# VISUOSPATIAL ATTENTION DURING LOCOMOTION

by

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A DISSERTATION

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DISSERTATION ABSTRACT

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Title: Visuospatial Attention During Locomotion

Locomotion requires visuospatial attention. However, the role and cortical control of visuospatial attention during locomotion remain unclear. Four experiments were conducted in this study to examine the role and cortical control of visuospatial attention during locomotion in healthy young adults. In the first experiment, we employed a visuospatial attention task at different phases of obstacle crossing during gait. The results suggested that toe-obstacle clearance was significantly reduced for the trailing limb when distraction interfered with visuospatial attention during the approaching phase of obstacle crossing. In the second experiment, subjects performed a visual Stroop task while approaching and crossing an obstacle during gait. The results for the second experiment indicated toe-obstacle clearance was significantly increased for the leading and trailing limbs. Taken together, it was found that different visual attention tasks lead to distinct modifications on obstacle crossing behaviors. In the third and fourth experiments, anodal transcranial direct current stimulation (tDCS) was applied over the right posterior parietal cortex (PPC) to examine the aftereffects on attention function and locomotor behavior. The results suggested that the orienting attention was significantly improved after anodal tDCS. In addition, the aftereffects of anodal tDCS potentially enhanced cognitive and motor performance while interacting with a challenging obstacle-crossing task in young

healthy adults, suggesting that the right PPC contributes to attending visuospatial information during locomotion. This study demonstrated that visuospatial attention is critical for planning during locomotion and the right PPC contributes to this interplay of the neural processing of visuospatial attention during locomotion.

This dissertation includes previously published and unpublished co-authored material.

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# CHAPTER I

# INTRODUCTION

## Background and Significance

Locomotion, moving from one place to the other, is one of the most common activities of daily living and requires integration of multiple systems to produce a successful and safe movement. Maintaining a stable motion of the body's center of mass in relation to the constantly changing base of support is particularly challenging while navigating in an environment surrounded with visual distractions. Although bipedal locomotion allows for free use of upper extremities, ongoing environmental stimuli constantly disturb this dynamically unstable system. Individuals with neurologic, musculoskeletal or other impairments could experience higher risks of tripping, imbalance or falling while walking, which could lead to poor quality of life and increased mortality. Epidemiology studies showed that more than 30% of community-dwelling elderly aged 60 and older (Mahlknecht et al., 2013; Verghese et al., 2006) and approximately 60% of the hospitalized neurological patients (Stolze et al., 2005) have reported gait disorders. This suggests a strong association exists between gait disorders and degeneration or impairment of the central nervous system (CNS).

How the CNS, especially cortical areas, controls and coordinates multiple systems during walking is a complex question and the answer remains unknown. Gait requires delicate interactions among three major afferent systems (visual, vestibular, and proprioceptive sensory systems), several efferent organs (muscles, bones, joints, tendons, ligaments), and the CNS connects and integrates these systems. Previous studies

(Armstrong, 1988; Dietz, 2003; Fasano & Bloem, 2013; Matsuyama, Mori, Nakajima, & Drew, 2004; Takakusaki, 2013) provided abundant information in spinal and subcortical control of locomotion. The central pattern generator (CPG) is described as a group of interneurons located in the spinal cord to produce and mediate rhythmic contractions of flexor and extensor motor neurons during locomotion (Dietz, 2003; Duysens & Van de Crommert, 1998; McCrea & Rybak, 2008). While the spinal cord generates the pattern of muscle synergies, the supraspinal areas are essential for planning, initiating and adjusting a rhythmic gait (Armstrong, 1988; T. Drew, Prentice, & Schepens, 2004; Garcia-Rill & Skinner, 1987a; 1987b; Le Ray, Juvin, Ryczko, & Dubuc, 2011). Fasano and Bloem (2013) summarized the pathways and relationships among subcortical structures contributing to locomotion, which connects the directions of projections within nuclei in the basal ganglia (including striatum, subthalamus, external and internal globus pallidus, substantia nigra), brainstem (such as pedunculopontine nucleus pars dissipata and pars compacta, nucleus reticularis), thalamus and cerebellum. However, for the cortical areas, only the primary and the supplementary motor cortex were identified, suggesting that the roles of other cortical areas in locomotion remain unclear. One reason that a cortical contribution to locomotion was overlooked may come from the fact that decorticate cats can walk on a treadmill spontaneously (Perret & Buser, 1972; Perret & Cabelguen, 1976; 1980). The results from the cat studies would be difficult to apply to human during normal gait. Compared to quadrupedal walking on a treadmill, humans walk bipedally over uneven surfaces in a changing environment. While the spinal and subcortical areas are recognized to directly control a rhythmic gait, the role of cortical areas, even those other than the motor cortex, could also be important for human walking.

## Visuospatial Attention

Environmental information in forms of visual, auditory and spatial stimuli are constantly demanding our attention during world walking. Among these relevant sensory inputs, visual inputs play a predominant role in safe navigation. Once visual information is received, visual attention serves as a gatekeeper to filter irrelevant and selects relevant information required for further action. Visual inputs contain spatial signals, which provide information regarding absolute and relative locations of objects. Visuospatial information therefore serves as a fundamental piece of information for navigation. Visuospatial attention, an ability to select relevant spatial stimuli in the visual field based on the goal to be achieved, plays a critical role in walking during daily life. Therefore, examining how visuospatial attention interacts with walking performance would provide an access to cortical control in locomotion.

How visuospatial attention contributes to locomotion remains unclear. In order to avoid being tripped or blocked, an individual needs to successfully and efficiently orient visuospatial attention toward the location of the obstacle in space for identification and then to calculate this selected information for planning and execution. This concept is intuitive but little has been examined for the role of visuospatial attention during locomotion. Current knowledge comes from studies conducted during reaching or grasping (Baldauf & Deubel, 2010; Barthélémy & Boulinguez, 2002; Corbetta & Shulman, 2002; Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003; Reed, Garza, & Roberts, 2007) or through correlational studies based on individuals with impairment in visuospatial attention. Broman and colleagues (2004) determined the relationship between divided visual attention and bumping while walking in 1504 community-

dwelling adults aged 70 and above. They found that divided visual attention measured by the useful field of view (UFOV) test was a significant and independent predictor for number of bumps during walking. A 50 ms increase in a divided visual attention test was associated with a 7.6% increase in a number of bumps, suggesting that a degraded divided visual attention was associated with a higher number of bumps while walking when other compound predictors such as visual field, visual acuity, and other physical and cognitive scores were controlled. Nagamatsu et al. ( 2009; 2013) recorded event-related potentials (ERPs) elicited by attention-directing cues in fallers and non-fallers older adults aged 65 and above. Their results suggested that although both fallers and non-fallers were able to orient attention to a particular location in space, only fallers demonstrated deficits in modulating and processing visuospatial information at oriented targets. Failure in utilizing visuospatial attention can lead to troubles with planning and guiding during walking and cause falls. Visuospatial inattention is common not only in the elderly (Mahoney, Verghese, Goldin, Lipton, & Holtzer, 2010) but also in other clinical populations, such as individuals with stroke (Chen Sea, Henderson, & Cermak, 1993), Parkinson's disease (Zhou et al., 2012), Alzherimer's disease (Liu, McDowd, & Lin, 2004) or traumatic brain injury (Hill-Jarrett, Gravano, Sozda, & Perlstein, 2015; Van Donkelaar et al., 2005).

To directly investigate the role of visuospatial attention during locomotion is challenging. In addition to examining locomotor behaviors from individuals with deficits or impairments in visuospatial attention, previous gait studies either focused on visuospatial processing or attention, instead of visuospatial attention, which can be viewed as the intersection of visuospatial processing and attention (Figure 1.1). One

possible reason for the limited literature may be due to the lack of appropriate paradigms to directly examine visuospatial attention during walking. Methods being used to examine visuospatial processing during locomotion can be classified into three categories: 1) to block partial or full visual fields (Graci, Elliott, & Buckley, 2010; Hawkins et al., 2010; Marigold & Patla, 2008; Mohagheghi, Moraes, & Patla, 2004), 2) to measure gaze behavior (Chandra et al., 2011; Di Fabio, Greany, & Zampieri, 2003; Geruschat, Hassan, & Turano, 2003; Higuchi, Cinelli, & Patla, 2009), and 3) to manipulate features of visuospatial processing in a virtual reality-based environment (Aravind, Darekar, Fung, & Lamontagne, 2014; Parsons, Courtney, Dawson, Rizzo, & Arizmendi, 2013; Tarr & Warren, 2002; Warren, Kay, Zosh, Duchon, & Sahuc, 2001). As for studies on attention during locomotion, a typical method is to use a dual-task paradigm by performing a cognitive task concurrently with a gait task (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; Lajoie, Teasdale, Bard, & Fleury, 1993; Woollacott & Shumway-Cook, 2002; Yogev-Seligmann, Hausdorff, & Giladi, 2008). Most of these selected cognitive tasks relied on non-visual modalities (e.g. auditory Stroop task, mathematics tasks) to avoid interference with the physiological structure underlying a gait task. Since visuospatial attention is composed of visuospatial processing and attention, using a visual-based cognitive task that interferes with the attentional system during a gait task that involves visuospatial processing seems to be a more realistic paradigm to tackle the role of visuospatial attention during locomotion.

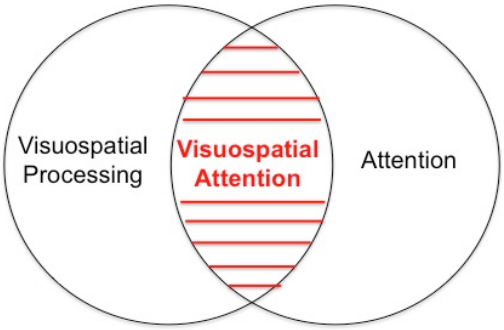


**Figure 1.1. Illustration of visuospatial attention as the intersection of visuospatial processing and attention.**

## Obstacle Crossing during Walking

Obstacle crossing during level walking is considered an advanced locomotion task with high visuospatial demands. First, obstacle crossing orients one's vision to detect and define the characteristics of the obstacle in the environment. Second, obstacle crossing requires vision to determine foot placements before and after crossing the obstacle. Third, obstacle crossing requires vision to plan foot trajectory prior to crossing and to avoid tripping incidences. In particular, no on-line visual information can be obtained during the crossing phase of the trailing limb. Thus, visuospatial information of the obstacle should have been collected during the approaching phase. Fourth, obstacle crossing challenges postural stability during the single support period while crossing. Lastly, obstacle crossing serves as a goal-directed movement among locomotor behaviors. In addition to the general locomotor goal, which is to travel to the destination, there is an intermediate goal to avoid tripping or falling. This goal is important and functional because more than half of the falls are trip-induced (Blake et al., 1988). It has been indicated that control of end-point trajectories could indicate one's balance control strategy and can be used to predict the risk of tripping (Lu, Chen, & Chen, 2006;

Sparrow, Shinkfield, Chow, & Begg, 1996). Therefore, obstacle crossing is a promising paradigm for the investigation of visuospatial attention during locomotion.

Adding an attention task relevant to an obstacle-crossing task enhances the involvement of attention during locomotion. Most of the cognitive tasks employed in dual-task gait paradigms do not involve visual or spatial components (e.g. calculating a mathematics question, responding to an auditory Stroop task). Although these non-visuospatial attention tasks can examine the overall executive capacity of the attention system, they do not probe the specific role of visuospatial attention at its related period of an obstacle-crossing task. For example, obstacle crossing itself may rely more on orienting attention compared to conflict attention because individuals need to orient their resources to identify and process information instead of dealing with conflict information. Due to the nature of our research interest, a visuospatial attention task should be implemented in a dual-task paradigm in order to target how visuospatial attention specifically contributes to the control of end-point trajectories during walking.

