

THE EFFECT OF A CONCOMITANT COGNITIVE TASK ON ONE'S UNPERCEIVED
DISPLACEMENT AND KNEE HEIGHT IN STEPPING IN PLACE WITHOUT VISION: A
KINEMATIC STUDY

Jessica Grostern, B.Sc.

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

School of Human Kinetics
Faculty of Health Sciences
University of Ottawa

ABSTRACT

While stepping in place without vision, individuals displace linearly and rotate, without perceiving these displacements. The aims of this study were to evaluate the effect of a concomitant cognitive task and the influence of knee height on these displacements in stepping in place for 50 steps. Sixteen adults (mean age = 22 years) performed four conditions of stepping: normal knee height and high knee height with and without a cognitive task. Antero-posterior (AP) displacement was significantly smaller in dual task than in single task at normal knee height, and AP and medio-lateral displacements were significantly larger at high than at normal knee height for single and dual task. No changes in body rotation were found. These findings suggest that automaticity is involved in the control of stepping in place with a concurrent cognitive task and that one's attentional capacity is exceeded when stepping in place with high knees and a cognitive task.

Key words: Stepping in place, Dual task, Knee height, Linear body displacement, Body Rotation, Focus of attention

ABRÉGÉ

En marchant sur place sans vision, les individus se déplacent linéairement et tournent sans le percevoir. Les objectifs de cette étude étaient d'évaluer l'effet d'une tâche cognitive concomitante et l'influence de la hauteur du genou sur ces déplacements lors de la marche sur place de 50 pas. Seize adultes (moyenne d'âge = 22 ans) ont effectué quatre conditions de marche sur place : avec une hauteur de genou normale et haute, avec et sans une tâche cognitive concurrente. Le déplacement en antéro-postérieur (AP) était significativement plus court en double tâche avec une hauteur normale du genou. Les déplacements AP et médio-latéraux étaient plus grand avec les genoux hauts qu'avec la hauteur normale en tâche simple et en double tâche. Aucun changement de la rotation du corps n'a été démontrée. Ces résultats suggèrent que l'automatisation est impliquée dans le contrôle de la marche sur place avec une tâche cognitive concurrente et que la capacité d'attention est dépassée lors de la marche sur place avec les genoux hauts et avec une tâche cognitive.

Mots clés: Marche sur place, Double tâche, Hauteur du genou, Déplacement linéaire du corps, Rotation du corps, Allocation de l'attention

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION.....1

CHAPTER TWO: LITERATURE REVIEW.....3

2.1. Age.....3

2.2. Footedness.....4

2.3. Number of steps.....5

2.4. Effects of sensory stimulations.....6

 2.4.1. Stimulation of neck muscles.....6

 2.4.2. Galvanic vestibular stimulation.....8

 2.4.3. Ankle loading.....8

 2.4.4. Auditory cues.....9

2.5. Factors to be investigated.....9

 2.5.1. Stepping in place and concurrent cognitive task.....10

 2.5.2. Stepping style: knee height.....13

CHAPTER THREE: PURPOSE OF STUDY.....16

3.1. Research questions.....16

3.2. Specific aims.....16

 3.2.1. Concurrent cognitive task.....16

 3.2.2. Knee height.....16

3.3 Hypotheses.....16

 3.3.1. Concurrent cognitive task.....16

 3.3.2. Knee height.....17

CHAPTER FOUR: METHODOLOGY	18
4.1. Study population.....	18
4.2. Inclusion and Exclusion criteria.....	19
4.3. Design of Study.....	20
4.4. Data collection.....	23
4.4.1. Kinematics.....	23
4.4.2. Measure of attentional focus.....	24
4.5. Data analyses.....	24
4.5.1. Data de-sampling and normalization of stepping duration.....	24
4.5.2. Linear displacements	24
4.5.3. Body rotation.....	25
4.5.4. Knee height.....	26
4.5.5. Self-reported attentional focus.....	26
4.6. Statistical analyses.....	27
CHAPTER FIVE: RESULTS	28
5.1. Stepping characteristics.....	28
5.2. ML and AP displacements.....	28
5.3. Body rotation.....	29
5.4. Effect of dual task on ML and AP displacements and BR.....	29
5.5. Effect of knee height on ML and AP displacements and BR.....	30
5.6. Attentional focus during dual task conditions.....	30

CHAPTER SIX: DISCUSSION.....	31
6.1. A kinematic study of stepping in place without vision.....	31
6.2. Smaller forward displacement in the dual task condition.....	33
6.3. Larger linear displacements at high knee height.....	35
6.4. No effect of dual task and knee height on body rotation.....	39
6.5. Limitations.....	40
6.5.1. Non-parametric statistics.....	40
6.5.2. Stepping style.....	40
6.5.3. Fatigue.....	41
6.5.4. Footedness.....	41
6.6. Contributions.....	41
6.7. Future research.....	42
CHAPTER SEVEN: CONCLUSION.....	43
CHAPTER EIGHT: REFERENCES.....	44
CHAPTER NINE: APENDIX.....	50

LIST OF TABLES

1. Table 1. Mean maximum knee height in cm (1 S.D.) in the four conditions.....50

2. Table 2. Mean duration of 50-step trials in seconds (1 S.D.) and corresponding stepping frequency in Hz in the four conditions.50

3. Table 3. Mean body rotation in ° (1 S.D.) at 5 duration intervals during stepping in place in the four conditions.....50

LIST OF FIGURES

1. Figure 1. Examples of 2-D body displacement in the horizontal plane in participant #10. A. normal knee (NK) condition (trial 9); B. normal knee dual task (NK DT) condition (trial 10); C. high knee (HK) condition (trial 17); D. high knee dual task (HK DT) condition (trial 11). ML and AP displacements are in mm. Each data point represents the coordinates (ML, AP) obtained at each 5% of trial duration. The intersection between the two axes represent the starting spot. The filled circle represents a view of the top of the participant's head at the final position of the displacement.....51

2. Figure 2. Mean absolute displacement in mm (+1 S.D.) at every 20% duration interval in the four conditions A. ML direction; B. AP direction.....52

LIST OF APPENDICES

Appendix A. Tables and Figures

Appendix B. Health Questionnaire

Appendix C. Waterloo Footedness Questionnaire

Appendix D. Consent Form

Appendix E. Ethics Certificate

LEGEND

1. Anterior-posterior: AP
2. Medial-lateral: ML
3. Normal knee height: NK
4. High knee height: HK
5. Dual-task: DT
6. Body rotation: BR
7. Reaction Time: RT
8. Waterloo Footedness Questionnaire: WFQ
9. Galvanic Vestibular Stimulation: GVS
10. Two Dimensional: 2-D
11. Three Dimensional: 3-D
12. Standard Deviation: S.D.
13. Centimeters: cm
14. Millimeters: mm
15. Centre of Mass: CoM
16. Centre of Gravity: CoG
17. Centre of Pressure: CoP

ACKNOWLEDGMENTS

I would like to thank Dr. Nicole Paquet, my thesis supervisor, for all of her guidance, support and mentorship throughout the past two years. With her knowledge, patience, and help I have developed research skills as well as a more thorough understanding of perceptual motor control which will translate towards my future career and endeavors.

Secondly, I would like to thank Dr. Yves Lajoie and Dr. Julie Nantel who comprised my thesis committee for all of their advice and support in completing my thesis. You provided depth and insight that helped me write a more thorough and insightful thesis.

I would like to thank Deborah Jehu and Natalie Richer, who are some of my lab mates, for their continued guidance and mentorship throughout this journey. You have been very helpful in answering my questions and mentoring me and I have been lucky to have such kind and knowledgeable lab mates.

Finally, I would like to thank my parents for their continued support throughout my graduate studies. Thank you for continuing to push me to pursue my dreams and achieve my goals. I couldn't have done it without your support and encouragement.

PREFACE

The conduction of this study was approved by the University of Ottawa Research Ethics Board.

CHAPTER 1: INTRODUCTION

Stepping in place without vision with the goal of staying on the same spot is a difficult task that can hardly be performed successfully. It involves lifting each foot from the ground in a rhythmic pattern to perform a marching movement while simultaneously trying not to displace in any direction but rather to have each foot reach the ground at the exact same spot as the previous step. When stepping in place without vision, healthy individuals usually move forward and turn while being unaware of these linear and angular displacements.

Previous studies have determined that healthy participants moved forward by up to 50 cm after 50 steps and up to 1 m after 100 steps, and turned up to 30° after 50 steps and up to 45° after 100 steps (Fukuda, 1959). Previc and Saucedo (1992) found that nondisabled adults turned on average 45° after 1 minute of stepping. Paquet, Taillon-Hobson and Lajoie (2014) reported that participants moved forward 97 cm and turned 64°, on average, when stepping in place for 100 steps. Thus, individuals are slowly drifting and turning from the starting position during stepping.

The task of stepping in place is a form of ‘blind navigation’, in which the task is to avoid departing from the start line while stepping without vision instead of walking towards a target. Blind navigation is known to involve complex interaction and integration of motor, sensory, and cognitive functions (Trullier, Wiener, Berthoz, & Meyer, 1997). According to Wolbers and Hegarty (2010), four neurological elements are involved in blind navigation: sensory cues from the environment and self-motion, spatial computations, spatial representations, and executive processes. In the absence of vision, individuals perceive their body’s self-motion through sensory feedback from vestibular inputs and somatosensory inputs from cutaneous and proprioceptive

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

sensors, as well as from motor efference copies associated with body movements (Böök & Gärling 1981).

So far, ‘unperceived’ linear and angular displacements have been described in terms of final body position relative to its starting position (Fukuda, 1959; Hickey et. al, 1990; Honaker et. al, 2009). Kinematics of body displacements during the whole course of the stepping task have not yet been reported, and thus, there is very little knowledge about displacement’s trajectory during stepping in place without vision. Only one example of foot marks made from perforation of paper have been reported three decades ago (Gagey, Bizzo, & Debruille, 1983). It showed that during the 50-step task, the participant deviated linearly in a diagonal composed of an antero-posterior (AP) and a medio-lateral (ML) displacement. A significant contribution of this thesis is that linear and angular body displacements have been recorded with the use of a 3-D motion analysis system during stepping in place and that the corresponding body displacements are described. This research work provides additional knowledge about the timing of linear and angular displacements during the whole course of the stepping task.

CHAPTER TWO: LITERATURE REVIEW

The task of staying on the same spot during stepping in place without vision is rarely successful, as almost all tested healthy individuals progressively turn and drift away from their starting position (e.g. Fukuda, 1959, Previc & Saucedo, 1992, Paquet, Taillon-Hobson & Lajoie, 2014). Such linear and angular displacements were found to be influenced by two personal factors: age (Nyabenda, Briart, Deggouj & Gersdorff, 2004; Paquet, Jehu & Lajoie, 2017) and footedness (Previc & Saucedo, 1992; Paquet, Taillon-Hobson & Lajoie, 2014). Also, there is a factor associated with the task that influences displacements: the number of steps (Bonanni & Newton, 1988; Paquet, Jehu & Lajoie, 2016). These factors are discussed in more details in the next sections.

In addition, previous studies showed that linear and angular displacements during stepping in place could be modified by sensory stimulations: stimulation of neck muscles (Bove, Courtine & Schieppati, 2002), galvanic vestibular stimulation (Osler & Reynolds, 2012), ankle loading (Paquet, Taillon-Hobson, Lajoie, 2015), and auditory stimulation (Munnings, Chisnall, Oji, Whittaker & Kanegaokar, 2015). The findings of these studies are reviewed in the next sections.

2.1. Age

In a study comparing the final body rotation (BR) after stepping in place without vision for 45 steps, a significant correlation of age with BR has been reported in 20 young and 20 older adults. (Nyabenda, Briart, Deggouj & Gersdorff, 2004). The mean BR of participants aged 60–79 years was 38°, while it was 14° in participants aged 20–39 years. A possible rationale for this discrepancy is that the sample may not have been entirely representative of the population due to its small size. As well, the rhythm at which they stepped was 1Hz, which is slower than other

studies. It is possible that the younger participants were able to take advantage of this slow pace, and therefore were able to rotate less. Such difference in BR was not observed in the study by Paquet, Jehu and Lajoie (2017) between older (65 to 75 years old), who rotated 74° and young adults (18 to 36 years old) who rotated was 66° after completing 100 steps. However, significantly larger lateral and longitudinal (forward) displacements were obtained in the older participants compared to the young participants. Between these two studies, the groups of young participants had high variability in the body rotation, and the difference was smaller between the groups of older adults. For a hypothetical 90 steps, which is more similar to 100 steps, young participants would have turned 28° in the study conducted by Nyabenda, Briart, Deggouj & Gersdorf (2004) and older adults would have turned 76°, if the rotation continued to increase by the same amount after another 45 steps.

