased automaticity for 10-11-year-old children. However, the SampEn results showed no influence of condition which indicates that the change in MPF were more likely due to the increased complexity of the task for a given age. Wavelet measures showed a trend towards a statistically significant band frequency and condition interaction. The wavelet results demonstrated that the contribution of the ultra-low frequency band was smaller in the DT condition than in the PT condition, regardless of age (Figure 5). Since the ultra-low frequency band is associated with the visual system (Quek et al., 2014), these results suggest that children might be less dependent on their visual system in a DT condition when compared to a PT condition, regardless of age. This interpretation supports the idea of the re-weighting of sensory information (Chagdes et al., 2009). In the DT condition, children may have a heavier weighting of the visual system towards completing the cognitive task, leaving the other sensory systems to take greater importance in the postural stance. This result gives no clear indication into the automaticity of the postural control, since no other higher frequency bands were statistically significantly more utilized, suggesting children relied less on their visual system during the DT condition, but did not solicit any other systems significantly more. This result does however provide some insight into the development of the sensory system and abilities of children between the ages of 6 and 11 years old to re-weight the sensory information.

The wavelet analysis showed that regardless of age, the highest contributor was the ultra-low frequency band, followed by the very-low frequency band, followed by the low frequency band, then the moderate frequency band. This corresponds to the largest recruited system being the visual system, followed by the vestibular system, followed by the cerebellum, then the proprioceptive system. This could be seen as an incongruity with the research by Assaiante & Amblard (1995) who suggest that 6-10-year-olds rely more heavily on their vestibular system, and are in a descending temporal organization. The authors suggest a transient neglect of the visual system in this period of time, which is not demonstrated though these wavelet results. It is possible however that this transient neglect of peripheral visual information is not as relevant in the PT than in the DT. Since participants may have been more consciously focused on their posture, they may have increased the amount of attention paid to the visual cues. In addition, participants were asked to focus on a visual target during postural control tasks, which could have had an influence on the results.

Postural strategy

In addition to these results, participants had a faster MV, a smaller MPF, and a larger SampEn in the AP direction than in the ML direction. The ML direction of postural sway is controlled primarily by the hips, whereas the AP direction of postural sway is primarily controlled by the ankles. The faster MV and decreased MPF of the AP direction could be an indication that in the ankles, children make fewer adjustments, at a higher speed. With no difference in the SD of COP, it is difficult to suggest a specific strategy of control, however it may be an indication of an open-loop control (Riach & Starkes, 1994). On the other hand, in the ML direction, the slower MV and increased MPF could be an indication of a closed-loop type of control (Riach & Starkes, 1994). SampEn results demonstrated that postural adjustments were less regular in the AP direction than in the ML direction which could indicate more automaticity, however both measures were still quite close to 0, which indicates they were both still quite regular. It might be beneficial to conduct a similar experiment with the addition of a measure to determine if postural adjustments return to a point of origin or not to help determine the open- or closed-loop type of control (Collins & Luca, 1993), such as rambling-trembling, used by Richer (Richer, 2018) to determine supra-spinal and reflexive components. These results might support the work done by Shumway-Cook & Woollacott (Shumway-Cook & Woollacott, 1985) who suggest there is an increased importance of the ankle proprioceptive receptors in 7-10-year-olds.

Dual-Task from a multiple-resource theory of attention perspective

Whereas this thesis has been conducted from the assumptions held by the central resource theory of attention (Kahneman, 1973) since this is the prevailing theory in DT methodology in postural control research, the interpretations might be different when considering the multiple-resource theory of attention (Wickens, 2002). Contrary to the central-resource theory, the multiple-resource theory stipulated that there are different “pools” of attention available for different kinds of activities (Wickens, 2002). Since most of the results indicated no influence of condition on measures, it might be hypothesised that children operate within the confines of a multiple-resource theory – the attention of a PT was derived from one pool of attention, whereas the attention necessary for the cognitive task was derived from a different pool of attention. That being said, there was in interaction of age, condition and direction on the MPF (Figure 4) This result demonstrated that children aged 6-7 and 8-9 years had an increased MPF in the DT condition compared to the PT condition, whereas children aged 10-11 years had a decreased MPF in the DT compared to the PT condition. This result could be interpreted from a sensory integration perspective, suggesting the children aged 10-11 performed better in the DT condition on account of their ability to better integrate sensory information coming from the cognitive task compared to their younger counterparts. This explanation is however unlikely, as demonstrated through the wavelet results (Figure 5), suggesting that all children relied less heavily on their visual system in the DT condition compared to the PT condition, not only the 10-11-year-olds. The current research did not demonstrate strong enough evidence to support either theory of attention, but that it does support research demonstrating the development of the closed-loop control of posture.

CHAPTER 5: CONCLUSION

In summary, our hypothesis that older children would be more stable than younger children was supported by our results, our hypothesis that older children would have a more automatic control of posture was not supported by our results, and our hypothesis that a DT condition would illicit a more automatic postural response was not conclusively supported by our results. Our results demonstrated that older children were more stable in their postural control than younger children, yet none of our measures clearly indicated an increased automaticity in postural control in the DT condition. With a limited attentional capacity lens, this research supports previous literature which suggests that children do not have the same attentional capacity as adults, however it puts into question the specific age-range of 7-10 years old demonstrating the beginning of adult-like postural control. This research would suggest that 10-11 years old is a more appropriate age-range at which children demonstrate a significant improvement in postural control. This research also supports previous research suggesting that older children demonstrate a closed-loop control of posture, whereas younger children demonstrate a more open-loop control of posture (Kirshenbaum et al., 2001; Riach & Starkes, 1994). This research also supports research which suggests that around 8 years of age, children might be starting to develop the closed-loop control of posture, but might revert back to an open-loop control of posture if sufficiently challenged, causing more variability of measures in children this age (Olivier, Palluel, & Nougier, 2008; Riach & Starkes, 1994; Rival et al., 2005).

Limitations of this research include the limited information collected from participants – particularly their involvement in in sporting activities. This has been shown to influence postural control in some activities such as dance (Stins et al., 2009). Further limitations include the inconsistent break times between trials, conditions, and children. This occurred because children were asked to take breaks as long as necessary to avoid cognitive or physical fatigue, and some children needed more time than others. Similarly, this experiment was conducted under the assumption that the cognitive level of participants within given groups would be similar. This is unlikely the case, and a preliminary testing session could have been conducted to determine the children's cognitive level and given them an individualised cognitive task to better solicit their attention.