Once a behavioral model is established, we can use this paradigm to probe the cortical contribution of visuospatial attention during locomotion. From previous gait studies in animals and clinical populations with brain lesions, or using a dual-task paradigm, we partially understand the correlation between cortical function and walking. However, the neurophysiological mechanisms associated with this interplay between cortical processes and locomotion remains undetermined.

## Cortical Control of Locomotion

Not until recently, due to the advanced technology, can we start measuring cortical activity during locomotion. Many non-invasive tools have their own advantages and limitations. First, neuroimaging techniques such as single-photon emission computed tomography (SPECT), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have been used for locomotor-related studies. Fukuyama et al. (Fukuyama et al., 1997) reported the first neuroimaging study in upright gait by using SPECT with technetium-99m-hexamethyl-propyleneamine oxime (HM-PAO) injection to evaluate regional cerebral blood flow (rCBF) changes after a 4-minutes voluntary gait in healthy adults aged 42 to 63 years. La Fougere et al. (2010) injected [$^{18}$F]– fluoro-deoxy-glucose (FDG) in healthy adults aged 51 to 73 years and recorded their changes in rCBF via PET after walking for 10 minutes. fMRI is restricted to a static supine position with imagined locomotion (Jahn et al., 2008; 2004) (Deutschländer et al., 2009; Malouin, Richards, Jackson, Dumas, & Doyon, 2003), or to locomotor-like lower extremity tasks with various foot pedal devices (Goble et al., 2011; Hao et al., 2013; Mehta, Verber, Wieser, Schmit, & Schindler-Ivens, 2009; Sahyoun, Floyer-Lea, Johansen-Berg, & Matthews, 2004). Through the high spatial resolution of these neuroimaging tools, the researchers have identified several supraspinal regions basic to the locomotion network and confirmed that real and imagined locomotion are different (la Fougère et al., 2010). However, these neuroimaging tools have limited temporal resolution and impose the risk of radiation exposure (i.e. radiotracers in SPECT and PET). Besides, taking a neuroimaging scan is expensive, and each scan is mainly used for a single type of task. Performing an obstacle-crossing task during walking would be challenging even for PET

scan because it contains several temporal components and it would be difficult to identify corresponding stimulus-specific regions. In addition, none of these neuroimaging tools can be used for an on-line walking task because it is impossible to keep an upright and dynamic position in a scanner room.

Secondly, functional near-infrared spectroscopy (fNIRS) is another brain mapping tool being applied to monitor cortical oxidative metabolism during treadmill walking (Ferrari & Quaresima, 2012; Holtzer et al., 2011; Leff et al., 2011; Miyai et al., 2001a; Suzuki, Miyai, Ono, & Kubota, 2008). Near-infrared light can easily pass through biological tissues, such as skin and skull, and be absorbed by a few chromophores in the brain, such as hemoglobin (Hb). Through the task-related hemodynamic responses of changes in oxygenated hemoglobin (OxyHb) and deoxygenated hemoglobin (DeoxyHb), we can visualize cortical activation patterns of human locomotion (Hoshi, 2003; 2011). However, there are also several limitations of NIRS: 1) subcortical structures cannot be reached; 2) it is difficult to quantify Hb concentration changes; 3) real data are easily influenced by extracerebral tissues; 4) there is no standard method to analyze NIRS data; 5) most of the studies are conducted on a treadmill because locomotor tasks over ground can create artificial noises; and 6) like other neuroimaging tools, NIRS is low in temporal resolution.

Third, electroencephalography (EEG) is another promising tool to measure brain activity during locomotion. Unlike the hemodynamic measures mentioned previously, EEG detects electrical activities of the brain and has high temporal resolution. Due to an increased amount of channels, high-density EEG is well suited to monitor changes in electro-cortical activity during locomotion due to its extensive scalp coverage and

enhanced spatial resolution (Gramann, Gwin, Bigdely-Shamlo, Ferris, & Makeig, 2010; Gwin, Gramann, Makeig, & Ferris, 2011; Knaepen, Mierau, Tellez, Lefeber, & Meeusen, 2015; Lau, Gwin, & Ferris, 2014; Malcolm, Foxe, Butler, & De Sanctis, 2015). Besides, a wearable and wireless mobile brain/body imaging (MoBI) system could allow subjects to walk freely over ground without being limited to walking on a treadmill. However, this technique is still evolving. Although gait-related artifacts can be considerably minimized (Gwin, Gramann, Makeig, & Ferris, 2010), they may provide meaningful physiological information of importance. Through the independent component analysis (ICA), researchers could identify groups of brain areas or patterns of brain activities, but it is difficult to identify the contribution from a specific brain site. Besides, most of the high-density EEG wires are not shielded, which can easily induce movement-related artifacts. More channels also mean more time required by a high density EEG, which is not practical in a clinical setting.

Fourth, non-invasive brain stimulation (NIBS) such as the repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS) may serve as a potential tool to examine cortical contribution to locomotion although they are under researched. Through modulating activity in targeted brain sites or neural networks NIBS has been used to enhance cognitive or motor functions in several clinical populations (Fregni & Pascual-Leone, 2007) (Lefaucheur et al., 2014) including stroke (Feng, Bowden, & Kautz, 2013; Hummel & Cohen, 2006; Khedr, Ahmed, Fathy, & Rothwell, 2005; Nitsche, Boggio, Fregni, & Pascual-Leone, 2009; Schlaug, Renga, & Nair, 2008; Simonetta-Moreau, 2014), traumatic brain injury (Dhaliwal, Meek, & Modirrousta, 2015), Parkinson's disease (Fregni, Simon, Wu, & Pascual-Leone, 2005),

pain control (Moisset & Andrade, 2015; O'Connell, Wand, Marston, Spencer, & Desouza, 2010) and depression (Nitsche et al., 2009). The neurophysiological mechanism underlying NIBS has been widely proposed but has not been conclusively identified (Dayan, Censor, Buch, Sandrini, & Cohen, 2013; Fregni & Pascual-Leone, 2007; Pell, Roth, & Zangen, 2011; T. Wagner, Valero-Cabre, & Pascual-Leone, 2007).

Transcranial magnetic stimulation (TMS) uses the principle of electromagnetic induction to induce sufficient electrical magnitude to depolarize neurons. While repetitively applying the stimulation (i.e., rTMS), the modulated cortical excitability, either increasing or decreasing depending on the frequency, may last beyond the duration of the rTMS train itself (Pascual-Leone, Bartres-Fazf, & Keenan, 1999). tDCS are low-amplitude direct currents applied under scalp electrodes. Unlike TMS, tDCS does not elicit action potentials but modify membrane potential to increase or decrease the level of excitability depending on the anode or cathode electrode. Similar to rTMS, cortical excitability can be altered beyond the stimulation period (Medeiros et al., 2012; Nitsche & Paulus, 2000; 2011; Nitsche et al., 2008; 2005; Stagg & Nitsche, 2011).

Aftereffects produced by rTMS or tDCS provide researchers a direct access to probe the contribution of a specific brain during dynamic walking in healthy populations. Aftereffects of tDCS have been reported to last longer and are more reliable when compared to those after rTMS. After the application of 9 or 13 minutes tDCS, the cortical excitability could be modified for up to 1 hour after the stimulation (Nitsche, 2011; Nitsche et al., 2005; Nitsche & Paulus, 2000; Nitsche et al., 2004). Goh et al. (2015) compared aftereffects of a single session of high-frequency rTMS (5Hz, 1200 stimuli in total) with an anodal tDCS (1mA, 20 minutes) on corticospinal excitability via single

pulse TMS in the same individuals with chronic stroke. Their results suggested that both stimulation techniques significantly increased corticospinal excitability for 30 to 60 minutes after simulation. Although the aftereffects may vary between healthy populations and stroke patients (Suzuki et al., 2012), the evidence supported a long-lasting aftereffect of tDCS stimulation. Compared to high-density of rTMS, anodal tDCS appears to be economical, easy to use, better tolerated, and with more effective and long-lasting aftereffects.

Some researchers have utilized tDCS aftereffects to study locomotor behaviors. Jayaram et al. (2012) enhanced and diminished the rate of locomotor adaptation on the split-belt treadmill by applying anode and cathode tDCS over the cerebellum. Kaski et al. (2012) enhanced locomotor control by stimulating over the leg primary motor cortex for 15 minutes with an anodal tDCS. Since locomotion has been considered as a cognitively-demanding task (Al-Yahya et al., 2011; Hausdorff et al., 2005; Reilly, van Donkelaar, Saavedra, & Woollacott, 2008; Woollacott & Shumway-Cook, 2002; Yogev-Seligmann et al., 2008), more research is needed for understanding the cognitive demand during locomotion. tDCS, therefore, can be used to stimulate brain sites other than the cerebellum and the primary motor cortex that allow for probing the cognitive function during walking, such as the visuospatial attention.

Posterior parietal cortex (PPC) is a promising brain site for investigating visuospatial attention during locomotion. As discussed earlier, visuospatial attention is the intersection between visuospatial processing and attention. The dorsal visual stream processes information about the spatial orientation of the visual stimulus from the striate cortex to the neurons in the PPC. From the PPC, visuospatial information is further

projected to the prefrontal cortex for processing activities involving spatial working memory, to the premotor cortex for processing visually-guided actions, and to the medial temporal lobe for processing navigation information(Kravitz, Saleem, Baker, & Mishkin, 2011). The selected visuospatial information combined with the sensorimotor information from the limb positions was also integrated in the PPC (Beloozerova, 2003) and the signals after all the processing is lastly projected to the primary motor cortex before being sent to the body. Understanding the cortical networks underlying visuospatial attention and sensorimotor transformation during locomotion could provide insights into how humans use visual information for stepping and navigating.

In addition to being the hub of visuospatial processing, PPC also serves as a critical role in human attention networks (Fan & Posner, 2004; Petersen & Posner, 2012; Posner & Petersen, 1990; Posner, Sheese, Odludaş, & Tang, 2006). Based on the established attention model by Posner, the orienting attention network is centered on the PPC while the alerting network involves thalamic and cortical sites related to the brain's norepinephrine system and the executive network includes the anterior cingulate and prefrontal areas. The orienting of attention was first proposed by Posner (Posner, 1980) and referred as "aligning of attention with a source of sensory inputs or internal semantic structure stored in memory". The nature of orienting attention appears to be closely related to the neural framework for visuospatial processing. The PPC can potentially be the main brain site for both visuospatial processing and orienting attention.
How PPC contributes to locomotion is still poorly understood.

Previous studies have used cat treadmill walking as a model to investigate the role of PPC during locomotion (Andujar, Lajoie, & Drew, 2010; Beloozerova, 2003; T. Drew,

Andujar, Lajoie, & Yakovenko, 2008; K. Lajoie & Drew, 2007; Marigold & Drew, 2011). However, the role of PPC during locomotion in human has not been addressed in detail. Through the tool of tDCS, we may be able to target the PPC and further understand the visuospatial attention during locomotion.

In summary, visuospatial attention is important during locomotion. Without appropriately managing visuospatial information with attention skills, individuals can lose their balance or trip with the obstacle during walking. However, an experimental model to specifically address the interplay of visuospatial attention and locomotion has not been developed. The cortical control involved in this activity is largely overlooked due to the lack of appropriate neurophysiological tools that can be used for an upright and dynamic movement.

## Overall Goal and Specific Aims

The overall goal of this dissertation study was to examine the role and the underlying cortical mechanism of visuosptial attention during locomotion in young healthy adults.