From these results, it appears that the undetected body displacements during stepping in place without vision were amplified in older participants. They suggest that the ability to perceive both the angular and linear displacements is modified by aging. Since BR and drifting is quite slow, the results further suggest that the control of slow linear displacements in the absence of vision is particularly affected in older adults.

2.2. Footedness

Researchers have sought to determine the correlation between foot preference and the directions of turning during stepping in place. Previc and Saucedo (1992) determined footedness by asking participants ‘with which foot do you kick a ball?’ Then participants stepped in place for 1 minute. They found a small but significant correlation ($r = .26$) between the direction of angular deviation and footedness.

In a more recent study, 50 young adults stepped in place for 100 steps (Paquet, Taillon-Hobson & Lajoie, 2014). Participant's footedness was measured with the Waterloo Footedness Questionnaire (WFQ; Elias, Bryden & Bulman-Fleming, 1998). The study revealed that the direction of BR was significantly correlated with the footedness score ($r = .32$). In other words, participants who were right footed tended to turn towards the right. Thus, there seems to be an influence of foot dominance, or lower limb preference, on the side of BR during stepping in place without vision, but the results must be interpreted with prudence, since only 10% of BR was explained by the WFQ score.

2.3. Number of steps

Results from different studies allude to the significance of the number of steps during stepping in place on the linear and angular body displacements. Many studies used 50 or 100 steps (Fukuda, 1959; Reiss & Reiss, 1997; Takemori, Ida & Umezu, 1985). Other studies have used time, for instance 1 minute of stepping at self-selected pace (Peitersen, 1967; Previc & Saucedo, 1992.) and 30 seconds (Hickey, Ford, Buckley & Fitzgerald-O'Connor, 1990).

The number of steps used in the stepping in place task directly impacts the outcome. In a study done to determine the test-retest reliability of BR and distance of displacement during stepping in place without vision for both 50 and 100 steps, a lower inter-class correlation was found for the test that involved 100 steps (Bonanni & Newton, 1998).

Paquet, Jehu and Lajoie (2016) reported that BR, as well as lateral and longitudinal displacements were significantly larger with 100 steps than with 50 steps in a group of 50 healthy older adults (mean age = 69 years). In more details, participants turned on average 33° , moved laterally 45 cm and moved forward 103 cm after 50 steps, while they turned 74° , moved

laterally 124 cm and moved forward 165 cm after 100 steps. In addition, the trial-to-trial variability was significantly higher with 100 steps than with 50 steps. A possible rationale for this discrepancy is systematic error which implies that the more steps one take, the more they may displace and rotate. The BR and displacements were not exactly doubled when the number of steps were, however, a high amount of variability between the subjects at 100 steps may be responsible for this.

Altogether, the results suggest that individuals may move slightly and turn at every step, which would explain that larger linear and angular displacements are associated with a larger number of steps.

2.4 Effects of sensory stimulations

2.4.1. Stimulation of neck muscles

Applying a vibration to the body influences postural control from a physiological level. The muscle vibration induces action potentials in primary spindle endings attached to Ia afferent muscle fibers (Burke, Hagbarth, Lofstedt, & Wallin, 1976). This discharge of the primary afferent muscle fibers may cause a perceived elongation of the affected muscle to the person, which may cause them to feel as though the limb has displaced, even though it did not. When a vibration is applied to the ankle, specifically to the Achilles tendon, a forward tilt of the body may occur as a compensation to the perceived backwards tilt that results from the vibration (Pettorossi, & Schieppati, 2014). With regards to a vibration applied to the neck muscles in quiet standing, body tilt and increased sway would arise as a result. In locomotion, gait would deviate opposite to the side of the neck affected by the vibration (Bove, Courtine, & Schieppati, 2002).

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

Proprioceptive input to the neck has been determined to influence body orientation during stepping in place without vision (Bove, Courtine & Schieppati, 2002). In this study, six young, healthy participants stepped in place at their own pace while blindfolded in a dark room for one minute with and without vibrations to the right or left neck muscles that was applied during stepping. They found that the vibration caused BR in the opposite direction than the side it was applied. Participants rotated 70 degrees clockwise when the vibration was applied to their left neck muscles and 45 degrees counterclockwise when the vibration was applied to their right neck muscles. These findings demonstrate that proprioceptive input has a direct influence on unperceived angular displacements during stepping without vision.

Another study evaluated lateral and longitudinal displacements and BR in stepping in place without vision with and without applied neck muscle vibrations (Malmstrom, E.M., Fransson, P.M., & Bruinen, T.J., 2017). They applied a vibration to both the dorsal and ventral neck muscles which both resulted in changes in linear displacement and rotation when compared to no vibration. Linear progression in the forward direction was present in all conditions, but it was greatest when vibration was applied to the dorsal neck muscles and smallest when the vibration was applied to the ventral neck muscles. This suggests that one's perception and orientation of their position in space is directly influenced by neck proprioceptive inputs.

These findings suggest that neck proprioception plays a role in one's orientation and perception of their location in space. Vibrating the neck muscles is disorienting and produces postural changes which may result in changes in movement, as a compensatory result of these changes (Lund, 1980), thus influencing unperceived linear and angular displacements during stepping without vision.

2.4.2. Galvanic vestibular stimulation

Galvanic vestibular stimulation (GVS) was found to influence BR in blind stepping in place (Osler & Reynolds, 2012). In this study, twelve healthy, young participants were instructed to step on the spot, while blindfolded, at a cadence of 80 steps per minute as implemented by a metronome. They performed stepping with their head turned at five different imposed angles, under three conditions of GVS; anode applied to the right side of the mastoid processes, anode applied to the left side of the mastoid processes, and no GVS. They then performed twelve dynamic head movement trials where they turned their head as instructed throughout the trial, while given GVS. Clockwise BR was obtained with the addition of galvanic vestibular stimulation (GVS) with the anode on the right ear and the cathode on the left ear. In the static condition, they rotated an average of 22 degrees, whereas in the dynamic conditions they moved 25 degrees with the head moving upwards and 11 degrees with the head moving downwards. This implies that when there was vestibular input, in the form of GVS, a motor response was evoked as participants unconsciously rotated on the spot, while stepping. This response was changed according to the direction of the imposed head angle. This implies that neck proprioceptive input interacts with vestibular input for the motor response. In addition, the results suggest a direct influence of vestibular input on one's orientation in stepping in place, as GVS has a disorienting effect on one's perception of their position, resulting in unperceived rotation.

2.4.3 Ankle loading

Paquet, Taillon-Hobson and Lajoie (2015) investigated the influence unilateral ankle loading with a 2.3 kg weight on angular and linear displacement while stepping in place without vision for 100 steps. Results showed that BR was not modified by the ankle weight. However, forward displacement was significantly smaller with the weight (on average, 53 cm) than without

the weight (on average, 85 cm). This indicated that the undetected BR during stepping in place was not modified by the ankle weight, but that the control of linear displacement in the sagittal plane was improved with the weight. Perhaps the better performance at staying on the spot during stepping was due to the force required to lift the weight in the vertical plane and the associated vertically oriented sensory cues that provided additional feedback about body displacement.

2.4.4 Auditory cues

Munnings, Chisnall, Oji, Whittaker and Kanegaokar (2015) evaluated the undetected displacement and rotation of 44 young, healthy participants who stepped in place without vision under several conditions, including with a sound-localizing source, being a metronome, versus without a sound-localizing source. They discovered that BR decreased in the conditions where a sound-localizing source was present. From these findings, it has been suggested that auditory cues can orient a person in space, which can influence one's displacement and BR in the absence of vision.

2.5. Factors to be investigated

In summary, there are several factors that are known to influence the skill to stay on the spot while stepping in place without vision. Personal factors, such as age and footedness are important, as well as auditory, vestibular and somatosensory stimulation. Lastly, the testing condition, namely the number of steps, also plays a role.

In contrast, other factors are largely unknown. For instance, the impact of a concurrent cognitive task and the influence of the stepping style on linear and angular body displacements have not yet been studied. It is likely that a concurrent cognitive task during stepping in place should influence the outcome because as for all blind navigation tasks, the interaction and

integration of motor, sensory, and cognitive functions are involved (Trullier, Wiener, Berthoz, & Meyer, 1997). For example, if a participant does not pay attention to the specific instruction to stay on the spot during stepping, the body displacements will likely be different than if the instruction is carefully followed.

Similarly, it is likely that the stepping style should influence the outcome, in particular the height with which the knees are lifted during stepping. For instance, stepping with low knee height is likely easier to perform than stepping with high knee height, as balance control is less challenging with low knee height.

In support for the rationale of the present study, these factors are discussed in the next sections.

2.5.1. Stepping in place and concurrent cognitive task

To this date, there is very little knowledge about the effect of a concurrent cognitive task on one's unperceived displacement during stepping in place without vision. There is, however, information available about a different type of blind navigation task, from three studies.

Paquet, Lajoie, Rainville and Sabagh-Yazdi (2008) conducted a study in which they sought to evaluate the effect of a concurrent cognitive task in a blind navigation study. Participants had to walk with their vision blocked to a target that was placed a distance of 8 meters ahead of them, and stop when they perceive that they have reached the target. They did so with and without the condition of having to count backwards while they walked. With the cognitive task, the participants' distance was not changed. However, participants counted slower and walked at a slower pace under the dual-task condition. Their performance on the cognitive task suffered as a result of the concurrent cognitive task, but their navigation precision did not. This aligns with the capacity sharing theory, which implies that two tasks can be performed

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

simultaneously, however, a finite amount of attentional capacity exists that must be shared between the tasks. Once all of the attention is allocated, if the amount of attention required to perform both tasks exceeds the capacity, performance on one of the dual-tasks will begin to suffer and performance on the other will remain consistent. In this case, performance on the cognitive task was affected as they counted slower, and performance on the navigation precision task remained the same, under a limited amount of attentional capacity, which was exceeded by the demands of the dual-task presented (Woollacott, & Schumway-Cook, 2002, Tombu, & Jolicoeur, 2003).

With the same blind navigation task, Lajoie, Paquet & Lafleur (2013) compared the navigation performance with and without the addition of a reaction time (RT) task. The concurrent cognitive task was to respond “top” as fast as possible to an auditory stimulus while performing the blind navigation task. It was found that participants walked a longer distance in the dual task condition compared to the control condition, which brought them closer to the 8-meter target. Thus, navigation performance did not deteriorate with a concurrent cognitive task, but RT was found to be slower in the dual task condition where participants also had to allocate attention towards the navigation task. This suggests that the attentional capacity required to complete both the navigation task and the concurrent cognitive task was too demanding for participants, and as a result, RT deteriorated while navigation precision did not.

Richer, Paquet and Lajoie (2013) conducted a study with the aim of evaluating the impact of age and obstacles on one’s RT as well as their navigation precision in the same blind navigation task. They also sought to determine the effect of the RT task on one’s performance in the navigation task. In half of the single task trials, there were two obstacles placed along the path. While significant effects of age and spatial location of the RT stimulus was found, no

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

significant effects of the RT task on one's performance on the blind navigation task was found. RT was also found to increase in the conditions where obstacles were present. The navigation task became more difficult, thus requiring a higher amount of attention when obstacles were present. As a result, performance on the RT task suffered in terms of speed, as RT became slower, when obstacles were present.

Altogether, these three studies indicate that a concurrent cognitive task, being continuous (counting backward) or punctual (RT task) does not influence much one's perception of their body displacement during walking blindfolded towards a previously seen target. However, the cognitive task was affected. Thus, the results of these three studies suggest that attention is limited, and must be divided among tasks in a dual-task scenario, in order to be able to simultaneously perform both tasks. This is explained by the capacity sharing theory for information processing which states that performance on one attention demanding task deteriorates as a result of a simultaneous secondary attention demanding task when the attention capacity required to perform both tasks is exceeded (Woollacott, & Schumway-Cook, 2002; Tombu, & Jolicoeur, 2003).