Since this research has not found any conclusive evidence of automaticity of postural control in children aged 6-7, 8-9, or 10-11 years old, further studies should investigate the automaticity of postural control in children and adolescents, say aged 12-15 years old. Research in automaticity of postural control can be important in the field of academia, and obesity. Children spend the majority of their day at school. With the rise of child obesity, school boards might consider putting in stand-up desks for children in schools. Research into automaticity of postural control could be of use in discussions of whether children's learning might be negatively affected by these stand-up desks, or any other task they are given at school while learning (sit still, stand still, etc.) as any of these tasks could have a negative influence on their aptitude to pay attention to curriculum material.

BIBLIOGRAPHY

Assaiante, C. (2011). Action and representation of action during childhood and adolescence: A funtional approach. *Neurophysiologie Clinique*, *42*, 43–51. https://doi.org/10.1016/j.neucli.2011.09.002

Assaiante, C., & Amblard, B. (1995). An ontogenetic model for the sensorimotor organization of balance control in humans. *Human Movement Science*, *14*(1), 13–43. https://doi.org/10.1016/0167-9457(94)00048-J

Assaiante, C., Mallau, S., Viel, S., Jover, M., & Schmitz, C. (2005). Development of postural control in healthy children: A functional approach. *Neural Plasticity*, *12*(2–3), 109–118. https://doi.org/10.1155/NP.2005.109

Blanchard, Y., Carey, S., Coffey, J., Cohen, A., Harris, T., Michlik, S., & Pellecchia, G. L. (2005). The Influence of Concurrent Cognitive Tasks on Postural Sway in Children. *Pediatric Physical Therapy*, *17*(3), 189–193. https://doi.org/10.1097/01.PEP.0000176578.57147.5d

Chagdes, J. R., Rietdyk, S., Haddad, J. M., Zelaznik, H. N., Raman, A., Rhea, C. K., & Silver, T. A. (2009). Multiple timescales in postural dynamics associated with vision and a secondary task are revealed by wavelet analysis. *Experimental Brain Research*, *197*(3), 297–310. https://doi.org/10.1007/s00221-009-1915-1

Collins, J. J., & Luca, C. J. De. (1993). Open-loop and closed-loop control of posture : A random-walk analysis of center-of-pressure trajectories. *Experimental Brain Research*, *95*, 308–318.

Cuisinier, R., Olivier, I., Vaugoyeau, M., Nougier, V., & Assaiante, C. (2011). Reweighting of sensory inputs to control quiet standing in children from 7 to 11 and in adults. *PLoS ONE*, *6*(5). https://doi.org/10.1371/journal.pone.0019697

Donker, S. F., Roerdink, M., Greven, A. J., & Beek, P. J. (2007). Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Experimental Brain Research*, *181*(1), 1–11. https://doi.org/10.1007/s00221-007-0905-4

Doyle, R. J., Hsiao-Wecksler, E. T., Ragan, B. G., & Rosengren, K. S. (2007). Generalizability of center of pressure measures of quiet standing. *Gait and Posture*, *25*(2), 166–171. https://doi.org/10.1016/j.gaitpost.2006.03.004

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Figura, F., Cama, G., Capranica, L., Guidetti, L., & Pulejo, C. (1991). Asessment of static balance in children. *Journal of Sports Medicine and Physical Fitness*, *31*(2), 233–242.

Hatzitaki, V., Zlsi, V., Kollias, I., & Kioumourtzoglou, E. (2002). Perceptual-motor contributions to static and dynamic balance control in children. *Journal of Motor Behavior*, *34*(2), 161–170. https://doi.org/10.1097/01.PEP.0000072447.53166.9D

Hsu, Y. S., Kuan, C. C., & Young, Y. H. (2009). Assessing the development of balance function in children using stabilometry. *International Journal of Pediatric Otorhinolaryngology*, *73*(5), 737–740. https://doi.org/10.1016/j.ijporl.2009.01.016

Kahneman, D. (1973). Attention and effort. *Englewood Cliffs, NJ*. https://doi.org/10.2307/1421603

Kirshenbaum, N., Riach, C. L., & Starkes, J. L. (2001). Non-linear development of postural control and strategy use in young children: A longitudinal study. *Experimental Brain Research*, *140*(4), 420–431. https://doi.org/10.1007/s002210100835

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1993). Attentional demands for static and dynamic equilibrium. *Experimental Brain Research.*, *97*(1), 139–144. https://doi.org/10.1007/BF00228824

Massion, J. (1994). Postural control system. *Current Opinion in Neurobiology*, *4*(6), 877–887. https://doi.org/10.1016/0959-4388(94)90137-6

Mccann, R. S., & Johnston, J. C. (1992). Locus of the single-channel bottleneck in dual-task interference. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(2), 471–484.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research*, *67*(1), 22–29. https://doi.org/10.1519/JSC.0b013e31823f275c

McNevin, N. H., & Wulf, G. (2002). Attentional focus on supra-postural tasks affects postural control. *Human Movement Science*, *21*(2), 187–202. https://doi.org/10.1016/S0167-9457(02)00095-7

Mickle, K. J., Munro, B. J., & Steele, J. R. (2011). Gender and age affect balance performance in primary school-aged children. *Journal of Science and Medicine in Sport*, *14*(3), 243–248. https://doi.org/10.1016/j.jsams.2010.11.002

Olivier, I., Cuisinier, R., Vaugoyeau, M., Nougier, V., & Assaiante, C. (2007). Dual-task study of cognitive and postural interference in 7-year-olds and adults. *NeuroReport*, *18*(8), 817–821. https://doi.org/10.1097/WNR.0b013e3280e129e1

Olivier, I., Cuisinier, R., Vaugoyeau, M., Nougier, V., & Assaiante, C. (2010). Age-related differences in cognitive and postural dual-task performance. *Gait and Posture*, *32*(4), 494–499. https://doi.org/10.1016/j.gaitpost.2010.07.008

Olivier, I., Palluel, E., & Nougier, V. (2008). Effects of attentional focus on postural sway in children and adults. *Experimental Brain Research*, *185*(2), 341–345. https://doi.org/10.1007/s00221-008-1271-6