Four specific aims were identified and four experiments were conducted to address each aim, respectively. The first two aims were targeted on the role of visuospatial attention during locomotion and the last two aims were focused on the underlying cortical mechanism of visuospatial attention during locomotion.

**Aim 1:** To establish a functional experimental paradigm that combined visuospatial attention and obstacle-crossing tasks to probe how and where attention is directed when approaching and stepping over a barrier during gait.

**Aim 2**: To identify different roles of visuospatial attention during locomotion by comparing two visual attention tasks on obstacle crossing in young healthy adults.

**Aim 3**: To determine the effects of anodal transcranial direct current stimulation (tDCS) over right posterior parietal cortex (PPC) on attention function.

**Aim 4:** To examine the effects of transcranial direct current stimulation (tDCS) over right posterior parietal cortex (PPC) on concurrent performance of visuospatial attention task and obstacle crossing.

## Hypotheses

**Hypothesis 1**: The first hypothesis was that as the processing resources are limited, the increased demand of visuospatial attention would alter the swing foot trajectory and result in a reduction in the toe-obstacle clearance while crossing over an obstacle.

**Hypothesis 2**: The second hypothesis was that different attention tasks would lead to distinct modifications in obstacle-crossing behaviors.

**Hypothesis 3**: The third hypothesis was that there would be a causal relationship between the PPC and orienting attention.

**Hypothesis 4**: The fourth hypothesis was that the right posterior parietal cortex (PPC) would be the critical hub for attending visuospatial information during locomotion.

## Flow of the Dissertation

This dissertation is structured in a journal format. Chapters II through V include co-authored material and have been published, submitted or prepared for submission to peer-reviewed scientific journals.

Chapter II demonstrates that visuospatial attention and the processes underlying obstacle crossing during locomotion interact in both a spatially and temporally dependent manner. This work has been published in the *Experimental Brain Research*. Li-Shan Chou and Paul van Donkelaar are co-authors.

Chapter III demonstrates that two different visual attention tasks led to distinct modifications on obstacle crossing behaviors. This work has been submitted to a peer-reviewed scientific journal and is currently under review. Li-Shan Chou is a co-author.

Chapter IV examines the effects of transcranial direct current stimulation (tDCS) over the right posterior parietal cortex (PPC) on attention function in healthy young adults. This work has been prepared for submission to a peer-reviewed scientific journal. Li-Shan Chou is a co-author.

Chapter V examines the effects of transcranial direct current stimulation (tDCS) over the right posterior parietal cortex (PPC) on visuospatial attention and obstacle crossing in healthy young adults. This work has been prepared for submission to a peer-reviewed scientific journal. Li-Shan Chou is a co-author.

Chapter VI concludes the findings and provides recommendations for future research.

# CHAPTER II

# DISTRACTING VISUOSPATIAL ATTENTION WHILE APPROACHING AN OBSTACLE REDUCES THE TOE-OBSTACLE CLEARANCE

This work was published in volume 233, issue 4, of the journal *Experimental Brain Research* in 2015. On-Yee Lo, Paul van Donkelaar, and Li-Shan Chou are the authors. On-Yee Lo contributed to the concept of the studies, recruited subjects, collected data, wrote analysis software, performed data analysis, and prepared the initial manuscript. Dr. Paul van Donkelaar and Dr. Li-Shan Chou contributed to the concept of the study, provided editorial support, and critically reviewed and revised the manuscript.

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## Introduction

About 40% of falls in the elderly occur during walking, and among these falls, trip-induced falls are most frequently documented (Berg, Alessio, Mills, & Tong, 1997; Bleijlevens et al., 2010; Nachreiner, Findorff, Wyman, & McCarthy, 2007; Yasumura, Haga, & Niino, 1996). Declines in visuospatial attention ability may be a contributing factor to falls involving environmental hazards. Visuospatial attention refers to the ability to select a particular spatial location in the visual field for further processing and can be considered to be an intersection between visuospatial processing and attention. Behavioral (Posner & Petersen, 1990; Sheliga, Riggio, & Rizzolatti, 1994) and functional imaging (Corbetta, 1993; Corbetta & Shulman, 2002) studies have suggested that visuospatial attention is tightly coupled with goal-oriented movements, but most studies

used reaching and grasping as the paradigms (Baldauf & Deubel, 2010). The interaction between visuospatial attention and sensorimotor output remains unclear in the context of locomotion.

In this current paper, we examined obstacle avoidance during walking as a means to investigate this relationship. Obstacle avoidance is a visually guided goal-oriented movement in which one needs to avoid being tripped or blocked. The fact that individuals spend a significantly longer time examining the pathway environment during obstacle avoidance than unobstructed walking is consistent with this assumption (Patla et al., 1996). It is apparent that visuospatial attention contributes to this process by allowing individuals to accurately assess the characteristics of the obstacle so that it can be successfully avoided.

Several studies have indirectly examined the relationship between visuospatial attention and walking performance through correlation analyses. Broman et al. (2004) examined more than 1500 participants and reported that divided visual attention independently predicted the number of bumps while walking after controlling for visual acuity, visual field and non-visual attention level. Nagamatsu et al. (2009) recorded event-related potentials in elderly participants with and without a fall history and suggested fallers have significant deficits in visuospatial attention compared with the non-fallers. Finally, Catena et al. (2009) demonstrated that individuals suffering concussion with greater deficits in spatial attention had a reduced toe-obstacle clearance as compared to those with less or no deficits.

Performing a visuospatial attention task concurrently with an obstacle-crossing task could provide further understanding about how visuospatial attention contributes to

locomotion. Many studies have examined the role of visuospatial processing during obstacle crossing by blocking the visual field (Hawkins et al. 2011; Mohaghehi et al. 2004; Patla et al. 1996), characterizing gaze behaviors (Chandra et al. 2011; Fabio et al. 2003; Yamada et al. 2010), or manipulating visual input in a virtual reality environment (Warren et al. 2001; Aravind et al. 2014). However, these studies mostly focused on either visuospatial processing or non-visuospatial attention during locomotion, and the role of visuospatial attention during locomotion remains poorly understood. Furthermore, dual-task gait paradigms have been commonly employed to study the role of attention during locomotion (Woollacott et al. 2002; Yogev-Seligmann et al. 2008). In these dual-task paradigms, cognitive tasks were used to either interfere with the overall executive capacity of the attention system (e.g., auditory Stroop task) (Hegeman et al. 2012; Siu et al. 2008; Weerdesteyn et al. 2003), or to interfere with the physiological or psychological structures underlying the gait task (e.g., visual-related cognitive task) (Chen et al. 1994; Kim et al. 2007; McFadyen et al. 2009). However, it is unclear how the spatial (near or far from the obstacle) and temporal (approaching or crossing phase) effects of visuospatial attention interact with obstacle crossing during gait.

Thus, the purpose of this study was to combine visuospatial attention with obstacle crossing tasks to examine: 1) how a concurrent visuospatial attention task, as well as its proximity to the obstacle, affects the stepping behavior during walking and 2) how attention is distributed while approaching or crossing an obstacle based on the performance of the visuospatial attention task. We expect that concurrently responding to a visuospatial attention task while approaching an obstacle will affect the planning for obstacle crossing. As the processing resources are limited, we hypothesized that the

increased demand of visuospatial attention will alter the swing foot trajectory and result in a reduction in the toe-obstacle clearance. We also expect that individuals will prioritize their visual attention at locations closer to the obstacle to enhance safe crossing.

## Methods

### *Subjects*

Eleven young healthy adults (6 males/5 females, age: 25.9±5.5 years) were recruited from the local community for the study. All participants had normal or corrected-to-normal vision confirmed with the Snellen chart test. The Ishihara test was applied to exclude individuals with color blindness. At the time of testing, participants reported no history of neuromuscular diseases, head injury, or other medical conditions that could affect their locomotion. All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971), and right-footed as determined by the self-selected leg when kicking a ball. Prior to testing, all participants were informed of the experimental procedure that was approved by the Institutional Review Board and signed an informed consent form.

### *Visuospatial Attention Task*

The participant was instructed to identify the directional opening of a red C [RGB: 255, 0, 0] amongst 3 orange-red Cs [RGB: 255, 50, 0], randomly placed at four corners (front left [FL], front right [FR], back left [BL], back right [BR]) of a projected area on the floor (Figure 2.1) as accurately as possible. The opening of the red C could be directed toward (Front) or opposite to the walking direction (Back) while openings in the orange-red Cs could be facing front, back, right or left. All C stimuli were 2.5 inches

wide and 2.5 inches long. The openings in the Cs could be either narrow (1/5 width of the C's diameter, 0.5 inches) or wide (2/5 width of the C's diameter, 1 inches). Catch trials, in which only orange Cs were presented, were also included. The entire projection area on the floor was 26 inches wide and 34 inches long (Figure 2.1). During walking trials, C stimuli were presented for a duration of 200 ms immediately after the participant passed through a pair of photocells placed along the walkway at a location 2 or 3 steps prior to the visual target. After the visual stimulus was presented, the participant was asked to identify and verbally respond with the direction of the opening of the red C by saying "front" or "back" as quickly as possible. A total of 54 trials (4 target locations × 2 opening directions × 2 width × 3 trials + 6 catch trials) were included in the VA task and presented in a random order. Visual stimuli were implemented using SuperLab Pro (Cedrus Corp., San Pedro, CA) and an LCD projector (NEC Corp., Japan). The dependent variable of interest was the response accuracy on each trial.

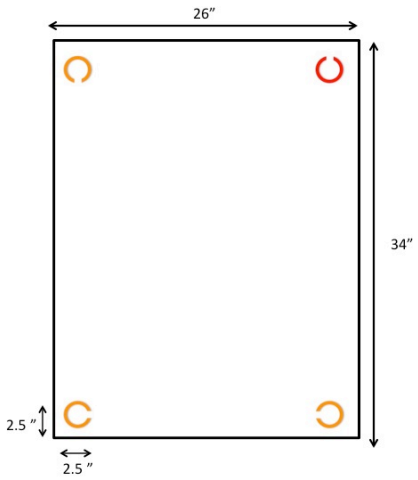


**Figure 2.1. Schematic drawing of the projected image used in the visuospatial attention (VA) task.** Participants were instructed to identify the directional opening of the red C amongst 3 orange-red Cs. The direction of the opening could be toward the walking direction (Front) or opposite to the walking direction (Back). The opening of the gap could be wide (2/5 width of the C's diameter, 1") or narrow (1/5 width, 0.5"). In this

example image, the red C is located at the top right so the correct answer should be "Front".

### *Obstacle Crossing and Motion Capture System*

The obstacle (a PVC pipe crossbar, 0.5 inches diameter, 1.3 m long) was set to a height at 10% of the participant's height and placed either after (ObsAfter) or before (ObsBefore) the VA task projection area. Participants initiated walking from a distance several strides away from the obstacle and were instructed to walk towards the obstacle, step over it, and continue walking toward the end of the walkway at a self-selected speed. Twenty-nine retro-reflective markers were placed on bony landmarks of the participant (Hahn & Chou, 2004), and another two markers were placed on both sides of the obstacle. Marker trajectory data were collected with a ten-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA) at a sampling frequency of 60 Hz. Kinematic data were filtered with a low-pass, fourth order Butterworth filter with a cutoff frequency of 8 Hz and were processed with Cortex software (Motion Analysis Corp., Santa Rosa, CA).

### *Protocol*

Participants completed four conditions in random order: (1) 54 trials of the VA task while standing (Stand, Figure 2.2 A); (2) 54 trials of the VA task during obstacle-crossing with the obstacle placed after the visual target (ObsAfter, Figure 2.2 B), (3) 54 trials of the VA task during obstacle-crossing with the obstacle placed before the visual target (ObsBefore, Figure 2.2 C), and (4) 5 trials of obstacle-crossing only (ObsOnly, Figure 2.2 D). Participants were allowed to rest as much as requested, and none of them complained of fatigue.