Results may be different for stepping in place, however, because this activity may relate more closely to postural control compare to walking towards a target. It has been determined that postural control improves when one is performing a secondary cognitive task. This was made evident in a study that looked at the effects of a RT task on postural control (Vuillerme, Nougier & Teasdale, 2000). This study evaluated static postural control by measuring center of pressure (CoP) displacements of the feet using a force plate during and immediately following the completion of a cognitive RT task that required attentional focus. Participants were asked to maintain a static posture, and stay in place. It was found that postural control improved with the

addition of a cognitive task as CoP displacements were smaller while the secondary RT task was being completed, and afterwards as well. This was later confirmed by other studies, including one that evaluated postural sway under the influence of a dual-cognitive task (Polskaia, & Lajoie, 2016). Seventeen young, healthy adults were instructed to stay in place as best as possible. They were given an auditory continuous cognitive task to perform concurrently. It was found that that postural sway decreased, as a function of reduced CoP, with the cognitive task.

In the present study, stepping in place without vision will be performed with a concurrent cognitive task. The study will shed light on a possible improvement of stepping in place without vision under a dual task.

2.5.2 Stepping style: knee height

Now, little is known about the influence of knee height on stepping in place. It has been determined that step height decreases with an increased stepping frequency when stepping in place with the eyes open (Ikeda, Y., Kamiyama, Y., Okuzumi, H., & Kokubun, M., 2011). It has also been determined stepping does not affect one's performance on a concurrent cognitive task when stepping at self-selected stepping height and frequency (Ikeda, Y., Okuzumi, H., & Kokubun, M., 2014). Other than these two studies there are limited reports of kinematic measures of step height or knee height during stepping in place in young, healthy individuals.

Stepping with higher knees is likely more challenging for balance than stepping at a self-selected, normal stepping height. First, lifting the knees high requires stronger muscle contractions of hip flexors. Second, for a given stepping frequency, knees are moved faster at high knee height than lower knee height. Third, the increased effort of stepping with high knees is likely associated with an additional attentional demand. Fourth, the higher knee position at each step likely moves the body center of mass forward. To maintain the vertical body posture

and to prevent a fall forward, posterior trunk and lower limb muscles must be activated.

Furthermore, a more complex muscle coordination is likely associated with high knee stepping compared with lower knee stepping. For instance, unipedal postural control differs from bipedal postural control in both the level of difficulty of the task as well as certain muscles activated. In single leg stance, the ankle joint is stabilized in the anterior-posterior (AP) direction by ankle plantar flexor and dorsiflexor muscles, and is stabilized in the medial-lateral (ML) direction by ankle invertor and evertor muscles (Winter, 2009). These are the muscles primarily responsible for maintaining balance on a firm surface. In addition, hip muscles are involved in stabilizing the trunk in single leg stance. Specifically, hip flexor and extensor muscles control body sway in the AP direction and hip adductor and abductor muscles control body sway in the ML direction (Winter, 2009). Furthermore, balance is controlled by proprioceptive, vestibular and visual sensory input (Tropp & Oderick, 1988). With vision obstructed, the hip joint, and the hip flexor and extensor muscles, become responsible for maintaining postural control (Riemann, Myers, & Lephart, 2003). In more proximal joints, such as the knee, and more so the hip, taking over postural control in unipedal stance, the center of gravity (CoG) of the body is moved closer to the area that functions as the base of support. (Tropp, & Oderick, 1988). In unipedal stance, one's center of mass (CoM) and center of gravity (CoG) are displaced with the lifting of the leg, and the base of support of the body is also reduced. These displacements increase as hip flexion increases, thus causing greater displacements in the AP and ML directions when the knees are raised high. It has been determined that sway velocity increases in unipedal stance with the addition of a dual cognitive task (Bisson, McEwan, Lajoie, & Bilodeau, 2013). Increased sway velocity is indicative that a dual task may have a de-balancing effect when in one legged standing.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

Thus, in condition of high knee stepping, it would be less probable that each foot reaches the ground at the exact same spot as the previous step, making the individual moving away from the starting spot. The question remains, however, whether body displacement would be a progressive drift away from the starting spot, or a random displacement in all directions to end close to the starting spot.

CHAPTER THREE: PURPOSE OF THE STUDY

3.1. Research Questions

With all the knowledge obtained through previous literature, there are still questions that remain unanswered. Firstly, what effects does a concurrent cognitive task have on one's unperceived displacement in stepping in place without vision? Secondly, what effects does knee height have on these displacements?

3.2. Specific aims

3.2.1. Concurrent cognitive task

The first aim is to determine the specific influence of a concurrent continuous cognitive task on angular and linear body displacements while stepping in place without vision for 50 steps.

3.2.2. Knee height

The second aim is to compare angular and linear body displacements between stepping at a normal stepping knee height (45° hip flexion) and stepping with high knee height (90° of hip flexion).

3.3. Hypotheses

3.3.1. Concurrent cognitive task

The first hypothesis is that a concurrent cognitive task will modify the linear and angular body displacements associated with stepping in place without vision. Body displacements would be smaller with the concurrent cognitive task than without. This is because postural control has been shown to improve in dual task conditions involving a concurrent cognitive task (e.g. Vuillerme, Nougier & Teasdale, 2000). We hypothesize that with a concurrent cognitive task, stepping would be better performed.

3.3.2. Knee Height

The second hypothesis is that the knee height will influence body displacements. Angular and linear displacements would be larger when stepping with high knee height than when stepping with a normal knee height because balance control at high stepping is likely more difficult and requires more complex patterns of hip and ankle muscle activation, especially to control body sway in the ML direction, than normal knee height stepping. In addition, higher stepping likely requires more attention than normal stepping, and this attention level may exceed one's attention capacity. As a result, unperceived linear and angular displacements during stepping in place will increase.

CHAPTER FOUR: METHODOLOGY

4.1. Study Population

Seventeen healthy, non-disabled young adults participated in this study. However, data from sixteen participants were used for the analyses. The data collected from participant #1 was excluded from the analyses as many data points were missing due to calibration problems with the Vicon Motion Analysis system.

The method of recruitment was by convenience sampling as current and former university undergraduate and graduate students participated on a volunteer basis. Prior to each participant's testing session, they were given and thoroughly explained the experiment and they were asked to sign a consent form that was first approved by the University of Ottawa Ethics Research board, in their preferred language (English or French). It was ensured that all participants willingly consented to partake in the experiment with a full understanding of the requirements of the study and their rights as a participant, including the right to withdraw from the study at any point. They were given the opportunity to ask any questions or address any concerns to the researcher prior to undergoing testing. Participants were asked to self-report their age, height and weight, which were recorded.

Participants ranged in age from 20 to 26 years old and the mean age was 22 years old. Their weight ranged from 49.0 kg to 81.8 kg and the mean weight was 63.0 kg. Participant heights ranged from 1.55 m to 1.58 m and the mean height was 1.66 m. The sample of participants had a gender distribution that was 75% female (n=12) and 25% male (n=4).

4.2. Inclusion and Exclusion Criteria

Participants were all in good health, as determined by the health questionnaire in appendix B that was administered to them prior to testing. This questionnaire ensured that participants were not experiencing any pain or discomfort in their back or lower limb, had no diagnosed neurological or vestibular condition, were not experiencing dizziness and did not have vertigo. It ensured that they had not consumed any alcohol or mind-altering medication prior to testing, and that they were feeling well overall, during their testing session.

Participants were only tested if they felt that they were capable of completing the stepping task, which was explained to them in full detail, prior. Any potential participants who had consumed any mind-altering medications (e.g. Benadryl, Gravol, benzodiazepines), street drug or alcohol within the twelve hours prior to the testing session were excluded. Each participant was asked if they had been experiencing any pain or discomfort, particularly in their back or lower limb. They were asked whether they had experienced any recent musculoskeletal injuries and if so, they were excluded. Any participants who had a history of dizziness, vertigo, or any diagnosed neurological condition, including any inner ear (vestibular) condition were excluded.

To determine their footedness, participants were administered the Waterloo Footedness Questionnaire (WFQ) orally, by the researcher. The WFQ (see Appendix C; Elias, Bryden & Bulman-Fleming, 1997) assesses foot dominance by having participants perform ten tasks related to foot function. One's score on the test depends on the sum of the foot preferences, as determined by a Likert scale, for all the tasks. The points are distributed as follows: -2 for left always, -1 for left usually, 0 for equal, 1 for right usually, 2 for right always. A score between 11

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

and 20 points yields right foot dominance, a score between -11 and -20 yields left foot preference, and a score between -10 and 10 would indicate that there is no significant dominance for either foot but rather a mixed preference (Elias, Bryden & Bulman-Fleming, 1997). Due to previous findings that footedness has a significant influence on the direction of body rotation during stepping in place without vision (Previc & Saucedo, 1992; Paquet, Taillon-Hobson & Lajoie, 2014) and considering that this study has a small sample size, only right-footed individuals (WFQ score between 11 and 20) were recruited for this study.

4.3. Design of Study

This experimental study was a repeated measures within-subject design where the same participants completed four testing conditions. It took place in a quiet laboratory with consistent lighting at LeesE053 at the University of Ottawa. Participants wore no footwear other than socks.

In all the conditions and prior to each trial, participants stood with the tip of their toes positioned just in front of a start line marked on the floor. They kept their arms by their sides.

Participants were instructed that their task was to step in place and try to stay at the same spot at all times during the stepping task. For the normal stepping height condition, meaning stepping at a pace and with hip flexion that is typical and natural, participants put on the opaque ski goggles, which served as a blind-fold that completely obstructed vision, and then stepped in place without vision for 50 steps at a pace as similar as possible to that demonstrated by the examiner. The demonstration was done at approximately 45 degrees of hip flexion and at an approximate frequency of 1.9 HZ. The participants then demonstrated their self-selected pace and height, based on that they witnessed demonstrated by the researcher. They were given an

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

opportunity for clarification and to ask any questions should they so desire at that point. They removed their goggles only to look at the start line prior to each trial. The goggles then remained on for the entire duration of the trial and participants returned to the start line with vision occluded, with specific instructions of where to step, given by the examiner who walked alongside them, guiding them in different directions. To ensure that participants were unaware of their displacements at the end of the stepping trial, the examiner guided them to walk in various directions while still blindfolded, before returning to the start line for the next trial. They would then be allowed to remove their goggles and look for the start line in order to re-orient themselves at the starting position. Thus, there was no knowledge of results, meaning that participants had no knowledge of where they were relative to the start line at the end of each stepping trial, or that they had displaced.

The steps were counted by the investigator who told the participants when to stop, by saying “stop” out loud, which allowed participants to stop stepping at exactly 50 steps. Participants did 10 of those normal knee height trials, i.e. 5 trials of the single task (normal knee: NK) and trials of the dual task (normal knee dual task: NK DT) that were presented in a random order.

In the dual task condition, a cognitive task was introduced in conjunction to the stepping task. The cognitive task was continuous and participants did not speak out loud during the trials, but rather gave one answer at the end of each trial. The participants were played three-digit sequences every two seconds. From those specific sequences, they were told to identify how many times one pre-determined digit was included. Each trial had a different digit to count, which was told to the participant just prior to the start of the trial. It was planned that trials would be excluded if participants gave an incorrect answer that differed from the real answer by 50% or more. An example of such would be if the number 7 was repeated 11 times throughout the trial,

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

and the participant responded with an answer less than or equal to 5 or greater than or equal to 17 as it was deemed unacceptable for a response to be more or less half of the correct answer. This cut-off was decided as we did not want participants to focus excessively on either the cognitive or stepping task but rather to allocate half of their focus towards both tasks simultaneously. However, all the trials met the requirements, and none were excluded.

The three-digit sequences were administered through a voice recording of the investigator counting sequences. It was played into the ears of the participant wirelessly through Bluetooth-operated, noise-reducing headphones. The headphones remained on consistently throughout all the trials, even during those when no sound was played (i.e. the single task trials).