Palmieri, R. M., Ingersoll, C. D., Stone, M. B., & Krause, B. A. (2002). Center-of-Pressure Parameters Used in the Assessment of Postural Control. *Journal of Sport Rehabilitation*, *11*(1), 51–66. https://doi.org/10.1123/jsr.11.1.51

Polskaia, N., & Lajoie, Y. (2016). Reducing postural sway by concurrently performing challenging cognitive tasks. *Human Movement Science*, *46*, 177–183. https://doi.org/10.1016/j.humov.2015.12.013

Polskaia, N., Richer, N., Dionne, E., & Lajoie, Y. (2015). Continuous cognitive task promotes greater postural stability than an internal or external focus of attention. *Gait and Posture, 41*(2), 454–458. https://doi.org/10.1016/j.gaitpost.2014.11.009

Potvin-Desrochers, A., Richer, N., & Lajoie, Y. (2017). Cognitive tasks promote automatization of postural control in young and older adults. *Gait and Posture, 57*(April), 40–45. https://doi.org/10.1016/j.gaitpost.2017.05.019

Quek, J., Brauer, S. G., Clark, R., & Treleaven, J. (2014). New insights into neck-pain-related postural control using measures of signal frequency and complexity in older adults. *Gait and Posture*, *39*(4), 1069–1073. https://doi.org/10.1016/j.gaitpost.2014.01.009

Reilly, D. S., Donkelaar, P. Van, Saavedra, S., & Woollacott, M. H. (2008). Executive function of attention. *Journal of Motor Behavior*, *40*(2), 90–102. https://doi.org/10.3200/JMBR.40.2.90-102.Interaction

Riach, C. L., & Hayes, K. C. (1987). Maturation of postural sway in young children. *Developmental Medicine and Child Neurology*, *29*, 650–658. https://doi.org/10.1111/j.1469-8749.1987.tb08507.x

Riach, C., & Starkes, J. (1993). Stability limits of quiet standing postural control in children and adults. *Gait & Posture*, *1*(2), 105–111. https://doi.org/10.1016/0966-6362(93)90021-R

Riach, C., & Starkes, J. (1994). Velocity of centre of pressure excursions as an indicator of postural control systems in children. *Gait and Posture*, *2*(3), 167–172. https://doi.org/10.1016/0966-6362(94)90004-3

Richer, N. (2018). Postural Mechanisms in Young and Older Adults. (PhD). University of Ottawa. Ottawa. Canada

Richer, N., Polskaia, N., & Lajoie, Y. (2017). Continuous cognitive task promotes greater postural stability than an internal or external focus of attention in older adults. *Experimental Aging Research*, *43*(1), 21–33. https://doi.org/10.1080/0361073X.2017.1258214

Rival, C., Ceyte, H., & Olivier, I. (2005). Developmental changes of static standing balance in children. *Neuroscience Letters*, *376*(2), 133–136. https://doi.org/10.1016/j.neulet.2004.11.042

Schaefer, S., Krampe, R. T., Lindenberger, U., & Baltes, P. B. (2008). Age differences between children and young adults in the dynamics of dual-task prioritization: Body (balance) versus mind (memory). *Developmental Psychology*, *44*(3), 747–757. https://doi.org/10.1037/0012-1649.44.3.747

Schmid, M., Conforto, S., Lopez, L., & D'Alessio, T. (2007). Cognitive load affects postural control in children. *Experimental Brain Research*, *179*(3), 375–385. https://doi.org/10.1007/s00221-006-0795-x

Shumway-Cook, A., & Woollacott, M. H. (1985). The growth of stability. *Journal of Motor Behavior*, *17*(2), 131–147. https://doi.org/10.1080/00222895.1985.10735341

Stins, J. F., Michielsen, M. E., Roerdink, M., & Beek, P. J. (2009). Sway regularity reflects attentional involvement in postural control: Effects of expertise, vision and cognition. *Gait and Posture, 30*(1), 106–109. https://doi.org/10.1016/j.gaitpost.2009.04.001

Stins, J. F., Roerdink, M., & Beek, P. J. (2011). To freeze or not to freeze? Affective and cognitive perturbations have markedly different effects on postural control. *Human Movement Science, 30*(2), 190–202. https://doi.org/10.1016/j.humov.2010.05.013

Wickens, C. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*(2), 159–177.

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait and Posture*, *3*(4), 193–214. https://doi.org/10.1016/0966-6362(96)82849-9

Wolff, D. R., Rose, J., Jones, V. K., Bloch, D. A., Oehlert, J. W., & Gamble, J. G. (1998). Postural balance measurements for children and adolescents. *Journal of Orthopaedic*

Research, *16*(2), 271–275. https://doi.org/10.1002/jor.1100160215

Woollacott, M. H., & Shumway-Cook, A. (1990). Changes in posture control across the life span--a systems approach. *Physical Therapy*, *70*(12), 799–807.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait and Posture*, *16*(1), 1–14. https://doi.org/10.1016/S0966-6362(01)00156-4

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Q.J.Exp.Psychol.A*, *54*(4), 1143–1154. https://doi.org/10.1080/0272498014300011