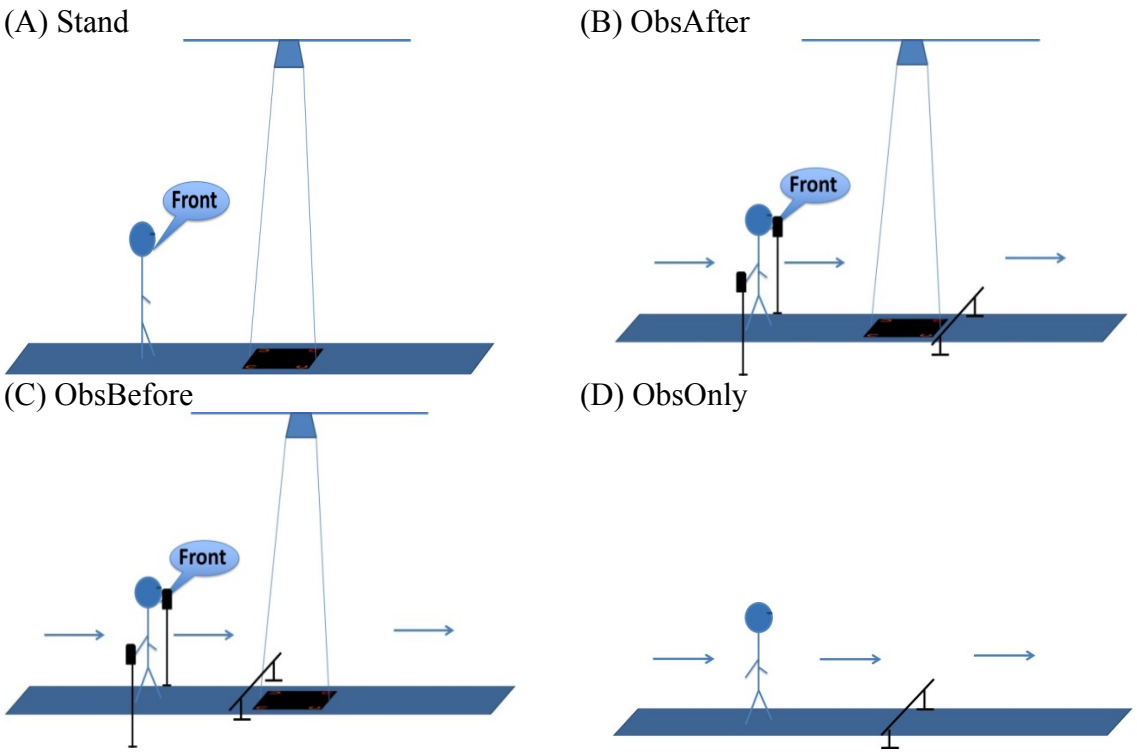


**Figure 2.2. Study conditions.** (A) Stand: participants performed the VA task while standing. (B) ObsAfter: participants performed the VA task while crossing the obstacle. The obstacle was placed AFTER the visual target. (C) ObsBefore: participants performed the VA task while crossing the obstacle. The obstacle was placed BEFORE the visual target. (D) ObsOnly: participants walked and crossed over the obstacle alone.

*Data Analysis*

Accuracy rate of the VA task, toe-obstacle clearances of leading and trailing legs, foot-obstacle horizontal distances of leading and trailing legs, gait velocities and tripping incidence were the primary dependent variables. The VA accuracy rate was calculated as the number of correct trials divided by the total possible trials for each condition. Toe-obstacle clearance was measured as the vertical distance between the markers placed on the obstacle and the swinging foot between the 2nd and 3rd metatarsals (toe marker) when the foot was directly above the obstacle. The foot-obstacle horizontal distances were 1) lead heel-obstacle distance defined as the horizontal distance between the leading

heel marker and obstacle at foot strike after crossing over the obstacle and 2) trail toe-obstacle distance defined as the horizontal distance between the trailing toe marker and obstacle before the trail limb left the ground for obstacle crossing. Overall gait velocity was calculated as the mean forward velocity throughout the task including the approaching and crossing phases. The crossing stride was defined as the gait cycle involving the crossing behavior starting with the heel-strike of the trailing limb before the obstacle, and the approaching phase was defined as the gait cycle immediately prior to the crossing stride. Gait velocities were also calculated for the approaching and crossing strides, respectively. Tripping incidence was recorded when the foot contacted the obstacle. For each participant, the average VA task accuracy rate was calculated using data from all 54 trials, and the average toe-obstacle clearances were derived from eleven to sixteen representative trials including both correct and incorrect responses to the VA task for each location. Only data from non-tripping trials were included in the analysis.

A one-factor analysis of variance (ANOVA) with repeated measures was conducted to compare mean toe-obstacle clearances, foot-obstacle horizontal distances and gait velocities among ObsAfter, ObsBefore, and ObsOnly conditions. A two-factor ANOVA with repeated measures was further conducted to analyze gait velocities for approaching and crossing phases among three conditions. A three-factor (location, difficulty, condition) ANOVA with repeated measures was conducted to determine the effects of visual target (red C) locations, difficulty levels (wide or narrow opening), and task conditions (ObsAfter, ObsBefore, and Stand) on VA task accuracy rates among three task conditions (ObsAfter, ObsBefore, and Stand). The four locations (FL, FR, BL, and BR) were grouped into the “Far” and “Near” locations for analysis, as one of our main

interests was the effect of proximity between the visual target and the obstacle along the direction of walking. The "Far" location included the FL and FR trials where the target stimulus was far from the participant whereas the "Near" location included the BL and BR trials where the target stimulus was near to the participant. Therefore, the "Far" and "Near" locations in the ObsAfter and ObsBefore conditions, respectively, would indicate a closer proximity of the visual target with the obstacle. Post hoc tests with the Bonferroni correction were further applied to detect statistically significant differences between condition means if the main or interaction effect was significant ($p<0.05$). All statistical analyses were conducted using SPSS version 19.0 (IBM Corp., Armonk, NY).

## Results

The VA task accuracy rates for trials with narrow openings were significantly lower than those with wide openings for both Far and Near locations of all three conditions ($F_{1, 10} = 30.34$, $p < 0.0001$). Although a significant main effect of the visual target location on VA task accuracy rate was detected ($F_{1, 10} = 4.97$, $p=0.05$; Table 2.1), only the difference between Far and Near locations in Stand condition was found to be significant ($p=0.012$). In addition, the accuracy rate at the Far location of ObsBefore condition was found to be significantly lower than those from the same location in ObsAfter and Stand conditions ($p=0.016$).

The trailing toe-obstacle clearance revealed a significant difference among the three conditions ($F_{2, 20}= 3.675$, $p = 0.044$) while the leading leg did not ($F_{2, 20}= 3.265$, $p = 0.059$). Post-hoc comparisons indicated that the trailing toe-obstacle clearance was reduced significantly in the ObsAfter compared to ObsOnly conditions ($p=0.031$).

Overall, there was a trend demonstrating that toe-obstacle clearances of both the leading (13.67±3.3 cm) and trailing (12.90±2.2 cm) legs in the ObsAfter condition were reduced compared to ObsBefore (Lead: 15.46±3.2 cm; Trail: 14.68±3.1 cm) or ObsOnly (Lead: 15.31±3.7 cm; Trail: 14.99±2.5 cm) conditions (Figure 2.3).

**Table 2.1. Mean (±SD) accuracy rates (%) of the visuospatial attention (VA) task at the Far and Near locations in Easy, Hard and Overall trials during the ObsAfter, ObsBefore, and Stand conditions**.

| | **ObsAfter¥** | | | **ObsBefore¥** | | | **Stand†¥** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Easy** | **Hard** | ***Overall*** | **Easy** | **Hard** | ***Overall*** | **Easy** | **Hard** | ***Overall*** |
| **Far** | 93.94 (10.0) | 82.58 (17.7) | *88.26 (13.4)* | 80.30* (16.8) | 78.79* (17.2) | *79.55* (16.0)* | 96.21 (7.8) | 88.64 (10.1) | *92.42 (5.5)* |
| **Near** | 87.88 (11.4) | 66.67 (23.0) | *77.27 (16.8)* | 81.82 (15.3) | 69.70 (20.2) | *75.76 (15.0)* | 83.3 (18.6) | 64.39 (21.1) | *73.86 (18.8)* |

* indicates a significant difference in ObsBefore compared to ObsAfter and Stand conditions.
† indicates a significant difference between Far and Near locations.
¥ indicates a significant difference between Easy and Hard trials.

Finally, no significant differences were detected in gait velocities (Table 2.2) or foot-obstacle horizontal distances (Table 2.3) among all three obstacle-crossing conditions. Gait velocities during the approaching phase (ObsAfter: 1.32± 1.3 m/s; ObsBefore: 1.29±0.07 m/s; ObsOnly: 1.28±0.07 m/s) were consistently faster than those of the crossing phase (ObsAfter: 1.25±0.13 m/s; ObsBefore: 1.22±0.09 m/s; ObsOnly: 1.18±0.08 m/s) for all conditions *(p=0.0001*, Table 2.2*)*. In addition, only two tripping incidences occurred overall, both in the ObsAfter condition.

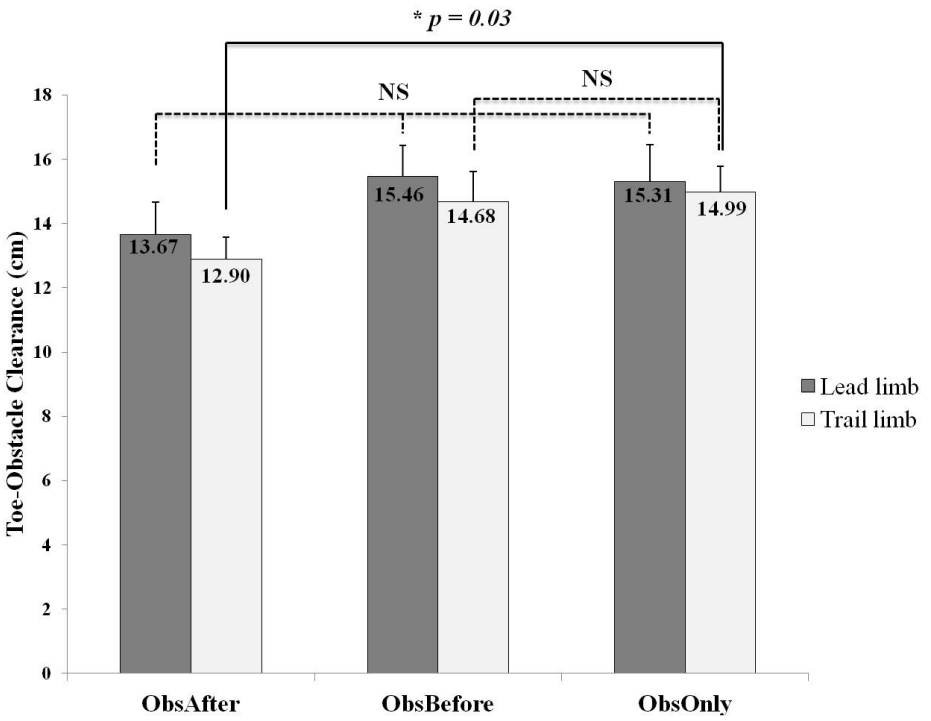


**Figure 2.3. Toe-obstacle clearance values for leading and trailing limbs in all conditions.** Toe-obstacle clearance was significantly reduced for the trailing limb in the ObsAfter compared with another two conditions.