After 10 trials of stepping at a natural stepping height, participants removed their goggles and were given instructions for the following 10 trials. Participants were given identical instructions to the first 10 trials, with the addition of an imposed higher knee height while stepping. They were told to step with their knees high up such that the hip would be flexed by approximately 90° . The investigator gave a demonstration of the requested knee height where the hip was flexed to an approximate 90° at an approximate frequency of 1.6 Hz. Participants performed 10 trials with high knees under two conditions: 5 trials at single task (high knee: HK) and 5 trials at dual task (high knee dual task: HKD) The 10 trials were done in the reverse order as the normal knee height condition.

Before trial 1, participants were told that both stepping and counting were of equal importance. They were told again before trial 11.

4.4. Data Collection

Data collection lasted approximately one hour per participant. Prior to any testing trials, participants were acclimatized to stepping and walking without vision, as it is not a task that most people frequently do in everyday life. They were acclimatized by walking around the laboratory wearing the vision-occluding goggles, with the investigator by their side.

Since a concern of this study was fatigue, as each participant was asked to do 20 trials of 50 steps during the testing session, it was ensured that participants were not overworked and were comfortable performing all trials. Participants were told that it would be acceptable for them to take a break between or even during trials at any point should they feel fatigued. However, no participant requested a break, nor did they complain of fatigue.

4.4.1. Kinematics

Kinematic data was recorded with 7 infra-red cameras of the Vicon512TM system. A set of 18 reflective markers were used to capture each participant's position: one on both the right and the left of the frontal bone, one on each of the right and left of the base of the occipital bone, one on each of the right and left acromion of their shoulders, one on each of the left and right anterior superior iliac spine, one on each of the left and right posterior superior iliac spine, one on each of the tibia plateau of the knee, one on each of the right and left lateral malleolus of the ankle, one on each of the right and left calcaneus, and one on each of the right and left first metatarsal. Most of the markers were attached to the participant's clothing with double sided tape and masking tape. The markers on the iliac spines were placed using a belt that had adjustable positions for the markers and those on the head were placed using a headband with markers attached to it. The markers' position in x, y and z was sampled at a rate of 200 Hz.

4.4.2. Measure of attentional focus

Participants were asked to self-report their attentional focus by giving a percentage value as to how much attention they had allotted to stepping and how much they had allotted to counting for the 5 dual task trials at normal knee height and for the 5 dual task trials at high knee height. They were given an example of 50% of attentional focus on the cognitive task and 50% of attentional focus if they thought that they had allocated the same attentional focus to both tasks . The reported percentage values were recorded.

4.5. Data Analyses

4.5.1. Data de-sampling and normalization of stepping duration.

Each marker's position in x (ML), y (AP) and z (vertical) acquired at 200 Hz during each trial was transferred onto an Excel file. The duration of each trial was determined as the time between the moment of the first vertical displacement of the starting knee marker and the moment of the lowest vertical displacement of the other knee marker at the very last step. This duration was then normalized as 100% duration. Then, subsequent markers positions in x (ML) and y (AP) were extracted at every 5% duration (0%, 5%, 10%, 15% ...).

A verification was done to ensure that the number of steps was equal for each 20% interval. It was found that participants' stepping rhythm was constant and 5 steps with the left leg and 5 steps with the right leg were done during each of 20% duration. This stepping rate was similar across conditions.

4.5.2. ML and AP linear displacements

Linear displacements of the body in the x-y plane were established from a virtual marker representing the center between the two shoulders. The position in x of the two shoulder markers were averaged to obtain the position in x of the virtual marker, and the position in y of the two

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

shoulder markers were averaged to obtain the position in y of the virtual marker. These x and y positions were extracted at every 5% of trial duration (0%, 5%, 10%, 15% ...). ML and AP displacements were calculated as the difference in position between 5% and 0%, between 10% and 0%, etc. All the obtained values (positive and negative, as collected by the 3-D motion analysis system) were converted in absolute values because the variables of interest were the extent of the displacements, and not the direction of the displacement. Results are reported for 20% duration intervals (20%, 40%, 60%, 80%, 100%). Outliers representing the mean \pm 2 S.D. were removed from the data set. A total of 82 outliers for ML displacement and 50 outliers for AP displacement were removed, amounting to 5.1% and 3.1% of the total number of trials for ML and AP displacements, respectively. Since results were reported at every 20% of the trial duration for 16 participants over 20 trials, the 82 outliers were removed from a total of 1600 data points. All outliers were positive, therefore too high, as values were all converted to absolute. There were similar quantities of outliers at each 20% duration interval.

4.5.3. Body rotation.

Body rotation (BR) is one's angular movement relative to space or to a vertical axis of rotation. BR corresponds to the participant's body angle at each position relative to its initial position. Using excel functions, body rotation was calculated using the following steps.

1. Calculating the initial body rotation

$R1 = \text{Degrees}(\text{ATAN}(\text{initial Y position left} - \text{initial Y position right})/(\text{initial X position left} - \text{initial X position right}))$

2. Calculating the final body rotation

$R2 = \text{Degrees}(\text{ATAN}(\text{final Y position left} - \text{final Y position right})/(\text{final X position left} - \text{final X position right}))$

3. $BR = R2 - R1$

BR was determined throughout each trial with the same analyses, at every 5% of trial duration. Thus, BR was calculated as the difference in position between 5% and 0%, between 10% and 0%, etc. and then, converted in absolute values. Like for linear displacements, BR results are reported for 20% duration intervals. Outliers representing the mean ± 2 S.D. were removed from the data set. A total of 16 outliers were removed from the data set.

4.5.4. Knee height

Position in z (vertical direction) of the right and left knee markers was inspected visually in the raw data and the maximum value for each step was noted. Knee height was the maximum value (the highest vertical position of the knee) minus the minimum value obtained during standing before the first step (the lowest vertical position of the knee). For each trial, 25 knee height values were obtained for the right knee and 25 for the left knee. Values were averaged for each side and each condition. Since there was no significant difference in knee height between the two legs, a combined left-right mean knee height was calculated and reported. Since rhythm and height of stepping were self-selected, knee height was not controlled for but rather measured and recorded. Participants were given a demonstration of an appropriate self-selected knee height to replicate.

4.5.5. Self-reported attentional focus

Percentages of attentional focus attributed to the stepping task and the cognitive task reported by participants were averaged for each dual task condition, i.e. NK DT and HK DT.

4.6 Statistical analyses

All statistical analyses were performed with IBM SPSS Statistics 24.

To verify whether data sets were normally distributed, a skewness index was calculated for ML and AP displacement and BR variables. For a majority, the skewness index was more than twice the value of its standard error, indicating departure from symmetry of distribution. Thus, parametric statistic tests were not appropriate for the analyses of these data.

This study included two independent variables: task condition (single task, dual task) and knee height condition (natural knee height, high knee height). Since there is no non-parametric tests that corresponds to a two-way ANOVA, the best option was to compare dependent variables for the four conditions with the non-parametric Friedman test. Thus, variables obtained during single task – normal knee height (NK), dual task – normal knee height (NK DT), single task - high knee height (HK), and dual task - high knee height (HK DT), were compared with the Friedman test. Subsequent pairwise comparisons were done with Wilcoxon Signed Rank tests. Statistical significance was set at $p \leq .05$. When pairwise comparisons were done among the 4 conditions, a Bonferroni correction was applied, i.e. $.05/4 = .0125$, and statistical significance was then set at $p \leq .0125$.

Two variables met the conditions for parametric tests: maximum knee height and duration of 50-step trials. These variables were compared with the two-way ANOVA for repeated measures, followed by pairwise comparisons for which a Bonferroni correction was applied. Statistical significance was then set at $p \leq .0125$.

CHAPTER FIVE: RESULTS

5.1. Stepping characteristics

Table 1 lists mean maximum height in cm (1 S.D.) at which the knees were lifted during stepping in place in the four conditions. A significant main effect of knee height condition was found ($F(1,31) = 207.85, p \leq .001, \eta^2 = .870$) in which a difference of 16.1 cm was found between normal knee and high knee in the single and dual task conditions. In addition, the analysis revealed a significant main effect of dual task condition ($F(1,31) = 7.83, p = .009, \eta^2 = .202$) in which differences of 1.1 cm and 1.2 cm were found between single and dual task at normal and high knee, respectively. Thus, participants stepped slightly lower in dual task than in single task, both at normal and high knee height. No significant interaction was found between the two factors.

Table 2 lists mean duration of 50-step trials in sec (1 S.D.) and corresponding stepping frequency in Hz in the four conditions. A significant main effect of knee height condition was found ($F(1,15) = 24.58, p \leq .001, \eta^2 = .621$) in which differences between normal and high knee height of 1.7 sec and 2.0 sec were found at single and dual task conditions, respectively.

5.2. ML and AP displacements

Figure 1 (A to D) illustrates four examples of 2-D body displacements in the horizontal plane obtained in participant #10. Each data point represents the coordinates (ML, AP) obtained at each 5% of trial duration. The filled circles represent the top of the participant's head at the end of the trajectory of their displacement and is indicative of the direction of displacement and BR. The starting position' coordinates represents the real body position in the room (instead of 0,0), and is at the intersection of the x and y axes.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

The relationship between AP and ML displacements reveals the progressive drifting of the body forward and sideways to the right in a diagonal trajectory. This figure also illustrates the difference in the amount of displacement between the conditions. It shows a greater displacement in HK (Figure 1C) compared to NK (Figure 1A). It also illustrates less displacement in HK DT (Figure 1D) compared to HK (Figure 1C).

Figure 2 (A and B) illustrates group means (+1 S.D.) of displacement in absolute values in ML and AP directions for the 5 duration intervals (20%, 40%, 60%, 80% and 100%) during stepping in place in the four conditions. The two illustrations show the progressive linear body displacement in ML and AP during the 50-step trials, with the final end point displacement at the 100% interval.

5.3. Body rotation

Table 3 lists group mean absolute BR in degree (1 S.D.) at the 5 duration intervals during stepping in place in the four conditions. BR was progressive throughout the 50 steps, which is illustrated by the progression from each interval in Table 3. The 100% duration interval is indicative of the final end point angular position. At the end of 50 steps, participants rotated an average of 20.5 degrees towards the right or left in the NK condition.

5.4. Effect of dual task on ML and AP displacements and BR

At normal knee height, dual task had a significant effect on AP displacement at the 60% duration (Friedman test $X^2= 12.08$, $p=.007$; Wilcoxon test $z=-2.75$, $p=.006$) and at the 100% duration ($X^2= 13.41$, $p=.007$; $z=-2.88$, $p=.004$).

At high knee height, no significant effect of dual task was found.

No significant effect of dual task on ML displacement and BR was found.

5.6. Effect of knee height on ML and AP displacements and BR

During the single task of stepping in place, knee height had a significant effect on AP displacement at the 80% duration ($X^2= 19.80$, $p=.001$; $z=-2.77$, $p=.006$).

During dual task, knee height had a significant effect on ML displacement at the 40% duration ($X^2= 13.51$, $p=.004$; $z=-3.43$, $p=.001$), at the 60% duration ($X^2= 13.59$, $p=.004$; $z=-4.22$, $p=.001$), and at the 100% duration ($X^2= 14.28$, $p=.003$; $z=-4.24$, $p=.001$). In addition, knee height during dual task had a significant effect on AP displacement at the 40% duration ($X^2= 11.56$, $p=.009$; $z=-3.26$, $p=.001$), at the 60% duration ($X^2= 12.08$, $p=.007$; $z=-3.78$, $p=.001$), at the 80% duration ($X^2= 19.80$, $p=.001$; $z=-3.96$, $p=.001$), and at the 100% duration ($X^2= 13.41$, $p=.004$; $z=-3.95$, $p=.001$).

At 100% of the duration of 50 steps, the group mean ML displacement was 19 cm longer for the HK compared to the NK. With a dual task, it was 43 cm longer for the HK DT condition than the NK DT. The average change in AP displacement from the start point was 24 cm longer for the HK condition than for the NK condition. With a dual task, it was 36 cm longer for the HK DT than for the NK DT.

No significant effect of knee height on BR was found.