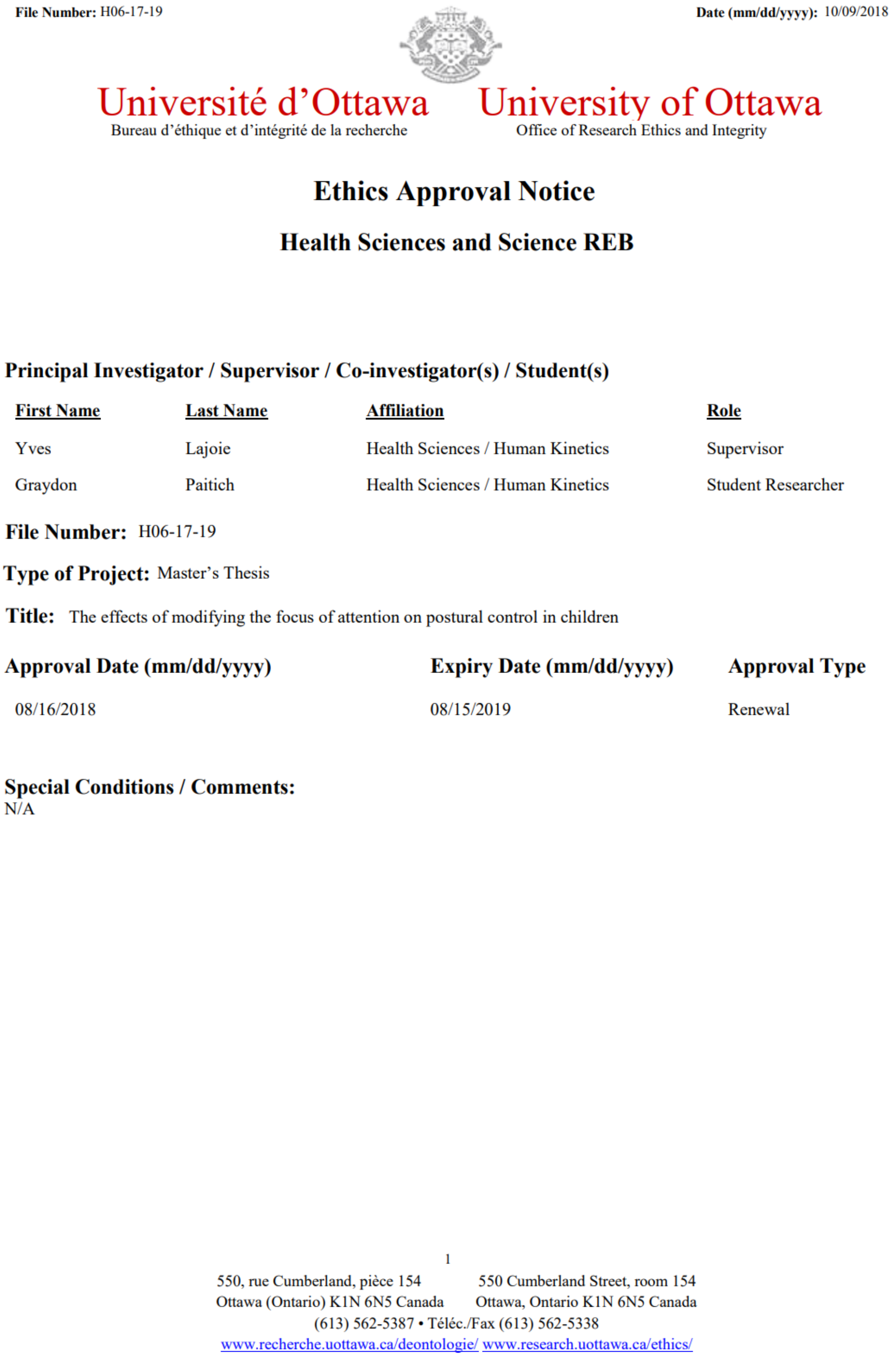
Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review*, *8*(4), 648–60. https://doi.org/10.3758/BF03196201

Wulf, G., Shea, C., & Park, J.-H. (2001). Attention and Motor Performance: Preferences for and Advantages of an External Focus. *Research Quarterly for Exercise and Sport*, *72*(4), 335–344. https://doi.org/10.1080/02701367.2001.10608970

Wulf, G., Töllner, T., & Shea, C. H. (2007). Attentional Focus Effects as a Function of Task Difficulty. *Research Quarterly for Exercise and Sport*, *78*(4), 257–264. https://doi.org/10.5641/193250307X13082490461183

APPENDICES

Appendix 1: REB approval



File Number: H06-17-19

Date (mm/dd/yyyy): 10/09/2018

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Ethics Approval Notice

Health Sciences and Science REB

Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

First Name	Last Name	Affiliation	Role
Yves	Lajoie	Health Sciences / Human Kinetics	Supervisor
Graydon	Paitich	Health Sciences / Human Kinetics	Student Researcher

File Number: H06-17-19

Type of Project: Master's Thesis

Title: The effects of modifying the focus of attention on postural control in children

Approval Date (mm/dd/yyyy)	Expiry Date (mm/dd/yyyy)	Approval Type
08/16/2018	08/15/2019	Renewal

Special Conditions / Comments:
N/A

550, rue Cumberland, pièce 154
Ottawa (Ontario) K1N 6N5 Canada
550 Cumberland Street, room 154
Ottawa, Ontario K1N 6N5 Canada
(613) 562-5387 • Téléc./Fax (613) 562-5338
www.recherche.uottawa.ca/deontologie/ www.research.uottawa.ca/ethics/

File Number: H06-17-19 **Date (mm/dd/yyyy):** 10/09/2018

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche
University of Ottawa
Office of Research Ethics and Integrity

This is to confirm that the University of Ottawa Research Ethics Board identified above, which operates in accordance with the Tri-Council Policy Statement (2010) and other applicable laws and regulations in Ontario, has examined and approved the ethics application for the above named research project. Ethics approval is valid for the period indicated above and subject to the conditions listed in the section entitled "Special Conditions / Comments".

During the course of the project, the protocol may not be modified without prior written approval from the REB except when necessary to remove participants from immediate endangerment or when the modification(s) pertain to only administrative or logistical components of the project (e.g., change of telephone number). Investigators must also promptly alert the REB of any changes which increase the risk to participant(s), any changes which considerably affect the conduct of the project, all unanticipated and harmful events that occur, and new information that may negatively affect the conduct of the project and safety of the participant(s). Modifications to the project, including consent and recruitment documentation, should be submitted to the Ethics Office for approval using the "Modification to research project" form available at: https://research.uottawa.ca/ethics/forms.

Please submit an annual report to the Ethics Office four weeks before the above-referenced expiry date to request a renewal of this ethics approval. To close the file, a final report must be submitted. These documents can be found at: https://research.uottawa.ca/ethics/forms.

If you have any questions, please do not hesitate to contact the Ethics Office at extension 5387 or by e-mail at: ethics@uOttawa.ca.

Signature:

Kim Thompson
Protocol Officer for Ethics in Research
For Barbara Graves, Chair of the Social Sciences and Humanities REB

Appendix 2: Consent form

Informed Consent

uOttawa
Faculté des sciences de la santé
Faculty of Health Sciences

Université d'Ottawa
Faculté des sciences
de la santé

École des sciences de
l'activité physique

University of Ottawa
Faculty of Health Sciences

School of Human Kinetics

Date: August 2018 – August 2019

Project Title: The effects of a dual-task on postural control in children.