**Table 2.2. Mean (±SD) gait velocities (m/s) for Overall, Approaching, and Crossing phases among the ObsAfter, ObsBefore and ObsOnly conditions.**

| | ***Overall*** | ***Approaching**** | ***Crossing*** |
|---|---|---|---|
| **ObsAfter** | 1.29(0.13) | 1.32(0.14) | 1.25(0.13) |
| **ObsBefore** | 1.28(0.08) | 1.29(0.07) | 1.22(0.09) |
| **ObsOnly** | 1.24(0.06) | 1.28(0.07) | 1.18(0.08) |

***Gait velocities for the approaching phase were significantly faster than those of the crossing phase in all three conditions (*p=0.0001*).

**Table 2.3. Mean (±SD) foot-obstacle distances (cm) in the ObsAfter, ObsBefore and ObsOnly conditions.**

| | ***Lead Heel-Obstacle Distance*** | ***Trail Toe-Obstacle Distance*** |
|---|---|---|
| **ObsAfter** | 23.55(6.90) | 28.99(8.28) |
| **ObsBefore** | 24.89(7.61) | 26.83(6.88) |
| **ObsOnly** | 24.12(7.42) | 27.18(7.74) |

## Discussion

The first purpose of this study was to investigate how a concurrent visuospatial attention task, as well as its proximity to the obstacle, affects the stepping behavior during obstructed gait. We found a significant reduction in the trailing toe-obstacle clearance during the ObsAfter condition, suggesting that the perception of obstacle height or the control of foot trajectory could be affected when there is an increased demand on visuospatial attention while approaching the obstacle. The second purpose of this study was to examine where viuospatial attention was distributed in the presence of an obstacle. Our results indicated that the VA task accuracy rate was higher at the Far than Near location in all conditions. This difference was most conspicuous in the Stand condition (18.6%), as compared to two obstacle crossing conditions (ObsAfter: 11.0%; ObsBefore: 3.8%), and appears to be related to the proximity of the visual target with the obstacle.

When the visual stimuli were presented in front of the obstacle, participants demonstrated a similar overall accuracy rate to that during standing; however, the trailing toe-obstacle clearances were lower than when stepping over the obstacle in isolation. We suggest that visuospatial attention is engaged while an individual is approaching the obstacle so that planning of an appropriate foot trajectory can be made to ensure a safe crossing. Performing a concurrent visuospatial attention task while approaching the obstacle may affect such planning, as shown by the reduction in toe-obstacle clearance. Similarly, previous studies have documented the anticipatory nature of visuomotor control of human adaptive locomotion (Higuchi, 2013) as well as the requirement of visuospatial attention in the anticipatory control of human locomotion (Owens, 2008). In Owens's study, participants walked in a virtual reality environment and tried to avoid

colliding with moving vertical obstacles while performing a visuospatial attention task (Brooks Letter Task) and were found to be able to learn to predict obstacle motion and preemptively avoid collision. However, such anticipation ability declined when a visuospatial attention task was also performed. Taken together, the data from Owens (2008) as well as that from the current study suggest that visuospatial attentional resources are required while anticipating and planning to avoid obstacles, whether in a real or virtual scenario.

On the other hand, when the visual stimuli from the VA task were presented after the obstacle (ObsAfter), participants showed a tendency to be less accurate than in the Stand condition; but toe-obstacle clearances were similar to those observed when stepping over the obstacle in isolation. This result agrees with previous findings in healthy young adults when crossing an obstacle and simultaneously performing a cognitive task (Hawkins et al., 2010; Siu, Catena, Chou, Donkelaar, & Woollacott, 2007). Siu et al. (2008) found that gait stability was similar to that observed in level walking while verbal reaction time (VRT) increased in the congruent version of the auditory Stroop task. Hawkins et al. (2011) also suggested that gait performance was not affected by a probe reaction time task (PRT). However, as the postural demands of the gait task increased, PRT was significantly increased. The attention demanding tasks in the above-mentioned studies (including our ObsBefore condition) were implemented within one step before, during, or after stepping over an obstacle. During this crossing phase where less visual attention was demanded than the approaching phase, the participants appeared to prioritize gait performance over cognitive performance. In addition, Harley et al. (2009) reported an increased toe clearance in young adults when a verbal fluency task

was performed during stepping over an obstacle as the number of valid words (cognitive performance) decreased. McFadyen et al. (2009) suggested the toe clearance margin remained the same when an attentional task was included. Taken together, these data suggest that young adults are able to maintain stable motor behavior but possibly sacrifice cognitive performance while concurrently responding to an attentional task during crossing over a predetermined obstacle.

Previous studies have observed increases in toe clearances of the leading and trailing legs when the visual field was partially or fully blocked during the approaching phase of obstacle crossing (Mohagheghi et al. 2004; Rhea and Rietdyk 2007); while the participants in our study demonstrated a decreased toe clearance when performing a 200 ms visuospatial attention task with a full visual field. Such differences might be expected. When approaching an obstacle with a partially or fully blocked visual field an individual would be alerted with the visual interference and have sufficient time to adopt a safe crossing strategy to avoid tripping. In contrast, the visuospatial attention task in the ObsAfter condition seems to interfere with planning for crossing but does not allow sufficient time to alter gait or to change crossing strategy. Significant reductions in the trailing limb toe clearances suggest that the visuospatial attention interference can be more relevant to visual exproprioception (information of the body position relative to environment) rather than visual exteroception (information of environmental characteristics) (Rhea and Rietdyk 2007). No change in the toe clearance when vision (Mohagheghi et al. 2004; Rhea and Rietdyk 2007) or visuospatial attention (current study) was disrupted during the crossing phase suggests that young healthy adults are able to gather and utilize visual information prior to crossing the obstacle.

Although no significant differences were detected for the horizontal foot-obstacle distances among three conditions, there seems to be a trend in which participants placed the trailing foot further away from the obstacle before crossing but landed the leading foot closer to the obstacle after crossing in the ObsAfter condition (Table 2.3). Such altered foot placements could be a consequence of the disrupted attention while approaching the obstacle, which affects foot trajectory and clearance while crossing the obstacle.

Another question examined in this study is how visuospatial attention is oriented as one approaches or crosses over an obstacle. The finding that participants demonstrated a higher accuracy rate in the ObsAfter (82.77%) than in the ObsBefore (77.65%) condition could be explained by that fact that more visual attention is directed to the obstacle during the approaching than crossing phase. The interpretation for inconsistent trends between the Far and Near locations in the ObsAfter and ObsBefore conditions are manifold. The modulation of accuracy rates at the Far and Near locations in these two conditions partially supported our hypothesis. Participants would orient their visuospatial attention toward the obstacle as 1) the visual target locations closer to the obstacle are relevant to the goal of safe crossing and/or 2) the visual target locations closer to the obstacle are closer to the center of visual fixation and could be more effectively maintained in the peripheral visual field.

In the ObsAfter condition, there was a trend for accuracy rate to be higher at the Far locations, suggesting the participants oriented more attention toward locations closer to the obstacle. This trend was consistent in both Easy and Hard trials. However, in the ObsBefore condition, the difference in the accuracy rates between the Far and Near

locations seems to be diminished. Furthermore, the accuracy rates at the Near locations close to the obstacle were slightly higher than the Far locations in the Easy trials but not in the Hard trials. In brief, the orientation toward the obstacle, as reflected in the VA task accuracy rates, appeared to be more obvious in ObsAfter than ObsBefore.

We suggest that this partial disagreement to our hypothesis is accounted for in part by the fact that participants orient visuospatial attention toward the locations relevant to the walking pathway. In a goal-oriented action, attention is reported to be directed to locations where information is critical for accomplishing the goal (LAND, 2009; Rothkopf, Ballard, & Hayhoe, 2007). In addition to safely stepping over the obstacle, gait progression to reach the end of the walkway could be considered as another goal in the gait task employed in this study. Therefore, attention has been directed to both the obstacle and travelling path leading to the end of the walkway so the accuracy rate was not consistently higher at the Near locations in the ObsBefore condition. Consistent with this point, Chandra et al. (2011) demonstrated that, compared to elderly individuals, healthy young participants spent more time directing gaze at the travel path rather than the obstacle. To the extent that gaze and attention interact, we believe that this may account for the slightly higher accuracy rates at the Far locations over the Near locations. However, due to the lack of eye tracking data, we are not able to confirm this interpretation.

In conclusion, our data suggest that: (1) increasing visuospatial attentional demands while approaching an obstacle leads to a reduction in toe-obstacle clearance of the trailing leg; and (2) visuospatial attention is systematically modulated both by the obstacle and the direction of walk pathway. Given that toe-obstacle clearance behavior is

affected in healthy young adults under these conditions, age-related, disease-related, or injury-related declines in visuospatial attention could be a plausible contributing factor to the increased risk of tripping when attention is divided during walking in the presence of an obstacle.

## Bridge

Chapter II demonstrated a paradigm to examine how and when visuospatial attention interferes the processes underlying obstacle crossing during locomotion. In the next chapter, we compare this paradigm with another visual attention task to examine whether and how various attention tasks affect obstacle-crossing behaviors differently.

# CHAPTER III

# EFFECTS OF DIFFERENT VISUAL ATTENTION TASKS ON OBSTACLE CROSSING IN HEALTHY YOUNG ADULTS

This work has been co-authored with Dr. Li-Shan Chou and has been submitted for publication. On-Yee Lo contributed to the concept of the study, recruited subjects, collected data, wrote analysis software, analyzed data, and prepared the initial manuscript. Dr. Li-Shan Chou contributed to the concept of the study and critically reviewed and revised the manuscript.

## Introduction

Tripping over an obstacle can lead to a fall, which is the leading cause of injury for persons over the age of 65 (Berg et al., 1997). Obstacle crossing requires cognitive resources to identify the characteristics and location of the obstacle so as to raise one's legs at appropriate heights and avoid being tripped. Growing evidence suggests that attentional demands are involved in stepping performance (Chen et al., 1996; Harley, Wilkie, & Wann, 2009; Siu, Lugade, Chou, van Donkelaar, & Woollacott, 2008). Most of these studies used dual-task paradigms, simultaneously performing a cognitive and an obstacle-crossing gait task, to examine how attention plays a role in sensory-motor processing during obstacle crossing.

Dual-task interference on stepping behavior in healthy young adults remains unclear. Findings were mixed and could be classified into three categories: a) dual-task interference caused obstacle contacts and toe clearances decreased (Chen et al., 1996;

Kim & Brunt, 2007; Lo, van Donkelaar, & Chou, 2015; Weerdesteyn, Schillings, Van Galen, & Duysens, 2003); b) dual-task interference did not cause obstacle contacts but toe clearances increased (Harley et al., 2009); and c) dual-task interference did not cause obstacle contacts nor changes in toe clearance or other gait parameters (Brown, McKenzie, & Doan, 2005; Lo, van Donkelaar, & Chou, 2015; Siu et al., 2007).

Different types of attentional tasks have been employed in these dual-task studies including simple reaction time test using visual (Chen et al., 1996; Kim & Brunt, 2007) or auditory (Brown et al., 2005) stimuli, verbal fluency tasks (Harley et al., 2009), visuospatial attention task (Lo et al., 2015), or auditory Stroop tasks (Siu et al., 2007; Weerdesteyn et al., 2003). In addition, the modalities used in these tasks were different (i.e. visual or non-visual). Kahneman (1973) suggested using a non-visual cognitive task to avoid structural interference in a dual-task paradigm study. However, previous findings did not appear to be consistent. Weerdesteyn et al. (2003) reported more obstacle contacts as Siu et al. (2007) found no changes in gait performance, while an auditory Stroop task was used in both studies. Although non-visual attention tasks might avoid interference with underlying physiological structure, visually demanding tasks are more directly relevant to daily activities. Furthermore, poor visual attention has been suggested as a significant risk factor for falls during walking, and it could be independent from the visual acuity, visual field and other visual characteristics (Broman et al., 2004). There is, therefore, a need to examine how different types of visual attention tasks affect obstacle-crossing behavior.