5.6. Attentional focus during dual task conditions

For the NK DT condition, the mean self-reported attentional focus that was allocated to the cognitive task was 68.4% whereas that allocated to the stepping task was 31.6%. For the HK DT condition, the percentages were 55.6% and 44.4%, respectively. A significant difference in the focus allocated to the cognitive task was found between NK DT and the HK DT, $t(15) = 3.29$, $p=.005$.

CHAPTER SIX: DISCUSSION

In this study, stepping in place for 50 steps without vision was associated with linear and angular body displacements. These body displacements were compared with and without a concurrent cognitive task, and while stepping with normal knee height versus high knee height. The main findings are: 1) Forward body displacement was significantly smaller in the dual task condition than in the single task condition when stepping at normal knee height; 2) Forward and ML body displacements were significantly larger in the high knee height condition than in the normal knee height condition, in both the single and dual task conditions; 3) Body rotation was not significantly different among conditions.

6.1. A Kinematic study of stepping in place without vision

In this study, we are describing not only the end effect of stepping in place without vision but also the 2-D body displacement (AP and ML directions) throughout the 50 steps (see Figure 1), as well as the height at which the knees were lifted (see Table 1). This data was captured using a 3-D motion analysis Vicon system that consisted of 7 infrared cameras. This study is novel as it is one of the first to describe one's body displacement in stepping in place without vision. More than 30 years ago, a study measured body trajectory during stepping in place using a more traditional method. In this case, the perforation of each step into a piece of paper underneath the participant's feet was used to trace their trajectory (Gagey, Bizzo, & Debrulle, 1983). From this, it was known that individuals were moving forward and sideways, into a diagonal trajectory while stepping without vision. Our results showed a similar displacement pattern (see Figure 1). Recently, Malmstrom and her colleagues (2017) reported the distance travelled and body rotation associated with stepping on the spot without vision for 35 seconds,

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

which roughly corresponds to 50 steps, with the use of a 3-D motion analysis system. They found that participants displaced an average of 80.5 cm after 25 seconds, which is a single number they obtained to represent the hypotenuse of ML and AP displacements based on the Pythagorean Theorem. Similar calculations with our ML and AP displacements gives an average travelled distance of 93.5 cm in the NK condition. The difference of 13 cm between the two studies may be explained by the fact that Malmstrom et al. (2017) did not report the final displacement but rather that at 25 seconds. They chose to use the initial 25 seconds of each trial recording as in the following 10 seconds, which they excluded, some of the participants displaced outside of the area captured by their recording devices as they had an environmental space constrain. All of their trials had an imposed time of 35 seconds whereas ours varied among participants and averaged 29.9 seconds. It is possible that the displacement continued to increase and would have been more similar to our average obtained at 29.9 seconds. Regarding body rotation, they obtained an absolute rotation of approximately 19° at 25 seconds which is similar to our absolute mean result of 20.5° at 29.9 seconds in the NK condition.

To our knowledge, the present study was the first to separately record and report AP and ML displacements together with body rotation during stepping in place without vision. It allowed us to evaluate the linear and angular body progression in the horizontal plane rather than just the endpoint of displacement at the end of the 50 steps. This is important as it allowed us to explore body displacement and rotation in stepping in place without vision to be able to better describe the phenomenon. We also now have a better understanding of the timing of the events as they occur throughout the stepping task. In other words, we were able to explore the spatio-temporal aspects of stepping in place without vision.

Kinematic recordings allowed us to determine the height at which the knees were lifted. Participants in our study stepped on average at a knee height of 15.0 cm in the NK condition. This is more than the step height of 11.1 cm reported by Ikeda et. al (2014) who had participants step with their eyes open at a self-selected knee height and self-selected stepping frequency. The reason for this difference is not clear, but it could be related to the demonstration by the investigator of the stepping style given to the participants. As mentioned in the methodology, our demonstration was to step with hip flexion of approximately 45 degrees at maximum, while there is no report of such demonstration in Ikeda and colleagues (2011 and 2014). Our kinematic study allowed to determine that our participants stepped on average at a frequency of 1.67 Hz in the NK condition. This is slightly lower than the 1.86 Hz stepping frequency reported by Ikeda et al. (2011). Such difference is likely attributable to the difference in stepping height between the two studies. For instance, Ikeda and colleagues (2011 and 2014) showed that as the stepping frequency increases, stepping height decreases. It can also be due to different demonstration of the stepping task to participants between the two studies.

6.2. Smaller forward displacement in the dual task condition

The study revealed that body displacement in the AP direction was significantly smaller in the dual task than in the single task condition when stepping at comfortable knee height (i.e. NK DT smaller than NK). Since AP displacements were systematically forward, never backward, it is then the forward displacement that was significantly smaller. This indicates that the performance of staying on the spot during stepping in place without vision was better with the concurrent cognitive task than without.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

The task of staying on the spot while stepping implies to place each foot on the ground at the exact same spot from which it was lifted for the previous step. With the addition of a cognitive task, this placement of the foot on the ground was likely better performed because forward progression was minimized and there was less body displacement. Foot placement error was systematic as participants displaced from the start line. Not only was there error in the re-placement of the foot back on the ground at each step but also the error was systematic as a progressive forward displacement occurred, away from the starting point.

It is notable that knee height was 1.2 cm lower during NK DT than during NK (see Table 1). This lower knee height between the conditions partly explains the smaller AP displacement which was 22.8 cm less during NK DT compared with NK. We found that knee height has a significant effect on AP displacement, with higher knee height associated with larger AP displacements (see Figure 2b). However, the small difference in knee height between NK DT and NK may not explain all the difference in AP displacement. One possible reason to explain this dual task effect is that postural control is more efficient when a cognitive task is concurrently done (Wulf, & McNevin, 2001; Richer et. al 2017). This, in turn, could contribute to minimize body sway during the many single leg stances that occur while stepping. As a result, body displacement could be decreased due to better foot placement during the 50 steps.

Another possible explanation is that the concurrent cognitive task also has an impact on one's perception of body displacements or body position relative to the vertical in dynamic blind navigation. Consistent with this, Lajoie and colleagues (2013) reported that participants had a better blind navigation performance in the dual task condition involving a reaction time task compared with the control condition. In that study, blindfolded participants walked towards a target placed 8 meters ahead of them. In our study involving stepping without vision, better

perception of body displacements would cause less displacement since participants would be more aware and in control of their foot placement for each step. In addition, a better perception and control of body position relative to the vertical would promote a more vertical body position, which in turn could result in less forward body displacement. Altogether, the findings support that perception and control of self-motion might have been improved under the dual task condition. The exact mechanism is yet to be established, but it likely concerns the complex interaction and integration of motor, sensory, and cognitive functions in blind navigation (Trullier, Wiener, Berthoz, & Meyer, 1997; Wolbers & Hegarty, 2010). A further evaluation of the verticality of the trunk by analyzing data obtained from the Vicon in this experiment is something that may be considered for a future study.

6.3. Larger linear displacements at high knee height

When stepping in place without vision, knee height had an effect on the ML and AP displacements. In the single stepping task, ML displacement was larger in HK than NK only at the end of the trial (at the 100% duration interval), and AP displacement was larger at the 80% duration interval (see figure 2). The impact of knee height was more pronounced in the dual task condition. ML and AP displacements in HK DT were larger than in NK DT as early as at the 20% (for ML) and 40% duration interval (for AP), and during the rest of the stepping trials (see figure 2). Thus, AP and ML displacements were larger at high knee height than at normal knee height.

The impact of the dual task on AP displacement was not observed when stepping at high knee height. Specifically, forward displacement was significantly smaller at NK DT than NK, but forward displacement was similar at HK DT and HK (see Figure 2). It is possible that this is in part caused by an increased difficulty when stepping with high knees. This difficulty may be

“cancelling” the benefit that the concurrent cognitive task has on stepping in place at a natural knee height in which displacement was minimized. Perhaps the triple task involved when stepping with high knees with the addition of a cognitive task is simply too difficult to yield any performance improvement. It is possible that there is a threshold of difficulty for the cognitive task that has benefits, after which performance will plateau or even eventually decline. This is in line with the U-shaped non-linear interaction model (Wulf et. al., 2001). This model suggests that postural performance (body sway) on a dual task involving a concurrent cognitive task would be best if the cognitive task is easy, and would deteriorate with increased difficulty of the cognitive task. At a moderate level of difficulty of the cognitive task, performance would plateau. After the plateau, attentional demands increase with increased difficulty of the task, causing declines in performance (Posner, & Keele, 1969). This theory possibly explains the decreased displacement in the NK DT condition and the increased displacement in the HK DT condition. In the NK DT condition, the level of difficulty of the cognitive task was relatively easy during stepping in place. Consequently, the performance of staying on the spot while stepping improved with the concurrent cognitive task. In the HK DT condition, it is possible that stepping with high knees plus performing the concurrent cognitive task required so much attention that the performance of staying on the spot suffered. Perhaps with a very easy cognitive task, performance in stepping in place in the HK DT condition would have been improved.

Larger ML and AP displacements when the knees are lifted higher may be due to biomechanical factors. First, higher knee position at each step likely moves the body center of mass forward while the individual is on single leg stance. This is likely more de-balancing than lifting the knees at a natural stepping height. The base of support is small in single leg stance, , whereas in bipedal stance the base of support is larger and the hip position is symmetrical.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

Lifting the knees high is more challenging for balance as the foot there is more distant to the ground, thus causing it to be more difficult to reposition the foot at the exact same spot on the ground from which it was lifted. As a result, the placement of each foot on the ground was at a slightly more forward and sideways position from which it was lifted for the previous step.

Second, it could be argued that the speed at which the knees were lifted influenced the control of balance during single leg stance, and subsequently ML and AP displacements. Certainly, knees are moved faster at a high knee height than at a lower knee height for a specific stepping frequency. However, we found that the average stepping frequency was significantly lower at high knee than at normal knee height (see Table 2). Thus, the knee lifting speed may not be a major factor explaining the larger ML and AP displacements at high than normal knee height.

Larger ML and AP displacements in high knee conditions may be due to biomechanical factors. The task of lifting the knees high requires stronger muscle contractions of hip flexors compared to stepping with lower knee height, and thus a larger effort. It also likely requires stronger contractions of hip and trunk stabilisation muscles. Muscle groups that are used to stabilize the hip joint in in single leg stance in the AP direction are hip flexors and extensors. To stabilize the ankle joint in the AP direction the plantarflexors and dorsiflexors must be activated. In the ML direction, single leg stability is ensured by the hip abductors and adductors, as well as the ankle invertor and evertor muscles (Winter, 2009). With high knee unipedal stance, the muscles stabilizing the hip take over the control of posture from those that support the ankle, which are the primary muscles used in bipedal standing (Riemann, Myers, & Lephard, 2003).

In stepping in place, the base of support of the body is constantly shifting. It becomes smaller in one legged stance than in bipedal stance. This decreased base of support may have a de-balancing effect on the control of balance. In one legged stance with high knees, one's center

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

of gravity (CoG) becomes more proximal, which may have had a de-balancing effect (Tropp & Oderick, 1988). Another de-balancing influence is sway velocity which tends to increase at high legged unipedal stance and have a deteriorating effect on balance control (Bisson, McEwan, Lajoie, & Bilodeau, 2013).

Balance control is influenced by three primary sources of input; visual, vestibular and proprioceptive (Tropp & Oderick, 1988). In the case of this study, visual input was obstructed entirely thus causing balance to rely on vestibular and proprioceptive input. This may have caused balancing to be more difficult.

Neurophysiological factors may also be involved. Indeed, our results show that a larger attentional focus was directed at the stepping task in the HK DT condition (43.5% of focus) than in the NK DT condition (31.5% of focus). This suggests that the attentional demand of the HK DT condition was larger than that of the NK DT because the larger effort to lift the knees combined with the request of staying in place while stepping and performing a concurrent cognitive task could be considered a triple task. The HK DT condition may have been more difficult than the other three conditions due to the attentional demand of three different simultaneous tasks, and this may explain why linear displacements were larger throughout the stepping trials. This is in line with the capacity sharing theory for information processing which explains that there is an allocated amount of attentional capacity to be shared among two simultaneous tasks and performance on one task will decrease if this attentional capacity is exceeded. (Woollacott, & Schumway-Cook, 2002, Tombu, & Jolicoeur, 2003). In this case, it suggests that performance was affected because the attention capacity required to perform HK DT was exceeded.