Principal Investigator: Graydon Paitich, MSc student
School of Human Kinetics, University of Ottawa

Supervisor : Yves Lajoie, Associate Professor
School of Human Kinetics, University of Ottawa

INVITATION
You are invited to join in a study about effects of focus on postural control. You are being invited to join this study because your child is between the ages of 6-11 years old and is representative of the normal population. The purpose of this study is to learn more about how different types of focus can affect postural control in children.

To be eligible for this study, your child must be between 6-11 years of age. They must be in good health with no injuries sustained in the last 6 months. They must also have no neurological, musculoskeletal or sensory deficits that could impact their performance. This research is a single-site project.

There are no conflicts of interest on the part of the researchers or their institution.

WHAT'S INVOLVED
As a participant, your child will be asked to complete a single session lasting approximately one-hour long. Within this session, your child will be asked to complete 3 different tasks. Each task will consist of 8 trials lasting 70 seconds each.

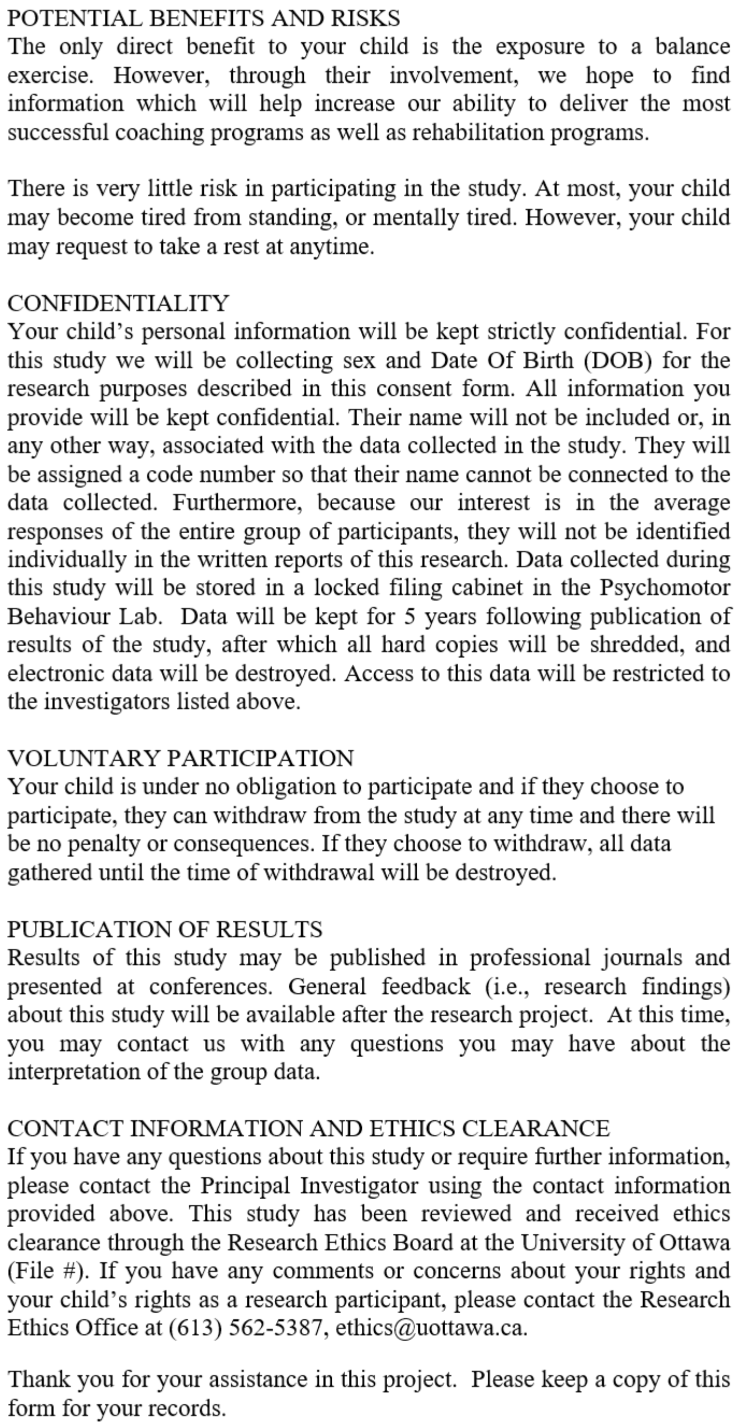
One of the tasks will consist of having your child stand as still as possible. Another will consist of having your child sit on a chair while performing a memory task in which your child will be shown a series of images, and be asked to remember the number of times they saw a particular image (ex. Triangle). The other task will consist of asking your child to complete the memory task previously mentioned, while standing as still as possible. All tasks requiring your child to stand will be performed on a force platform, which will allow us to measure their centre of pressure while performing the task.

Between trials, your child will be given one minute to rest, and between conditions, your child will be given two minutes to rest, including time to explain the next condition. The child may at any time rest for longer than the allotted time.

☐+1 613 562 5800 x 5851
☐+1 613 562-5149

125 Université/University (222)
Ottawa ON K1N 6N5 Canada

Office of Research Ethics and Integrity
Tabaret Hall
550 Cumberland St. Room 154
Ottawa ON K1N 6N5



POTENTIAL BENEFITS AND RISKS

The only direct benefit to your child is the exposure to a balance exercise. However, through their involvement, we hope to find information which will help increase our ability to deliver the most successful coaching programs as well as rehabilitation programs.

There is very little risk in participating in the study. At most, your child may become tired from standing, or mentally tired. However, your child may request to take a rest at anytime.

CONFIDENTIALITY

Your child's personal information will be kept strictly confidential. For this study we will be collecting sex and Date Of Birth (DOB) for the research purposes described in this consent form. All information you provide will be kept confidential. Their name will not be included or, in any other way, associated with the data collected in the study. They will be assigned a code number so that their name cannot be connected to the data collected. Furthermore, because our interest is in the average responses of the entire group of participants, they will not be identified individually in the written reports of this research. Data collected during this study will be stored in a locked filing cabinet in the Psychomotor Behaviour Lab. Data will be kept for 5 years following publication of results of the study, after which all hard copies will be shredded, and electronic data will be destroyed. Access to this data will be restricted to the investigators listed above.

VOLUNTARY PARTICIPATION

Your child is under no obligation to participate and if they choose to participate, they can withdraw from the study at any time and there will be no penalty or consequences. If they choose to withdraw, all data gathered until the time of withdrawal will be destroyed.