Visual distractions could be presented to daily life in many different ways. Two of the most commonly encountered visual distractions during walking are (1) responding to

an unexpected visual event that briefly shifts one's attention and (2) continuously engaging with a concurrent visual task. The former scenario predominantly distracts one's ability to orient attention while the latter one predominantly distracts one's ability to execute attention. In this investigation we examined and compared the effects of two different visual attention tasks, a visuospatial attention task and a visual Stroop task, on obstacle crossing in healthy young adults. Visuospatial attention task was designed to challenge predominantly orienting attention, and visual Stroop task was designed to challenge predominantly executive attention. We hypothesized that these two attention tasks would lead to different alterations in obstacle crossing behavior. In particular, responding to a suddenly appearing visuospatial attention task while approaching an obstacle would be less likely to employ any pre-planned strategies and result in decreased toe-obstacle clearances due to a reduced allocation of visuospatial attention toward the planning of obstacle crossing. In contrast, walking with a concurrent visual Stroop task could lead to increases in toe-obstacle clearances as subjects could have expected the upcoming challenges and chosen the strategy to raise their limbs higher to avoid tripping.

## Methods

Two experiments using different visual attention tasks were conducted, in which subjects completed an obstacle-crossing only task (O), a visual attention only task (V), and a dual-task obstacle-crossing task (DO) presented in a random order. Both experiments were approved by the Institutional Review Board. All subjects were informed of the experimental procedure and signed an informed consent form prior to testing.

The visual attention task employed in the first experiment was a visuospatial attention task (VSA), which required the subject to identify the opening direction of a red C amongst three orange-red Cs randomly placed at four corners of a rectangular visual image projected on the floor as soon and accurately as possible (Lo et al., 2015). The visual image was implemented using SuperLab Pro (Cedrus Corp., San Pedro, CA) with an LCD projector (NEC Corp., Japan) and was projected onto the floor location immediately prior to the obstacle. During DO trials, the visual image was presented for a period of 200 ms when the subject was approximately 3 steps before the obstacle. Subjects were instructed to walk towards the obstacle, respond to the visual task immediately after it appears, step over the obstacle, and continue walking towards the end of the walkway. Twelve trials were performed for each C location as well as 6 catch trials with only orange-red Cs presented so 54 (12*4 + 6) trials were performed for the VSA task. Data from 10 young healthy adults (25.1±5.1yrs, 5 males and 5 females) were collected for this experiment.

The visual attention task used in the second experiment was a visual Stroop task (Stroop). The Stroop task was presented to the subject via an iPod Touch with a smartphone application (EncephalApp_Stroop, www.encephalapp.com). Subjects were asked to respond with the color being used to display the word regardless the meaning of the word by touching the color button shown at the bottom of the screen as quickly and accurately as possible. During DO trials, subjects were instructed to walk toward the obstacle, step over it, and continue walking towards the end of the walkway while simultaneously responding to the visual Stroop task. Seven trials were performed for each condition. In each DO walking trial, at least 7 Stroop tests were performed. Similarly,

data from 10 young healthy adults (21.5±2.1yrs, 5 males and 5 females) were collected for this experiment.

Same methods for motion data acquisition and analysis were used in both experiments. Twenty-nine reflective markers were placed on bony landmarks of each subject (Hahn & Chou, 2004), and two additional markers were placed on both ends of the obstacle. The obstacle was made with a PVC pipe with 0.5 inches diameter and 1.3 meters long. Obstacle height was set at 10% of the subject's height (VSA: 15.2 – 18.5 cm; Stroop: 15.1 – 18.1 cm). Motion data were recorded using a ten-camera motion capture system (Motion Analysis Corp., Santa Rosa, CA) at a sampling frequency of 60 Hz. Marker position data were filtered with a low-pass, fourth order Butterworth filter with a cutoff frequency of 8 Hz and were processed (Cortex software, Motion Analysis Corp., Santa Rosa, CA).

Dependent variables included accuracy rates of the VSA or Stroop tasks, numbers of tripping occurrence, gait velocities, toe-obstacle clearances and foot placements of leading and trailing limbs. The accuracy rate of the visual attention task was calculated as the number of the correct trials divided by the number of total trials. Tripping incidence was recorded when the foot contacted the obstacle. Toe-obstacle clearances were calculated as the vertical distance between the toe marker and the obstacle when the toe marker was directly above the obstacle. Foot placements were determined by the horizontal distances between the obstacle and toe marker of the trailing limb prior to crossing and between the obstacle and heel marker of the leading limb immediately after crossing the obstacle. Gait velocity was measured based on the average forward velocity of the whole body center of mass (COM) movement (Hahn & Chou, 2004). We further

analyzed gait velocity during the approaching and crossing phases, respectively, where the approaching phase was defined as the gait cycle prior to the crossing stride. The crossing stride was defined as the gait cycle starting with the heel strike of the trailing limb before the obstacle to the heel strike of the same trailing limb after the obstacle.

In addition, the dual-task costs (DTC) were calculated for each visual attention task on the accuracy rates, toe clearances and gait velocities. DTC was calculated using the formula: DTC = (D-S)/S * 100%, where D indicates dual-task performance and S indicates single task performance. Positive DTC values on the accuracy rate or toe-obstacle clearances represent the subject answered more accurately or raised the foot higher during a dual-task condition than the obstacle crossing only condition. On the other hand, a negative DTC value on the gait velocity indicates the subject walked slower during the dual-task than single-task condition.

Independent t-tests were applied to assess the effect of dual tasking on the accuracy rates, toe clearances, gait velocities in each experiment, and DTC on the aforementioned dependent variables between two experiments. Significance level was set to 0.05.

## Results

Visual attention task accuracy rates of single or dual-task conditions were not different between VSA and Stroop experiments (Table 3.1). One leading and one trailing tripping incidences occurred when crossing the obstacle while performing the VSA task, but no tripping incidence was observed in the Stroop experiment.

When compared to the single-task obstacle crossing condition, significant reductions in trailing foot toe-obstacle clearances (*p=0.009*) were detected in the DO task of the VSA experiment. On the other hand, toe-obstacle clearances of leading and trailing feet were found to increase significantly in the Stroop experiment *(Lead: p=0.001; Trail: p=0.002)*. Foot placements before and after crossing the obstacle of the trailing and leading limbs, respectively, were not different between VSA and Stroop experiments, nor affected by the task condition. Gait velocities, either during the approaching or crossing phase, were found to be similar between single and dual-task conditions in VSA Experiment, but decreased significantly (*p<0.001*) when approaching or crossing the obstacle while performing Stroop tests.

**Table 3.1. Mean (±SE) dependent variables from the visuospatial attention task (VSA) and the visual Stroop task (Stroop) experiments**

| | VSA Experiment | | | Stroop Experiment | | |
|---|---|---|---|---|---|---|
| | Single Task | Dual Task | *sig.* | Single Task | Dual Task | *sig.* |
| Accuracy Rate (%) | 82.7±3.0 | 83.8±3.3 | *n.s.* | 93.2±2.4 | 91.6±2.7 | *n.s.* |
| Trip Incidence (#) | 0 | 2 | * | 0 | 0 | *n.s.* |
| Toe Clearance (cm) | | | | | | |
| Lead Toe Clearance | 15.0±1.2 | 13.9±1.0 | *n.s.* | 15.7±1.1 | 21.2±1.4 | *** |
| Trail Toe Clearance | 15.3±0.8 | 13.2±0.7 | ** | 18.7±1.4 | 26.3±1.9 | *** |
| Foot Placement (cm) | | | | | | |
| Lead Heel-Obstacle | 24.1±2.4 | 27.1±2.5 | *n.s.* | 23.9±2.2 | 28.3±2.5 | *n.s.* |
| Trail Toe-Obstacle | 25.4±1.8 | 24.6±1.9 | *n.s.* | 21.9±1.1 | 24.2±1.3 | *n.s.* |
| Gait Velocity (m/s) | | | | | | |
| Approaching | 1.31±0.04 | 1.27±0.02 | *n.s.* | 1.21±0.02 | 1.06±0.02 | *** |
| Crossing | 1.17±0.02 | 1.23±0.03 | *n.s.* | 1.07±0.02 | 0.93±0.01 | *** |

* indicates the significance between single and dual tasks is less than .05, ** indicates the significance is less than .01, and *** indicates significance is less than .001.

Dual-task costs (DTC) of visual attention accuracy rates were similar between the VSA and Stroop experiments (Figure 3.1A). However, DTC of toe clearances (Figure 3.1B) and gait velocities (Figure 3.1C) were significantly different between the VSA and Stroop experiments. When crossing over an obstacle, performing a concurrent Stroop

task increased toe clearances and reduced gait velocities to a greater extent as compared to the VSA.

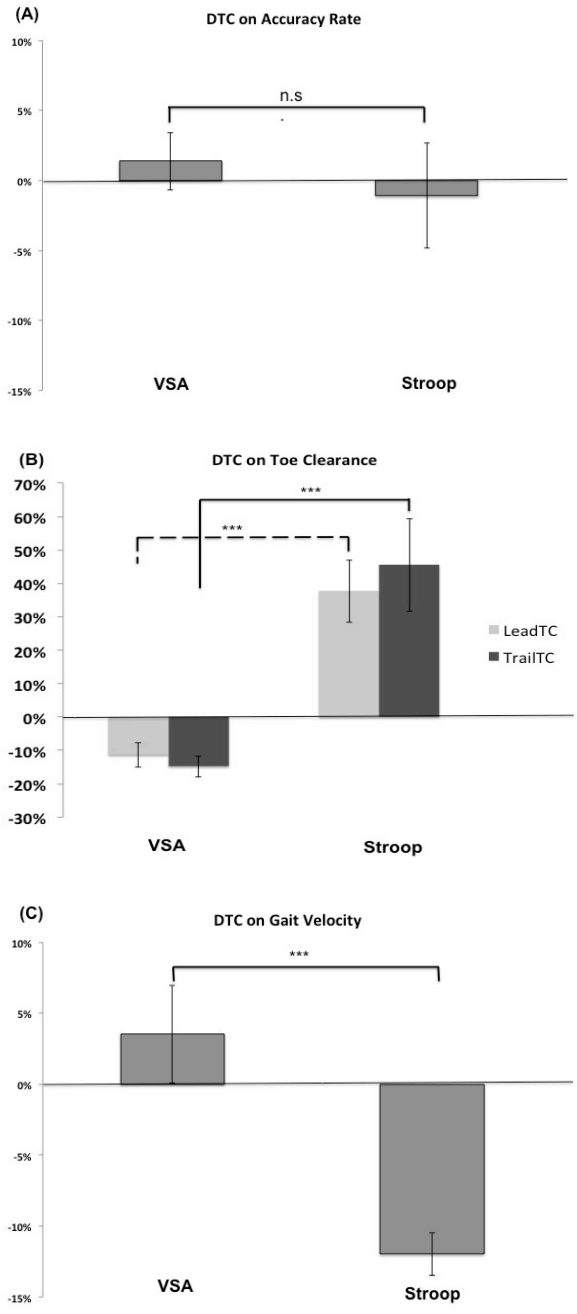


**Figure 3.1. Dual-task costs (DTC, %) on accuracy rate (A), toe clearances (B) and gait velocity (C) for the visuospatial attention (VSA) task and the visual Stroop task (Stroop) experiments.** Positive DTC values indicate subjects answered more accurately, raised the foot higher, or walked faster during the dual-task condition. *** indicates $p<0.001$.