6.4. No effect of dual task and knee height on body rotation

The body rotation reported in this study represents the amount of rotation (absolute values) rather than the direction of rotation. In the NK condition, the mean body rotation was 20.5°. We used absolute values rather than signed values since we were interested in evaluating the extent of angular displacement throughout 50 steps, as a quantity, rather than the direction of this displacement. This is somewhat similar to the results from Munnings and colleagues (2015) that found an average body rotation of 17.3° for 44 participants who completed 50 steps in place without vision.

Our results indicate that angular displacements were not significantly modified neither by the dual task condition, nor by the high knee height condition (see Table 3). This may be in part due to the large variability in the body rotation data. Body rotation was highly variable among participants and was both in the clockwise and counterclockwise directions. Even after signed body rotations were transformed into absolute values, variability was large, as shown by standard deviations in Table 3. Large variability in body rotation is a known characteristic of stepping in place without vision (e.g. Previc & Saucedo, 1992; Bonanni & Newton, 1998; Paquet et al., 2014; Munnings et al., 2015). For example, Munnings and colleagues (2015) yielded a similar variability to ours after 50 steps in place. Their resulting variability of two standard deviations was 29.4° which is similar to ours (i.e. 2 x our SD 13.5° in the NK condition = 27°) after 50 steps.

Another explanation as to why the dual task and high knee height conditions did not change body rotation may be that the control of angular displacement during blind stepping in place is less modifiable by a concurrent cognitive task or by stepping height than the control of

linear displacements. A previous study showed that body rotation during stepping on the spot without vision was not changed by the addition of a 2.3 kg weight at the ankle on the dominant leg (Paquet et al., 2015). In contrast, strong sensory stimulations such as unilateral neck vibration (Bove et al., 2002), galvanic stimulation (Osler & Reynolds, 2012) and auditory cues (Munnings et al., 2015) changed body rotation. Thus, it is possible that our concurrent cognitive task and high stepping conditions, like the 2.3 kg ankle weight, were not significant factors in the interaction between self-motion cues and computational mechanisms involved in the perception and control of body rotation during blind navigation tasks (Wolbers & Hagarty, 2010)

6.5.Limitations

There are several limitations to this study that were made evident throughout the data analysis.

6.5.1. Non-parametric statistics

Since the ML and AP displacement data and body rotation data obtained were not normally distributed, non-parametric statistics had to be used, which are less sensitive to differences than parametric statistics. However, non-parametric statistics were the appropriate option for the analyses of these data.

6.5.2. Stepping style

The stepping pace and height were not controlled and thus, varied among trials and participants. The rhythm of stepping was not imposed by a metronome and knee height was not imposed by a target. Participants would not have been able to follow the metronome, reach the knee height target and perform the cognitive task at the same time. However, the stepping

rhythm was reasonably similar among participants and the mean knee height corresponded to the demonstrated knee height, both at normal and at high knee height.

6.5.3. Fatigue

It is possible that fatigue influenced the results regarding the effects of knee height, as the 10 high knee trials were always done after the 10 normal knee height trials. However, no participants reported being fatigued during the testing session. They were given the opportunity to rest at any point although no participant requested a break which suggests that none of them experienced fatigue.

6.5.4. Footedness

Footedness is known to influence the direction of body rotation in blind stepping in place (Previc & Saucedo, 1992; Paquet et al., 2014). Thus, we only used right footed participants, as a means of attempting to reduce a bias by footedness. With that said, a lack of generalisation of the results may have been introduced as a result of the exclusion of left-footed individuals.

6.6. Contributions of the study

This study sought to fill a gap in current scientific knowledge regarding the kinematics involved with a blind stepping in place task. Our results provide an enhanced understanding of the impact of a concurrent cognitive task on one's linear and angular displacements on a blind, dynamic stepping movement in a dual-task paradigm. We also have an enhanced understanding of the effect of knee height on such displacements. From this study, we are better able to describe the one's undetected linear and angular displacement in stepping in place without vision. The stepping in place without vision task has been used for many years yet there still

have not been many results of kinematic studies with regards to it, as provided in this study. We are now better able to understand the body kinematics of stepping in place without vision with a concurrent cognitive task and varying knee heights.

6.8. Future research

Future research could further explore the kinematics involved with blind stepping in place. It would be interesting to track the center of mass throughout the same task done in this study, to be able to evaluate the dynamic postural control involved with blind stepping in place. In doing so, verticality of the trunk could be evaluated and correlated with body position throughout the stepping task, to assess whether minimized forward displacement with a dual-task can be attributed to a different trunk orientation. It would also be interesting to analyze the markers that were placed on the head, to determine if the position of the head in the horizontal plane throughout the duration of the task had any effect on body rotation or direction of ML displacement.

CHAPTER SEVEN: CONCLUSION

This study revealed that one's unperceived linear displacement in stepping in place without vision is influenced by a concurrent cognitive task, as well as the height of the knees during stepping. At a normal stepping height, displacement in the AP direction was shorter in dual-task than single task. ML and AP displacement were larger at high than normal knee height. This indicates that the stepping-in-place performance was improved with the concurrent cognitive task, while it was worsened when stepping with high knee height. It suggests that the concurrent cognitive task favoured a more automatic control of posture during stepping at normal knee height, and that stepping with high knees may have increased the attentional demand to the point that attentional resources were insufficient to ensure optimal performance of staying on the spot while stepping in place without vision.

CHAPTER EIGHT: REFERENCES

- Bisson, E.J., McEwan, D., Lajoie, Y., & Bilodeau, M. (2011). Effects of ankle and hip muscle fatigue on postural sway and attentional demands during unipedal stance. *Gait and Posture, 33*, 83-87.
- Bizid, R., Margnes, E., Francois, Y., Jully, J.L., Gonzalez, G., Dupui, P., & Paillard, T. (2009). Effects of knee and ankle muscle fatigue on postural control in the unipedal stance. *Eur. J. Appl. Physiol, 106*, 375-380.
- Bonanni, M., & Newton, R. (1988). Test-retest reliability of the Fukuda stepping test. *Physiotherapy Research International, 3(1)*, 58-68.
- Book, A., & Garling, T. (1981). Maintenance of orientation during locomotion in unfamiliar environments. *Journal of Experimental Psychology: Human Perception and Performance, 7(5)*, 995-1006.
- Bove, M., Courtine, G., & Schieppati, M. (2002). Neck muscle vibration and spatial orientation during stepping in place in humans. *Journal of Neurophysiology, 88*, 2232-2241.
- Bove, M., Diverio, M., Pozzo, T., & Schieppati, M. (2001). Neck muscle vibration disrupts steering of locomotion. *Journal of Applied Physiology, 91*, 581-588.
- Burdet, C., & Rougier, P. (2007). Analysis of center-of-pressure data during unipedal and bipedal standing using fractional brownian motion modelling. *Journal of Applied Biomechanics, 23*, 63-69.
- Burke, D., Hagbarth, K.E., Lofstedt, L., & Wallin, B.G. (1976). The responses of human muscle spindle endings to vibration of non-contracting muscles. *J. Physiol, 261*, 673-693.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

Elias, L.J., Bryden, M.P., & Bulman-Fleming, M.B. (1997). Footedness is a better predictor than is handedness of emotional lateralization. *Neuropsychologia*, *36*(1), 37-43.

Fukuda, T. (1959). The stepping test: Two phases of the labyrinthine reflex. *Acta Oto-Laryngologica*, *50*(1-2), 95-108.

Gagey, P.M., Bizzo, G., & Debrulle, O. (1983). Les paramètres du test de piétinement de Fukuda sont-ils valables? *Agressologie*, *24*(7), 331-336.

Grommes, C., & Conway, D. (2011). The stepping test: A step back in history. *Journal of the History of the Neurosciences*, *20*, 29-33.

Hickey, S.A., Ford, G.R., Buckley, J.G., & Fitzgerald O'Connor, A.F. (1990). Unterberger stepping test: a useful indicator of peripheral vestibular dysfunction. *The Journal of Laryngology and Otology*, *104*, 599-602.

Honaker, J. A., Boismier, T.E., & Shepard, N. P. (2009). Fukuda Stepping Test: Sensitivity and Specificity. *Journal of the American Academy of Audiology*, *20*(5), 311-314.

Huxhold, O., Li, S.H., Schmiedek, F., & Lindenberger, U. (2005). Dual-tasking postural control: Aging and the effects of cognitive demands in conjunction with focus of attention. *Brain Research Bulletin*, *69*, 294-305.

Ikeda, Y., Kamiyama, Y., Okuzumi, H., & Kokubun, M. (2011). Temporal and spatial parameters of stepping in place in children and adults. *Perceptual and Motor Skills*, *113*(1), 331-338.

Ikeda, Y., Okuzumi, H., & Kokubun, M. (2014). Dual task performance of the stroop color-word test and stepping in place. *Motor Control*, *18*, 76-87.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

Lajoie, Y., Paquet, N., & Lafleur, R. (2013). Attentional demand varies during a blind navigation pathway in young and older adults. *The Open Behavioural Science Journal*, 7, 1-6.

Lajoie, Y., Richer, N., Jehu, D.A., & Tran, Y. (2016). Continuous cognitive tasks improve postural control compared to discrete cognitive tasks. *Journal of Motor Behaviour*, 48(2), 264-269.

Lund, S. (1980). Postural effects of neck muscle vibration in man. *Experientia*, 36, 1398.

Malmstrom, E-M., Fransson, P-A., & Bruinen, T.J. (2017). Disturbed cervical proprioception affects perception of spatial orientation while in motion. *Experimental Brain Research*, 235, 2755-2766.

Munnings, A., Chisnall, B., Oji, S., Whittaker, M. & Kanegaonkar, R. (2015). Environmental factors that affect the Fukuda stepping test in normal participants. *The Journal of Laryngology and Otology*, 129, 450-453.

Osler, C. J., & Reynolds, R.F. (2012). Dynamic transformation of vestibular signals for orientation. *Experimental Brain Research*, 223, 189-197.

Paquet, N., Jehu, D., & Lajoie, Y. (2016b). Impact of the number of steps on the Fukuda stepping test in older adults. *Physical and Occupational Therapy in Geriatrics*, 34 (1), 104-111.

Paquet, N., Jehu D., & Lajoie, Y. (2017). Age-related differences in Fukuda stepping and Babinski-Weil tests, within-day variability and test-retest reliability. *Aging Clinical and Experimental Research*, 29(2), 223-230.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

- Paquet, N., Lajoie, Y., Rainville, C., & Sabagh-Yazdi, F. (2008). Effect of navigation direction on the dual-task of counting backward during blind navigation. *Neuroscience Letters*, 442, 148-151.
- Paquet, N., & Taillon-Hobson, A. (2015). Effect of ankle weight on blind navigation. *Perceptual & Motor Skills: Motor Skills & Ergonomics*, 120 (2), 502-518.
- Paquet, N., Taillon-Hobson, A., & Lajoie, Y. (2014). Fukuda and Babinski-Weil tests: Within-subject variability and test-retest reliability in nondisabled adults. *Journal of Rehabilitation Research and Development*, 51(6), 1013-1022.
- Peitersen, E. (1967). Vestibulospinal reflexes: Theoretical and clinical aspects of the stepping test. *Acta Oto-Laryngologica*, 85, 192-198.
- Petterossi, V.E., & Schieppatti, M. (2014). Neck proprioception shapes body orientation and perception of motion. *Frontiers in Human Neuroscience*, 8 (895), 1- 13.
- Polskaia, N. & Lajoie, Y (2016). Reducing postural sway by concurrently performing challenging cognitive tasks. *Human Movement Science*, 46, 177-183.
- Posner, M.I., & Keele, S.W. (1969). Attentional demands of movement. *Proceedings of the 16th congress of applied psychology*. Amsterdam: Swets and Zeitlinger.
- Prévic, F. H., & Saucedo, J.C. (1992). The relationship between turning behavior and motoric dominance in humans. *Perceptual & Motor Skills*, 75, 935-944.
- Reiss, M. & Reiss, G. (1997). Asymmetry of the stepping test. *Perceptual and motor skills*, 85, 305-306.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

Reiss, M. & Reiss, G. (1997). Further aspects of the asymmetry of the stepping test. *Perceptual and motor skills*, 85, 1344-1346.