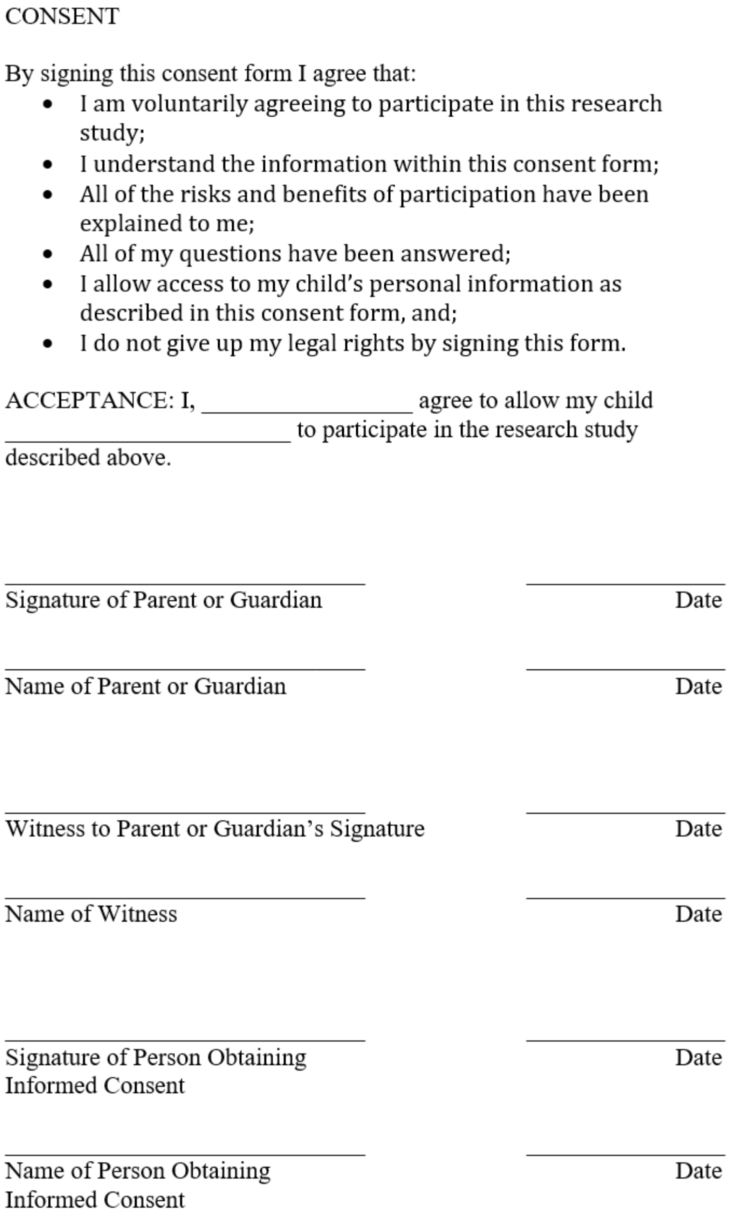
PUBLICATION OF RESULTS

Results of this study may be published in professional journals and presented at conferences. General feedback (i.e., research findings) about this study will be available after the research project. At this time, you may contact us with any questions you may have about the interpretation of the group data.

CONTACT INFORMATION AND ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact the Principal Investigator using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at the University of Ottawa (File #). If you have any comments or concerns about your rights and your child's rights as a research participant, please contact the Research Ethics Office at (613) 562-5387, ethics@uottawa.ca.

Thank you for your assistance in this project. Please keep a copy of this form for your records.



CONSENT

By signing this consent form I agree that:

- I am voluntarily agreeing to participate in this research study;
- I understand the information within this consent form;
- All of the risks and benefits of participation have been explained to me;
- All of my questions have been answered;
- I allow access to my child's personal information as described in this consent form, and;
- I do not give up my legal rights by signing this form.

ACCEPTANCE: I, ________________ agree to allow my child ______________________ to participate in the research study described above.

______________________________ ________________
Signature of Parent or Guardian Date

______________________________ ________________
Name of Parent or Guardian Date

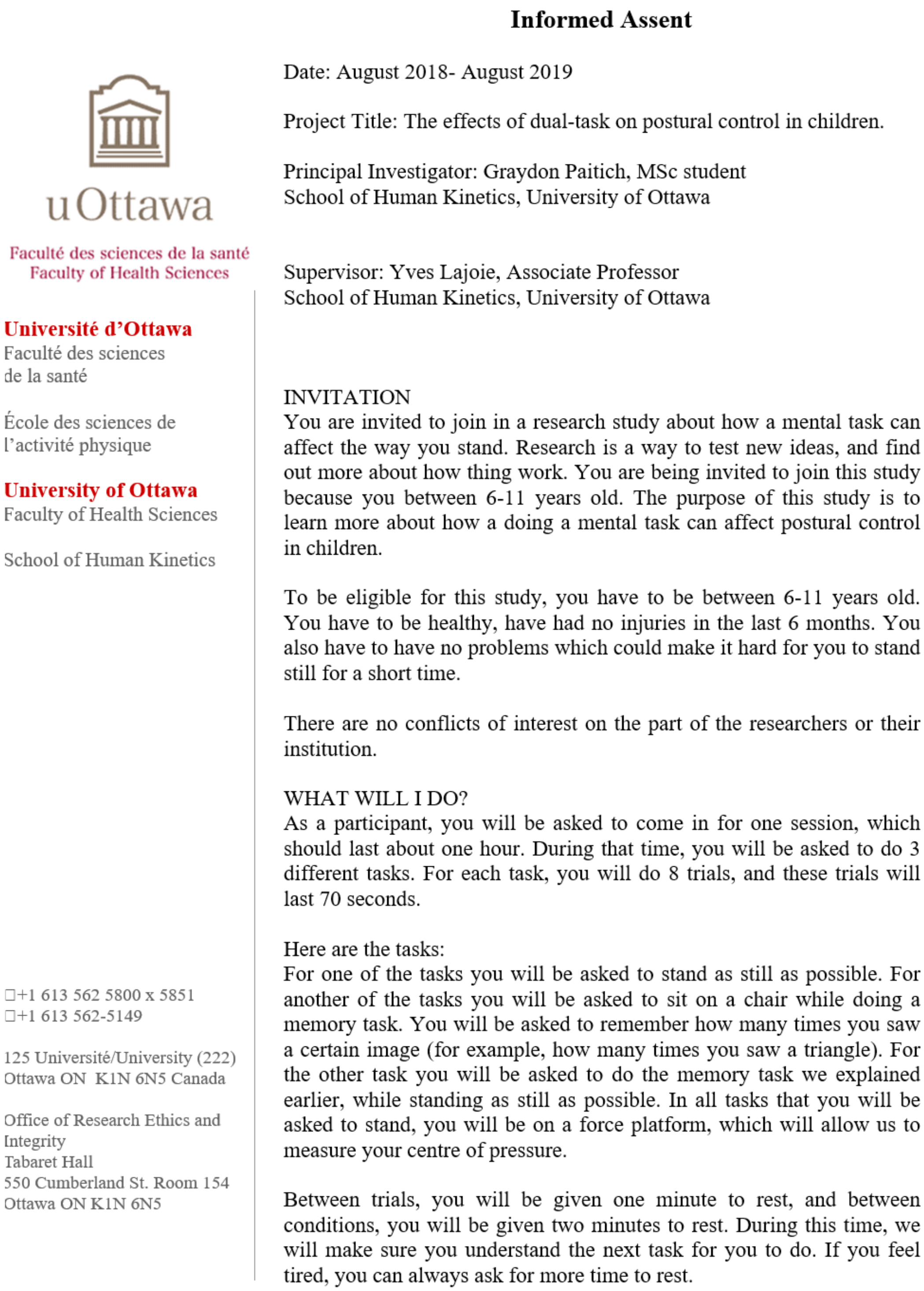
______________________________ ________________
Witness to Parent or Guardian's Signature Date