## Discussion

Two experiments were conducted to examine the effects of different visual attention tasks on obstacle crossing in young healthy adults. Our results suggested that concurrently performing a brief (200ms) visuospatial attention task while approaching an obstacle resulted in decreases of trailing toe-obstacle clearances. On the other hand, performing a visual Stroop task while crossing an obstacle crossing increased toe-obstacle clearances of both limbs. Findings from this study echo with previous studies that the type and complexity of cognitive tasks could affect gait performance to varying extents (Howell, Osternig, Koester, & Chou, 2014; P. Patel, Lamar, & Bhatt, 2014). During walking, concurrently engaging a cognitive task that requires further information processing or more working memory capacity (i.e. answer to a spelling or math question, visual Stroop task) would alter gait performance to a greater extent when compared to relatively simple cognitive tasks (i.e. reaction task, single auditory Stroop task). Furthermore, this current study added new knowledge on how different types of attentional tasks interfere an obstacle-crossing gait.

According to Posner and Peterson (Posner & Petersen, 1990), the attention system can be categorized into three networks: alerting, orienting and executive attention. The visuospatial attention task (VSA) in our study is associated predominately with orienting attention, whereas the visual Stroop task is associated with executive attention. The orienting network refers to the ability to prioritize inputs by selecting a location (spatial orienting), and the executive network refers to the ability to resolve conflicts by inhibiting incongruent information. By challenging different domains of attention at

certain stage of the motor task could detect the specific attention requirement during obstacle crossing.

We suspect that a brief distraction of visuospatial attentional resource during the approaching phase interferes with one's planning for crossing (Lo et al., 2015). The reduced trailing toe clearance implies that the feed-forward mechanism is interfered by performing the VSA task during the approaching phase, as visual feedback is not available when the trailing limb crossings over the obstacle. Patla and Vickers (Patla & Vickers, 1997) stated that such planning occurs at least two steps prior to the obstacle. As the VSA task was applied during the planning stage (approaching phase), visuospatial information acquiring for obstacle crossing could be interrupted and re-oriented to the VSA task. This ultimately led to the reduction in trailing toe clearance. Orienting attention can be overt (shift attention with eye movements) or covert orienting (shift attention without eye movements). Due to the lack of eye tracking data, we could not be specific about which orienting attention was employed by our subjects. However, the VSA task employed in this study probed not only the process of visuospatial information (i.e. processing speed), but also the overall allocation of the visuospatial information, including both overt and covert orienting.

Conversely, when approaching an obstacle while engaging with a visual Stroop task that involves further executive demand for a longer duration, young adults seem to be able to adopt a conservative crossing strategy to avoid tripping. Performing the visual Stroop task is expected to engage more cognitive resources than responding to the visuospatial attention task; as the former requires to constantly inhibit inappropriate responses in addition to selection of the appropriate information as the latter

predominately relies on selection. When subjects were explicitly aware of the difficulty of the cognitive task prior to obstacle crossing, they intentionally planned a conservative crossing strategy by walking slower and lifting their feet higher to avoid tripping.

Other factors should be considered besides the effects of attention. First, the length and timing of the visual demands were varied due to the discrete or continuous nature of two tasks. The VSA task appeared briefly and at the approaching phase while the Stroop task appeared continuously for the walking trial. Future studies should regulate the display of two tasks at the same length and timing to better control their possible effects. Second, displays of these two visual attention tasks guided the subject's view toward different locations. Subjects were cued to look at the space on the walkway related to obstacle crossing for the VSA task, while the subject's vision could be directed away from the obstacle to the iPod Touch for the visual Stroop task. Future studies could clarify this effect by projecting both visual tasks onto the walkway or both using a smartphone device. Third, the involvement of the fine motor control could potentially affect the subject's behaviors. The VSA task did not involve any hand movement, but the Stroop task required the subject to hold the phone throughout the walking trial. By either projecting both tasks onto the floor or both holding an iPod Touch could fundamentally clarify this results. Nevertheless, these visual tasks were chosen to better mimic real life scenarios with its relevance to attention. Our findings may not sufficiently provide the exact interpretation on why these behaviors were different but clearly reveal opposite effects on toe-obstacle clearances while engaging with different visual attention tasks.

One limitation of the study was that different subjects were tested in two experiments. However, they were healthy young adults with no significant differences in

age or sex distributions. Motion data of both experiments were collected using the same methodology by the same investigators. Although gait velocity and trailing toe clearance during single-task obstacle crossing were different between two subject groups, individual variability among subjects may contribute to these differences. These differences in subject pools, however, should not affect the trend of the dual-task costs calculated for each experiment.

Dual-task training is commonly used in clinical settings (Agmon, Belza, Nguyen, Logsdon, & Kelly, 2014; Silsupadol et al., 2009), but cognitive tasks used in the dual-task training paradigms were not consistent among studies. Our results suggested that employment of different cognitive tasks would induce distinct alterations in gait performance in young adults. Further studies are needed for older adults or clinical populations to reveal the effects of different cognitive domains on locomotor tasks, such as obstacle crossing.

## Bridge

Chapter III demonstrated that different visual attention tasks lead to distinct modifications on obstacle crossing behaviors. The paradigm of combining a visuospatial attention task while approaching an obstacle during gait was able to detect the contribution of visuospatial attention during locomotion. Before applying transcranial direct current stimulation (tDCS) over the PPC for a locomotor task (Chapter V), we would like to first examine the aftereffects of tDCS over the PPC through an established attention test in a sitting position (Chapter IV). In the next chapter, we will investigate the relationship between the PPC and attention function.

# CHAPTER IV

# EFFECTS OF TRANSCRANIAL DIRECT CURRENT STIMULATION (tDCS) OVER RIGHT POSTERIOR PARIETAL CORTEX (PPC) ON ATTENTION FUNCTION IN HEALTHY YOUNG ADULTS

This work has been prepared for publication. On-Yee Lo contributed to the concept of the studies, recruited subjects, collected data, wrote analysis software, performed data analysis, and prepared the initial manuscript. Dr. Li-Shan Chou contributed to the concept of the study, provided editorial support, and critically reviewed and revised the manuscript.

## Introduction

Attention refers to a series of cognitive operations in selecting, filtering, and utilizing information for further processing. Posner and Peterson (1990; 2012) describe attention as a system and categorize attention into three networks - alerting, orienting and executive – each with its own anatomy, circuitry and function. The alerting attention network involves triggering and sustaining an arousal status. This network occurs predominantly occurs in the reticular activating system located in the brain stem and thalamus as well as the parietal and frontal cortical sites related to the norepinephrine system (Aston-Jones & Cohen, 2005; Moruzzi & Magoun, 1995). The (spatial) orienting attention network indicates an ability to prioritize sensory inputs by selecting a location relevant to the behavioral goal. This network relies on cortical areas, such as the superior and inferior parietal areas and the frontal eye fields, as well as subcortical areas, such as

the pulvinar thalamus and the superior colliculus (Corbetta & Shulman, 2002; Posner, 1980). The executive attention network implies an ability to resolve conflicting information. This network mainly relies on the anterior cingulate gyrus and prefrontal cortex (Cieslik et al., 2013; Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008). Although these three systems are independent, they work closely together to accomplish a goal-directed task (Petersen & Posner, 2012; Raz & Buhle, 2006).

Neuroimaging, neurophysiology, and neuropsychology studies in animals and human have consistently supported the posterior parietal cortex (PPC) as critical for directing attention (Behrmann, Geng, & Shomstein, 2004; Corbetta & Shulman, 2002; Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Eimer, 1998; Rosner & Mittleman, 1996; Thakral & Slotnick, 2009). PPC is located at the portion of parietal cortex posterior to the primary somatosensory cortex. Intraparietal sulcus (IPS) separates PPC into the superior parietal lobe (SPL) and the inferior parietal lobe (IPL). SPL and IPL represent two biasing mechanisms: SPL, along with the superior frontal cortex, contributes to top-down or goal-directed actions, while IPL, along with the inferior frontal cortex, contributes to bottom-up or stimulus-driven actions (Corbetta & Shulman, 2002). Kastner et al. (1999) and Corbetta et al. (2000) have found that neural activities in the PPC areas increased prior to the visual target stimulus appearing, indicating that the signals are biased in favor of the attended location. The parietal-frontal attention network overlapping with the visuospatial processing (Kravitz et al., 2011) suggests that the PPC is the hub to select relevant visuospatial signals for goal-directed movements. Specifically, the right PPC carries and processes visuospatial information from both the left and right visual fields (Heilman & Van Den Abell, 1980) and directs spatial attention

signals toward either side of space (Szczepanski, Konen, & Kastner, 2010), whereas the left PPC contributes to only the right visual field and does not carry spatial attention signals.

Transcranial direct current stimulation (tDCS) is a non-invasive and well-tolerated brain stimulation technique to modulate cortical excitability and to probe cortical function (Nitsche & Paulus, 2000). Through animal studies, scientists found that by applying direct currents to the cortical surface, most of the neurons can be activated by positive currents and inhibited by negative currents (Bindman, Lippold, & Redfearn, 1964; Creutzfeldt, Fromm, & Kapp, 1962). Furthermore, these polarizing effects can last for 15-30 minutes after a 10-15 minute continuous stimulation (Bindman et al., 1964; Bishop & O'leary, 1950; Creutzfeldt et al., 1962; Purpura & McMurtry, 1965). Human studies also found neurophysiological intra- and after- effects of tDCS (Lauro et al., 2014; Nitsche & Paulus, 2011; Stagg & Nitsche, 2011). Nitsche and colleagues (Nitsche et al., 2004; 2005; Nitsche & Paulus, 2000) applied tDCS over the primary motor cortex and used transcranial magnetic stimulation (TMS) to verify cortico-spinal and intra-cortical excitabilities during and after a short period of tDCS stimulation. Their results suggested that anodal stimulation of the motor cortex enhanced cortical excitability and cathodal stimulation inhibited cortical excitability based on significant differences in the TMS input-output curve (I-O curve), short interval intra-cortical inhibition (SICI) and intra-cortical facilitation (ICF) (Nitsche et al., 2005). In particular, during stimulation, tDCS was thought to modulate the resting membrane potential as anodal tDCS enhanced the motor-evoked potential (MEP) amplitude (through I-O curve) relative to sham tDCS values whereas cathodal stimulation diminished the I-O curve relative to sham tDCS.

After tDCS, its effects were suggested to be dependent upon the shifts in intra-cortical inhibition and facilitation as anodal tDCS reduced inhibition (SICI) and enhanced facilitation (ICF), whereas cathodal tDCS enhanced SICI and reduced ICF. These modulations could be further explained by the influence of sodium and calcium ion channels (Nitsche et al., 2004; 2005), neurotransmitters (Cambieri et al., 2012) and/or neurotrophic factors (Antal et al., 2010a; Antal, Terney, Kuhnl, & Paulus, 2010b; Fritsch et al., 2010).