Richer, N., Paquet, N. & Lajoie, Y. (2013). Impact of age and obstacles on navigation precision and reaction time during blind navigation in dual-task conditions. *Gait and Posture*, 39, 835-840.

Richer, N., Saunders, D., Polskaia, N. & Lajoie, Y. (2017). The effects of attentional focus and cognitive tasks on postural sway may be the result of automaticity. *Gait and Posture*, 54, 45-49.

Riemann, B.L., Myers, J.B., & Lephard, S.M (2003). Comparison of the ankle, knee, hip, and trunk corrective action shown during single-leg stance on firm, foam, and multiaxial surfaces. *Arch Phys Med Rehabilitation*, 84, 90-95.

Sabharwal, S. & Kumar, A. (2008). Methods for assessing leg length discrepancy. *Clinical Orthopaedics and Related Research*, 466(12), 2910-2922.

Schmid M. & Schieppati, M. (2004). Neck muscle fatigue and spatial orientation during stepping in place in humans. *Journal of Applied Physiology*, 99, 141-153.

Serafini, F., Caovilla, H.H., & Gananca, M.M. (2008). Digital craniocorpography and peripheral vestibular diseases. *International Tinnitus Journal*, 14(1), 34-36.

Takemori, S., Ida, M., & Umezu, H. (1985). Vestibular training after sudden loss of vestibular function. *ORL*, 47(2), 76-83.

Tombu, M. & Jolicoeur, P. (2003). A central capacity sharing model of dual-task performance. *Journal of Experimental Psychology Human Perception Performance*, 29, 3-18.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

Toussaint, Y., Do, M.C., & Fagard, J. (2008). What are the factors responsible for the deviation in stepping on the spot? *Neuroscience Letters*, *435*, 60-64.

Tropp, H., & Odenrick, P. (1988). Postural control in single-limb stance. *Journal of Orthopaedic Research*, *6*, 833-839.

Trullier, O., Wiener, S., Berthoz, A., & Meyer, J-A. (1997). Biologically based artificial navigation systems: review and prospects. *Progress in Neurobiology*, *51*. 483-544.

Vuillerme, N., Nougier, V., & Teasdale, N. (2000). Effects of a reaction time task on postural control in humans. *Neuroscience Letters*, *291*, 77-80.

Winter, D.A. (2009). *Biomechanics and Motor Control of Human Movement, Fourth Edition*. Waterloo, Ontario: John Wiley & Sons, Inc.

Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities? *Trends in Cognitive Sciences*, *14(3)*, 138-146.

Woollacott, M. & Shumway-Cook (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait and Posture*, *16*, 1-14.

Wulf, G., McNevin, N., & Shea, C. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology*, *54A(4)*, 1143-1154.

Zhang, Y. B., & Wang, W.Q. (2011). Reliability of the fukuda stepping test to determine the side of vestibular dysfunction. *The Journal of International Medical Research*, *39*, 1432-1437.

CHAPTER NINE: APPENDICES

Appendix A: Tables and Figures

Table 1. Mean maximum knee height in cm (1 S.D.) in the four conditions.

Normal knee height	
Single task	15.0 (5.8)
Dual task †	13.8 (5.2)
High knee height *	
Single task	31.1 (11.3)
Dual task †	29.9 (9.6)

* Significant main effect of knee height

† Significant main effect of dual task

Table 2. Mean duration of 50-step trials in sec (1 S.D.) and corresponding stepping frequency in Hz in the four conditions.

	Duration	Frequency
Normal knee height		
Single task	29.9 (3.7)	1.67
Dual task	29.6 (3.9)	1.69
High knee height *		
Single task	31.7 (3.8)	1.58
Dual task	31.6 (3.5)	1.58

* Significant main effect of knee height

Table 3. Mean body rotation in ° (1 S.D.) at 5 duration intervals during stepping in place in the four conditions.

	Duration intervals				
	20%	40%	60%	80%	100%
Normal knee height					
Single task	4.7 (2.3)	8.4 (4.8)	11.4 (5.9)	15.2 (8.0)	20.5 (13.5)
Dual task	4.4 (3.6)	5.0 (4.7)	6.7 (5.8)	9.8 (9.5)	12.8 (11.9)
High knee height					
Single task	3.0 (1.8)	6.4 (5.5)	9.9 (6.6)	17.3 (13.8)	27.6 (26.3)
Dual task	6.1 (4.4)	9.4 (8.4)	15.6 (14.7)	20.5 (17.6)	26.8 (23.0)

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

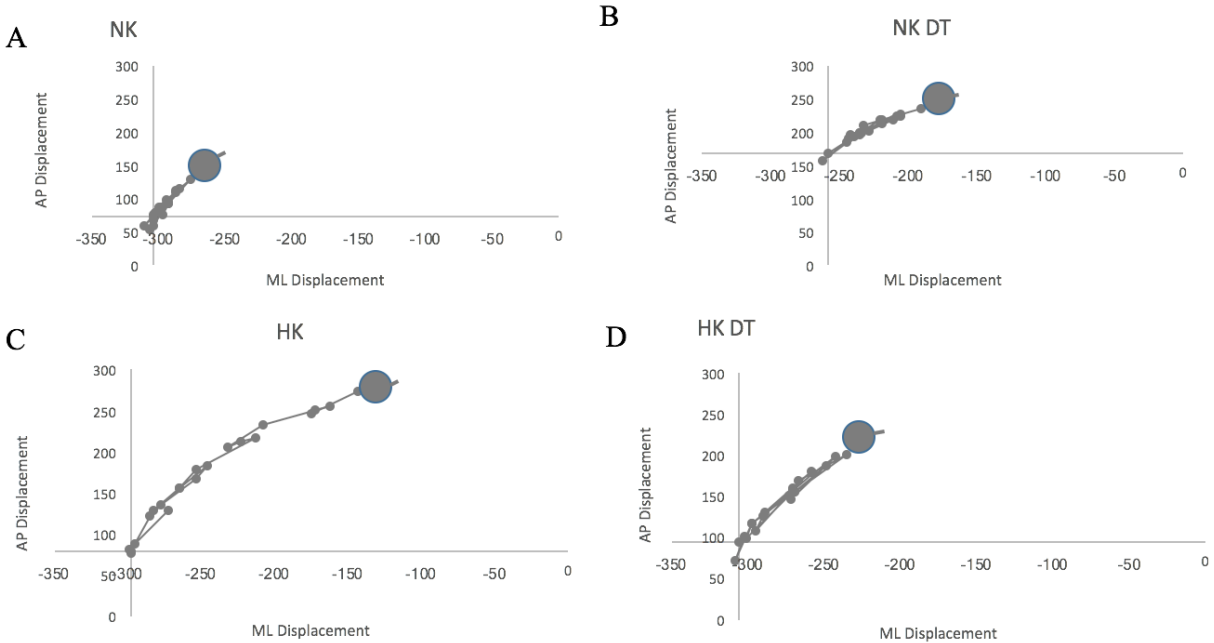


Figure 2. Examples of 2-D body displacement in the horizontal plane in participant #10. A. normal knee (NK) condition (trial 9); B. normal knee dual task (NK DT) condition (trial 10); C. high knee (HK) condition (trial 17); D. high knee dual task (HK DT) condition (trial 11). ML and AP displacements are in mm. Each data point represents the coordinates (ML, AP) obtained at each 5% of trial duration. The intersection between the two axes represent the starting spot. The filled circle represents a view of the top of the participant's head at the final position of the displacement.

Effects of Dual-Task and Knee Height on Body Displacements in Blind Stepping in Place

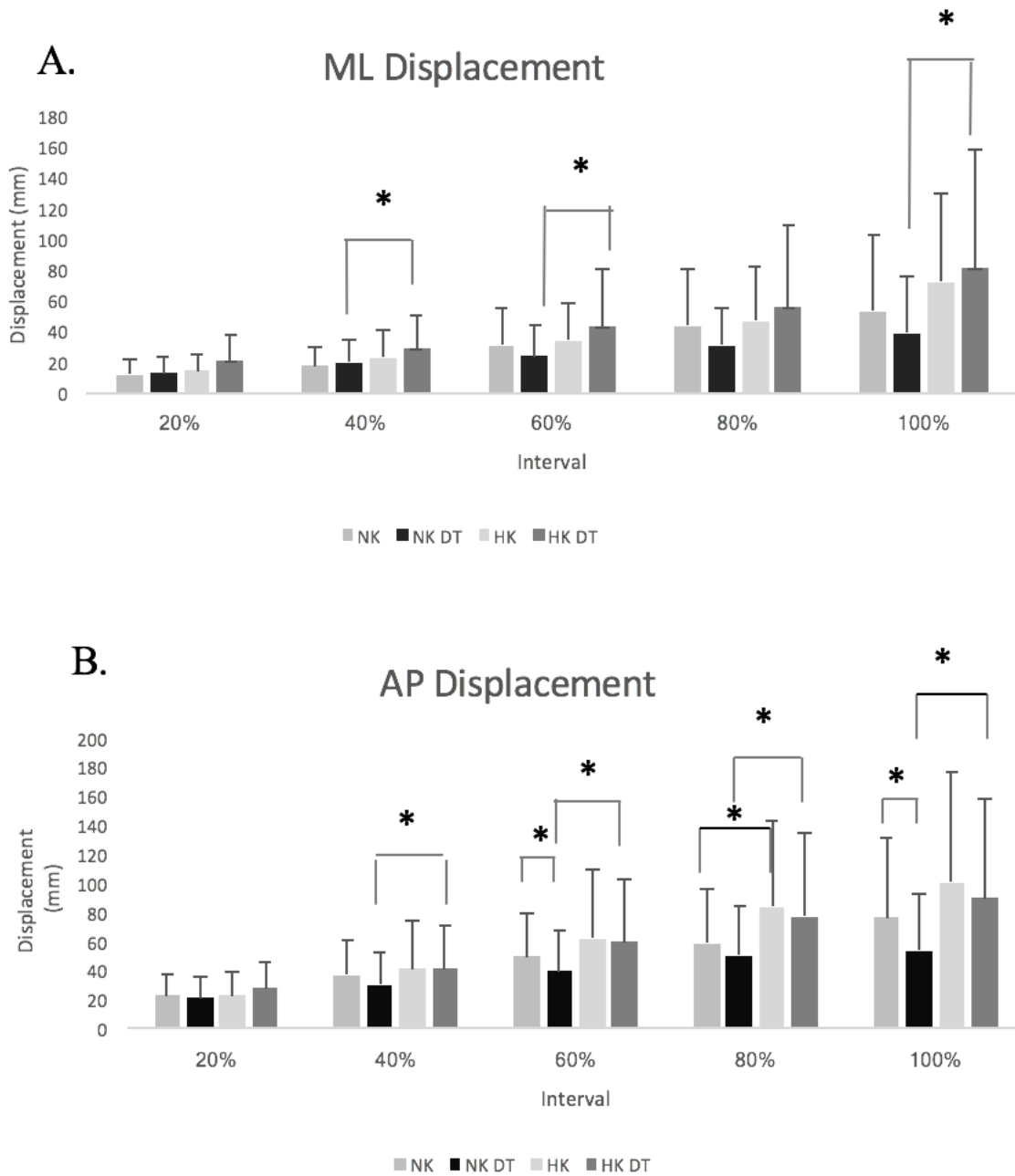


Figure 2. Mean absolute displacement in mm (+1 S.D.) at every 20% duration interval in the four conditions A. ML direction; B. AP direction.

* indicates $p \leq 0.0125$

THE EFFECT OF A CONCOMITANT COGNITIVE TASK ON ONE'S UNPERCEIVED
DISPLACEMENT AND KNEE HEIGHT IN STEPPING IN PLACE WITHOUT VISION: A
KINEMATIC STUDY

APPENDIX B

Health Questionnaire administered to each participant prior to testing.

Name:

Sex: M/F

Age:

Height (cm):

Weight (kg):

Have you been experiencing any pain in your lower limb or back? (Y/N)

Do you have vertigo or have you been experiencing any dizziness? (Y/N)

Do you have any diagnosed neurological or vestibular condition? (Y/N)

Have you consumed any alcohol or mind altering drugs within the past 12 hours? (Y/N)

Is there any reason you do not feel like you should be participating in this study? (Y,N). If so, please explain.