______________________________ ________________
Name of Witness Date

______________________________ ________________
Signature of Person Obtaining Informed Consent Date

______________________________ ________________
Name of Person Obtaining Informed Consent Date

Appendix 3: Ascent form



Informed Assent

uOttawa
Faculté des sciences de la santé
Faculty of Health Sciences

Université d'Ottawa
Faculté des sciences
de la santé

École des sciences de
l'activité physique

University of Ottawa
Faculty of Health Sciences

School of Human Kinetics

□+1 613 562 5800 x 5851
□+1 613 562-5149

125 Université/University (222)
Ottawa ON K1N 6N5 Canada

Office of Research Ethics and
Integrity
Tabaret Hall
550 Cumberland St. Room 154
Ottawa ON K1N 6N5

Date: August 2018- August 2019

Project Title: The effects of dual-task on postural control in children.

Principal Investigator: Graydon Paitich, MSc student
School of Human Kinetics, University of Ottawa

Supervisor: Yves Lajoie, Associate Professor
School of Human Kinetics, University of Ottawa

INVITATION
You are invited to join in a research study about how a mental task can affect the way you stand. Research is a way to test new ideas, and find out more about how thing work. You are being invited to join this study because you between 6-11 years old. The purpose of this study is to learn more about how a doing a mental task can affect postural control in children.

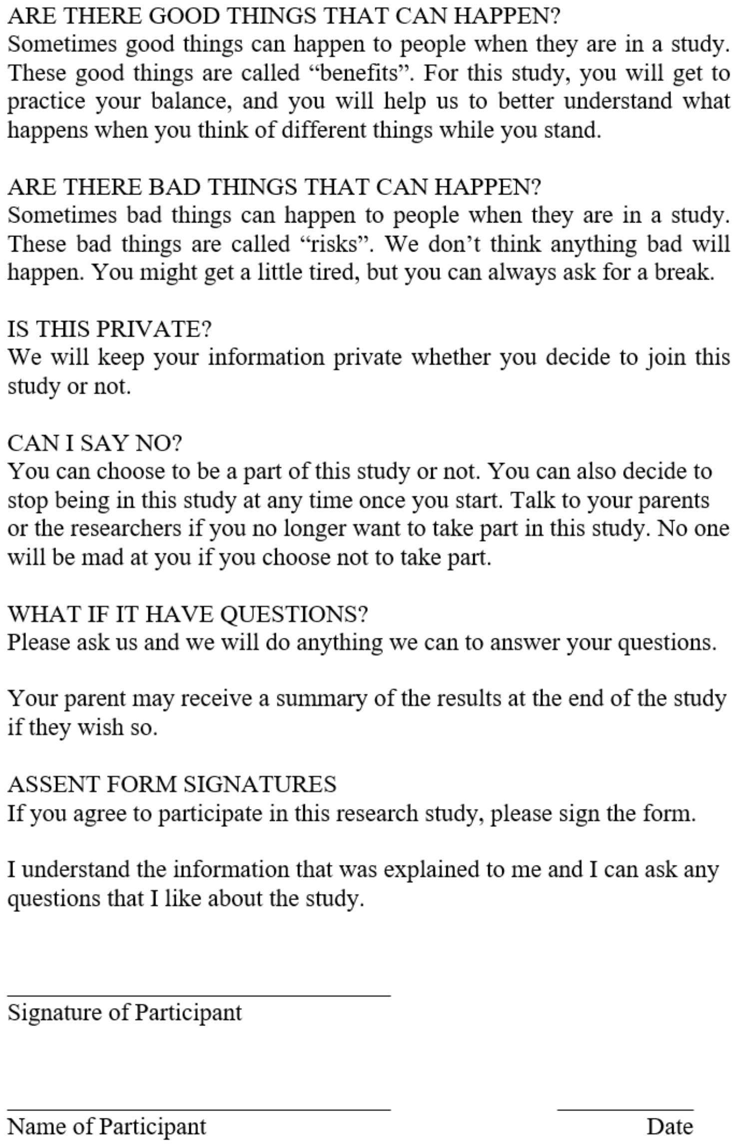
To be eligible for this study, you have to be between 6-11 years old. You have to be healthy, have had no injuries in the last 6 months. You also have to have no problems which could make it hard for you to stand still for a short time.

There are no conflicts of interest on the part of the researchers or their institution.

WHAT WILL I DO?
As a participant, you will be asked to come in for one session, which should last about one hour. During that time, you will be asked to do 3 different tasks. For each task, you will do 8 trials, and these trials will last 70 seconds.

Here are the tasks:
For one of the tasks you will be asked to stand as still as possible. For another of the tasks you will be asked to sit on a chair while doing a memory task. You will be asked to remember how many times you saw a certain image (for example, how many times you saw a triangle). For the other task you will be asked to do the memory task we explained earlier, while standing as still as possible. In all tasks that you will be asked to stand, you will be on a force platform, which will allow us to measure your centre of pressure.