THE EFFECT OF A CONCOMITTANT COGNITIVE TASK AND KNEE HEIGHT ON ONE'S UNPERCEIVED DISPLACEMENT IN STEPPING IN PLACE WITHOUT VISION: A KINEMATIC STUDY

APPENDIX C

Waterloo Footedness Questionnaire (Elias, Bryden, & Bulman-Fleming, 1997).

Instructions: Answer each of the following questions as best you can. If you *always* use one foot to perform the described activity, circle **Ra** or **La** (for **right always** or **left always**). If you *usually* use one foot circle **Ru** or **Lu**, as appropriate. If you use **both feet equally often**, circle **Eq**.

Please do not simply circle one answer for all questions, but imagine yourself performing each activity in turn, and then mark the appropriate answer. If necessary, stop and pantomime the activity.

1. Which foot would you use to kick a stationary ball at a target straight in front of you?	La	Lu	Eq	Ru	Ra
2. If you had to stand on one foot, which foot would it be?	La	Lu	Eq	Ru	Ra
3. Which foot would you use to smooth sand at the beach?	La	Lu	Eq	Ru	Ra
4. If you had to step up onto a chair, which foot would you place on the chair first?	La	Lu	Eq	Ru	Ra
5. Which foot would you use to stomp on a fast-moving bug?	La	Lu	Eq	Ru	Ra
6. If you were to balance on one foot on a railway track, which foot would you use?	La	Lu	Eq	Ru	Ra
7. If you wanted to pick up a marble with your toes, which foot would you use?	La	Lu	Eq	Ru	Ra
8. If you had to hop on one foot, which foot would you use?	La	Lu	Eq	Ru	Ra
9. Which foot would you use to help push a shovel into the ground?	La	Lu	Eq	Ru	Ra
10. During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?	La	Lu	Eq	Ru	Ra
11. Is there any reason (i.e. injury) why you have changed your foot preference for any of the above activities?	YES	NO			(circle one)
12. Have you ever been given special training or encouragement to use a particular foot for certain activities?	YES	NO			(circle one)
13. If you have answered YES for either question 11 or 12, please explain:					

THE EFFECT OF A CONCOMITANT COGNITIVE TASK AND KNEE HEIGHT ON ONE'S UNPERCEIVED DISPLACEMENT IN STEPPING IN PLACE WITHOUT VISION: A KINEMATIC STUDY



uOttawa
L'Université canadienne
Canada's university

APPENDIX D

Consent form given to each participant, in their preferred language, prior to their participation in the study.

Faculté des sciences de la santé Faculty of Health Sciences
École des sciences de la réadaptation School of Rehabilitation Sciences

Consent Form (EN)

Projet title: The effect of a concomitant cognitive task on one's unperceived displacement in stepping in place without vision: A kinematic study

Researchers:

Jessica Grostern, BSc.,

Nicole Paquet, PT, PhD

Invitation to Participate: I am invited to participate in the abovementioned research conducted by Jessica Grostern, in the context of a Master's thesis, under the supervision of Nicole Paquet.

Purpose of the Study: The purpose of the study is to investigate how the execution of a cognitive task during stepping in place without vision affects the one's unperceived displacement. In addition, the study is aimed at determining whether this displacement is influenced by the height at which the knees are raised during stepping in place.

Participation: My participation will consist of one experimental session during which I will step in place for consecutive 50 steps while wearing opaque goggles that completely block vision. For some trials, I will have to memorize numbers while stepping, and for others, I will have to raise my knees high (my thigh will be horizontal) during stepping. For some trials, I will have to do both (memorization and high knee height). Small reflective markers will be fixed to my clothes and my body movements will be recorded with cameras that are part of a 3-D motion analysis system. The session will be held at the Psychomotricity Laboratory (Lees E053) and will last 45 to 60 minutes.

Risks: I will be blindfolded during stepping in place and thus, it is possible that I lose my balance. To avoid that I fall, the investigator will always be close to me so I can rely on her if necessary.

Benefits: My participation in this study will help to better understand the perception and control of unperceived displacements during stepping in place without vision in dual task conditions.

THE EFFECT OF A CONCOMITANT COGNITIVE TASK AND KNEE HEIGHT ON ONE'S UNPERCEIVED DISPLACEMENT IN STEPPING IN PLACE WITHOUT VISION: A KINEMATIC STUDY

Confidentiality and anonymity: I have the information I will share will remain contents will be used only for scientific be protected by keeping in a locked project. **Anonymity** will be protected by names.



received assurance from the researcher that strictly confidential. I understand that the publications and that my confidentiality will location all the documents related to this using numbers to identify subjects instead of

Conservation of data: The data collected on paper, and electronic support will be kept in a secure manner during 5 years in a locked locker in Dr. Paquet's office and on a USB key with a password. Then, all the data will be destroyed if the results are published. Otherwise, data will be kept until publication of the results for a maximum of 5 more years after which, they will be destroyed.

Voluntary Participation: I am under no obligation to participate and if I choose to participate, I can withdraw from the study at any time and/or refuse to answer any questions. If I choose to withdraw, all data gathered until the time of withdrawal will be destroyed.

Acceptance: I, _____, agree to participate in the above research study conducted by Jessica Grostern and Nicole Paquet of the School of Rehabilitation Sciences.

If I have any questions about the study, I may contact the researcher.

If I have any questions regarding the ethical conduct of this study, I may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON K1N 6N5

Tel.: (613) 562-5387

Email: ethics@uottawa.ca

There are two copies of the consent form, one of which is mine to keep.

Participant's signature: _____ Date: _____

Faculté des sciences de la santé	Faculty of Health Sciences
École des sciences de la réadaptation	School of Rehabilitation Sciences

Formulaire de consentement (FR)

Titre du projet: Les effets d'une tâche cognitive concomitante sur le déplacement non-perçu lors de la marche sur place sans vision : une étude cinématique

Chercheurs:

Jessica Grostern, BSc.,

Nicole Paquet, pht, PhD

Invitation à participer: Je suis invité(e) à participer à la recherche nommée ci haut qui est menée par Jessica Grostern dans le contexte d'une thèse de maîtrise supervisée par Nicole Paquet.

But de l'étude: Le but de l'étude est d'étudier comment l'accomplissement d'une tâche cognitive pendant la marche sur place sans vision affecte le déplacement involontaire de l'individu. De plus, l'étude vise à déterminer si ce déplacement est influencé par la hauteur du mouvement des genoux pendant la marche sur place.

Participation: Ma participation consistera en une séance expérimentale pendant laquelle je vais marcher sur place pendant 50 pas consécutifs avec un bandeau opaque qui bloque complètement la vision. Pour certains essais, je vais devoir accomplir une tâche de mémorisation de chiffres, et pour d'autres, je vais devoir lever mes genoux bien hauts (jusqu'à ce que ma cuisse soit horizontale) pendant la marche sur place. Pour certains essais, je vais devoir faire les deux (mémorisation et genoux levés haut). Des petits marqueurs réfléchissants seront fixés sur mes vêtements et les mouvements de mon corps seront enregistrés à l'aide de caméras faisant partie d'un système d'analyse du mouvement en 3-D. La séance aura lieu au Laboratoire de psychomotricité (Lees E053) et durera entre 45 et 60 minutes.

Risques: Puisque j'aurai les yeux bandés pendant la marche sur place, il est possible que je perde mon équilibre. Pour éviter que je fasse une chute, la chercheuse sera toujours près de moi pour que je puisse m'y appuyer si nécessaire.

Bienfaits: Ma participation à cette recherche aura pour effet de mieux comprendre la perception et le contrôle des déplacements pendant la marche sur place sans vision en situation de double tâche.

Confidentialité et anonymat: J'ai l'assurance du chercheur que l'information que je partagerai avec elle/lui restera strictement confidentielle. Je m'attends à ce que le contenu ne soit utilisé que pour des publications scientifiques et selon le respect de la confidentialité en mettant tous les documents produits lors de l'expérience dans un endroit fermé à clé. **L'anonymat** est garanti en utilisant un chiffre au lieu de mon nom.

Conservation des données: Les données recueillies sur papier et sur support électronique seront conservées de façon sécuritaire pendant 5 ans dans un classeur fermé à clé dans le bureau de Dr. Paquet et sur une clé USB ayant un mot de passe. Ensuite, toutes les données seront détruites à condition que les résultats de l'étude aient été publiés. Sinon, les documents seront conservés jusqu'à la publication des résultats ou pendant un maximum de 5 autres années, puis seront détruits ensuite.

Participation volontaire: Ma participation à la recherche est volontaire et je suis libre de me retirer en tout temps, et/ou refuser de répondre à certaines questions. Si je choisis de me retirer de l'étude, les données recueillies jusqu'à ce moment seront détruites.

THE EFFECT OF A CONCOMITANT COGNITIVE TASK AND KNEE HEIGHT ON ONE'S UNPERCEIVED DISPLACEMENT IN STEPPING IN PLACE WITHOUT VISION: A KINEMATIC STUDY

Acceptation: Je, _____, accepte de participer à cette recherche menée par Jessica Grostern et Nicole Paquet de l'École des sciences de l'activité physique.

Pour tout renseignement additionnel concernant cette étude, je peux communiquer avec les chercheurs.

Pour tout renseignement sur les aspects éthiques de cette recherche, je peux m'adresser au Responsable de l'éthique en recherche, Université d'Ottawa, Pavillon Tabaret, 550, rue Cumberland, salle 154, Ottawa, ON K1N 6N5

Tél.: (613) 562-5387

Courriel : ethics@uottawa.ca

Il y a deux copies du formulaire de consentement, dont une copie que je peux garder.

Signature du participant: _____ Date: _____

THE EFFECT OF A CONCOMITANT COGNITIVE TASK AND KNEE HEIGHT ON ONE'S UNPERCEIVED
DISPLACEMENT IN STEPPING IN PLACE WITHOUT VISION: A KINEMATIC STUDY

APPENDIX E

Ethics Certificate



File Number: H12-16-12

Date (mm/dd/yyyy): 01/03/2017

First Name

Nicole Jessica

Last Name

Paquet Grostern

Affiliation

Health Sciences / Human Kinetics Health Sciences / Human Kinetics

Role

Supervisor Student Researcher

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)

THE EFFECT OF A CONCOMITTANT COGNITIVE TASK AND KNEE HEIGHT ON ONE'S UNPERCEIVED DISPLACEMENT IN STEPPING IN PLACE WITHOUT VISION: A KINEMATIC STUDY

First Name: Nicole, Jessica

Last Name: Paquet, Grostern

Affiliation: Health Sciences / Human Kinetics Health Sciences / Human Kinetics

Role Supervisor, Student Researcher

File Number: H12-16-12 **Type of Project:** Master's Thesis

Title: The Effect of a Concomitant Cognitive Task on One's Unperceived Displacement in Stepping in Place Without Vision: A Kinematic Study

Approval Date (mm/dd/yyyy)

01/03/2017

Expiry Date (mm/dd/yyyy)

01/02/2018

Approval Type

Approval

N/A

550, rue Cumberland, pièce 154 Ottawa (Ontario) K1N 6N5 Canada

550 Cumberland Street, room 154 Ottawa, Ontario K1N 6N5 Canada

1

(613) 562-5387 • Téléc./Fax (613) 562-5338

www.recherche.uottawa.ca/deontologie/ www.research.uottawa.ca/ethics/



File Number: H12-16-12

Date (mm/dd/yyyy): 01/03/2017

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: <http://research.uottawa.ca/ethics/submissions-and-reviews>.

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: <http://research.uottawa.ca/ethics/submissions-and-reviews>.

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.

THE EFFECT OF A CONCOMITTANT COGNITIVE TASK AND KNEE HEIGHT ON ONE'S UNPERCEIVED
DISPLACEMENT IN STEPPING IN PLACE WITHOUT VISION: A KINEMATIC STUDY

Signature:

Riana Marcotte Protocol Officer for Ethics in Research For Daniel Lagarec,
Chair of the Health Sciences and Sciences REB

www.recherche.uottawa.ca/deontologie/ www.research.uottawa.ca/ethics/