Between trials, you will be given one minute to rest, and between conditions, you will be given two minutes to rest. During this time, we will make sure you understand the next task for you to do. If you feel tired, you can always ask for more time to rest.



ARE THERE GOOD THINGS THAT CAN HAPPEN?

Sometimes good things can happen to people when they are in a study. These good things are called “benefits”. For this study, you will get to practice your balance, and you will help us to better understand what happens when you think of different things while you stand.

ARE THERE BAD THINGS THAT CAN HAPPEN?

Sometimes bad things can happen to people when they are in a study. These bad things are called “risks”. We don’t think anything bad will happen. You might get a little tired, but you can always ask for a break.

IS THIS PRIVATE?

We will keep your information private whether you decide to join this study or not.

CAN I SAY NO?

You can choose to be a part of this study or not. You can also decide to stop being in this study at any time once you start. Talk to your parents or the researchers if you no longer want to take part in this study. No one will be mad at you if you choose not to take part.

WHAT IF IT HAVE QUESTIONS?

Please ask us and we will do anything we can to answer your questions.

Your parent may receive a summary of the results at the end of the study if they wish so.

ASSENT FORM SIGNATURES

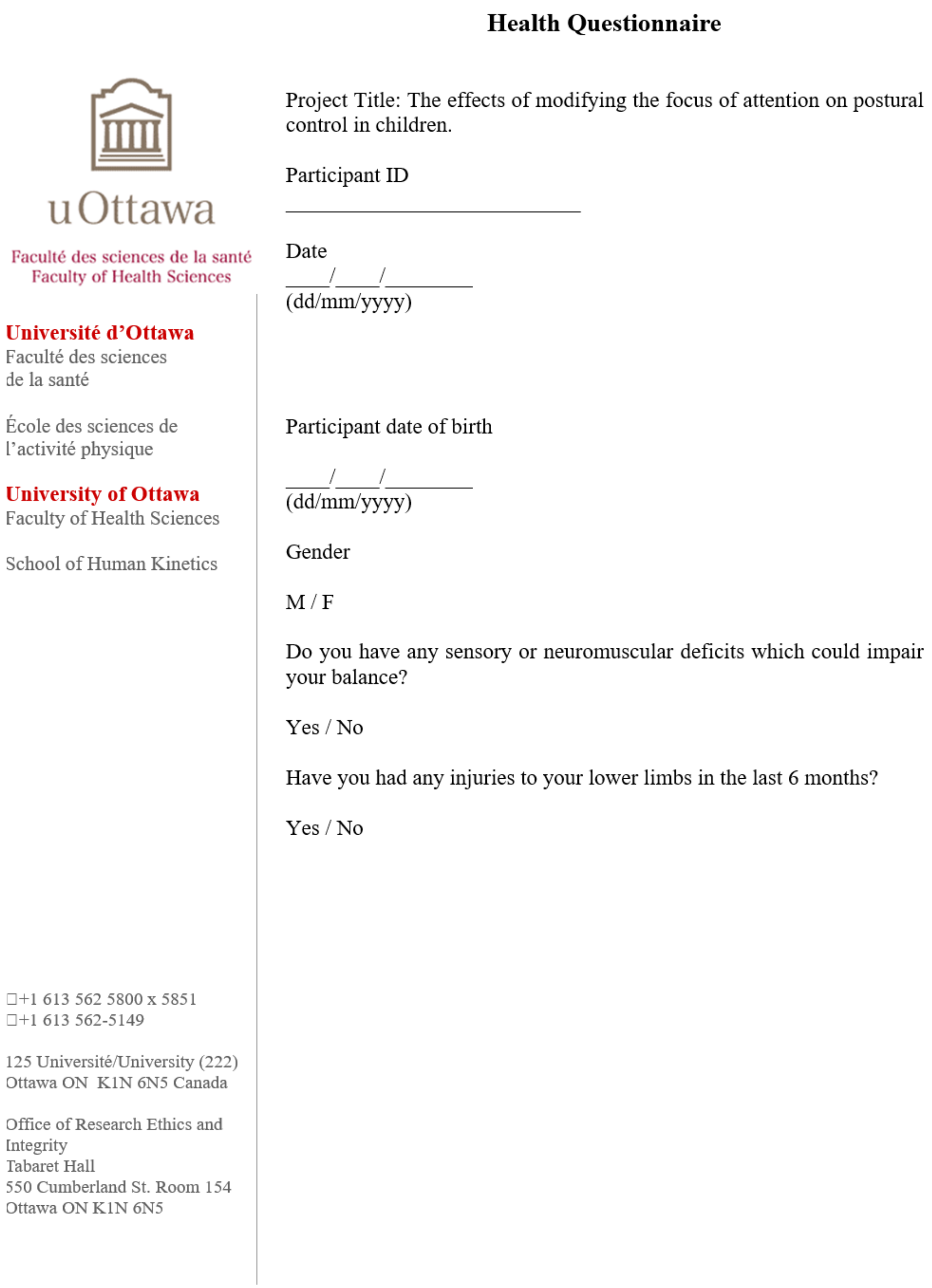
If you agree to participate in this research study, please sign the form.

I understand the information that was explained to me and I can ask any questions that I like about the study.

____
Signature of Participant

________________________________ ____________
Name of Participant Date

Appendix 4: Health questionnaire



Health Questionnaire

uOttawa
Faculté des sciences de la santé
Faculty of Health Sciences

Université d'Ottawa
Faculté des sciences
de la santé

École des sciences de
l'activité physique

University of Ottawa
Faculty of Health Sciences

School of Human Kinetics

☐+1 613 562 5800 x 5851
☐+1 613 562-5149

125 Université/University (222)
Ottawa ON K1N 6N5 Canada

Office of Research Ethics and
Integrity
Tabaret Hall
550 Cumberland St. Room 154
Ottawa ON K1N 6N5

Project Title: The effects of modifying the focus of attention on postural control in children.

Participant ID

____

Date
____/____/________
(dd/mm/yyyy)

Participant date of birth

____/____/________
(dd/mm/yyyy)

Gender

M / F

Do you have any sensory or neuromuscular deficits which could impair your balance?

Yes / No

Have you had any injuries to your lower limbs in the last 6 months?

Yes / No