How tDCS modulates the PPC, especially in its effects on the attention network, remains unknown. Behavior studies suggest that anodal tDCS to the right parietal lobe could enhance multisensory spatial orienting (Bolognini, Olgiati, Rossetti, & Maravita, 2010), visual memory (Jones & Berryhill, 2012), visuospatial localization (Wright & Krekelberg, 2014) and learning for concealed object detection (Clark et al., 2012) but has little effect on attention. Neurophysiology studies provided the baseline effects on enhanced neurotransmission, large-scale network connectivity and cerebral excitability after anodal tDCS over the PPC via proton magnetic resonance spectroscopy ($^{1}$H-MRS), resting-state functional magnetic resonance imaging (rs-fMRI) and a combination of Transcranial Magnetic Stimulation (TMS) and Electroencephalography (EEG). Clark et al. (2011) found that glutamate and glutamine significantly increased under the stimulating electrode. Hunter et al. (2015) confirmed the enhanced glutamateric concentration and further reported an increased parietal-frontal functional network connectivity. Lauro et al. (2014) found that anodal tDCS of the right PPC increased global cortical excitability for up to 15 minutes after the end of the stimulation. Whether

these neurophysiological after-effects lead to attention enhancement, and, especially, which subtype of attention, is still unknown.

The purpose of this study was to apply anodal tDCS over the right PPC and examine the tDCS effects on the attention network. In particular, we use a validated Attention Network Test (ANT) to tackle three subtypes of attention. We hypothesized that the orienting attention network would be enhanced after the anodal tDCS stimulation due to the representative hub of PPC in the process of visuospatial attention. The alerting and executive attention networks may also be improved due to the global excitability, but should not be as significant as the enhancement of the orienting attention network.

## Methods

### *Subjects*

Eleven healthy young adults participated in this study (6 males/5 females; age: 22.8±4.6 years; education: 15.8±1.4 years). All subjects reported no known history of neurological or psychiatric disorders, had normal or corrected-to-normal vision and were right-handed, determined via the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were also asked to avoid any intake of alcohol or caffeine for the 24 hours prior to testing. Subjects signed the informed consent forms approved by the Institutional Review Board at the University of Oregon prior to their participation in the study.

### *Attention Network Test (ANT)*

The Attention Network Test (ANT) (Fan, McCandliss, Sommer, Raz, & Posner, 2002) measures the efficiency of three attentional networks - alerting, orienting, and executive attention - in a 30-min testing session which was presented to the subject

through a Java program developed by the Sackler Institute for Developmental Psychobiology. During testing, subjects sat in front of a 13-inch laptop monitor (Toshiba, Portege R835) with a 50 cm viewing distance in a quiet and isolated cubicle. The instruction was to focus on the fixation cross and to press the keyboard arrow (right or left) corresponding to the direction of a target arrow appearing above or below the center fixation cross, as quickly and accurately as possible. Figure 4.1 displays the general sequence of one trial. First the screen would display a central fixation cross for 400 to 1600 ms followed by a pre-cue event for 100 ms. There were four possible pre-cue conditions: no, central, double, or spatial cues. No cues indicated that no asterisk but only the central fixation cross appeared. Central cues indicated that an asterisk appeared on top of the central fixation cross. Double cues indicated that two asterisks appeared on both 5° above and 5° below the central fixation cross. Spatial cues indicated that an asterisk appeared at either 5° above or 5° below the central fixation cross. These spatial cues provided valid information to the target arrow that would be subsequently displayed after the second fixation view. Three possible flanker conditions - neutral, congruent, or incongruent – would then be displayed. Subjects were instructed to press the correct keyboard arrow to match the direction of the target arrow (pointing either to right or left). The neutral condition indicated that the target arrow appeared in isolation on either above or below the central fixation cross. The congruent condition indicated that the target arrow (the arrow in the center) and the flanker arrows (four other same-sized arrows, two to the left and two to the right of the target arrow) pointed in the same direction, whereas the incongruent condition indicated that the target arrow and the flanker arrows pointed in the opposite direction. Once the subject responded, the target arrow disappeared and

the central fixation would appear untill the next trial. If no response was detected, the target arrow disappeared after 1700 ms. The total duration of each trail lasted 4 seconds.

Each subject completed a series of 24 practice trials with visual accuracy feedback prior to the experimental trials without visual accuracy feedback. Three blocks of experimental trials were then conducted. Each block was composed of 96 trials (4 pre-cue conditions x 2 target locations (above or below) x 2 target directions (right or left) x 3 flanker conditions x 2 repetitions) for a total of 288 experimental trials. Subjects were allowed to rest between blocks until they felt ready to continue to the next block. All the subjects completed the ANT within 30 minutes.

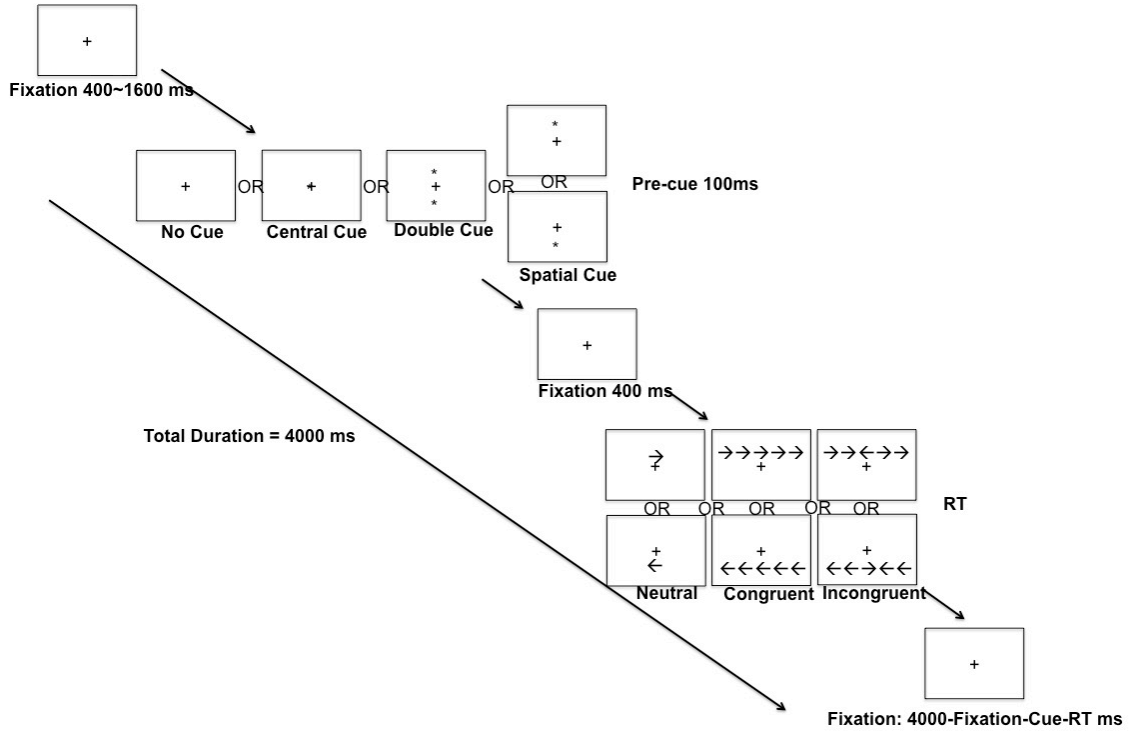


**Figure 4.1. Experimental procedure of Attention Network Test (ANT).**
Subjects focus on the fixation cross and respond with the keyboard right or left based on the target arrow appearing above or below the fixation cross.

The alerting, orienting, and executive effects were calculated based on the grand median reaction time (RT) of the accurate experimental trials (Figure 4.2). They were measured by the RT difference between no cue and double cues, central and spatial cues, and incongruent and congruent conditions, respectively. A greater value in the alerting or orienting effects indicates more efficiency in alerting and orienting attention networks due to faster cue-related performance. A lower executive effect value indicates a better executive attention network due to a faster response to conflicting situations.

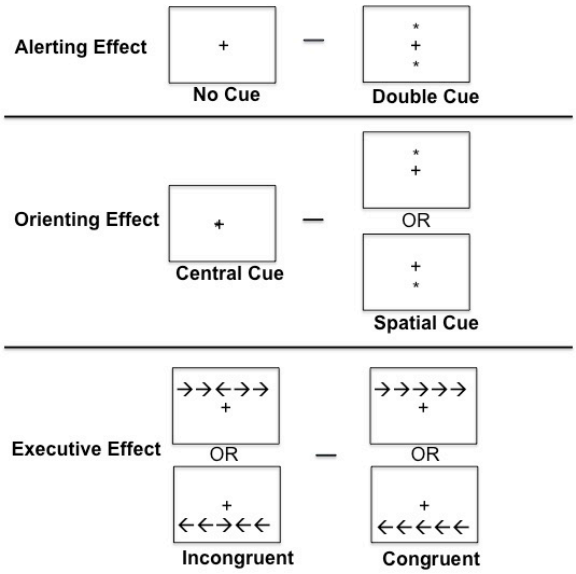


**Figure 4.2. Measurement of three attention effects.**

*Transcranial Direct Current Stimulation (tDCS) Protocol*

Subjects performed the Attention Network Test (ANT) before and after brain stimulation (Figure 4.3). Subjects visited the lab twice for anodal and sham tDCS conditions, respectively, in random order. The tDCS was delivered by a 1x1 line tDCS low-intensity stimulator (Sotetix Medical Inc., New York, NY). The anode electrode was placed over P4 according to the international 10-20 EEG system for right PPC

stimulation. The reference site was placed above the left supraorbital ridge. During the anodal condition, a constant current of 1.5mA was applied for 20 minutes. For the sham condition, no constant current was delivered except in the first and last 30 seconds ramping up and down. The electrodes were inserted into a 5 cm x 7 cm EASYpad™ (Soterix Medical Inc., New York, NY) soaked with approximately 14 ml saline per sponge. Prior to participation, each subject was screened by a safety questionnaire to avoid any potential risks. Following each session, a side effect questionnaire was administrated to monitor possible side effects.

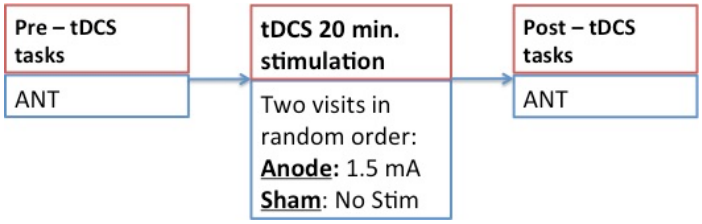


**Figure 4.3. Experimental protocol.** Subjects performed the ANT before and after the anode or sham stimulation condition.

*Dependent Variables and Statistics Analysis*

The alerting, orienting, and executive effects derived from the ANT and their changes before and after the stimulation were the dependent variables. A customized Matlab program was used to calculate the dependent variables.

Median reaction times for ANT conditions of no, double, center, spatial, incongruent, and congruent cues were first calculated in order to measure the three attention effects. Paired t-tests were used to detect the effect of tDCS (pre- and post-stimulations of the anodal or sham condition) on ANT measures. The tDCS aftereffects on three attention effects were further analyzed with the formula: ***Aftereffects (%)*** =

***(Post-stimulation – Pre-stimulation value) / Pre-stimulation value * 100%.*** Paired t-tests were used to detect the differences in the aftereffects (%) between anodal and sham conditions. All statistical analyses were conducted using SPSS version 19.0 (IBM Corp., Armonk, NY).

## Results

The orienting effect was significantly enhanced from 32.7 ms to 59.1 ms ($p<.001$) after anodal tDCS, but no significant changes were found in the other attention effects (Table 4.1, Table 4.2). None of the attention effects were changed after the sham stimulation. The normalized aftereffects value (%) suggested that only the orienting effect was significantly improved ($p=0.04$) after anodal tDCS as compared to sham tDCS (Figure 4.4).

**Table 4.1. Grand median (±SE) of reaction time (RT, ms) and aftereffects (%) for Flanker cues before and after anodal and sham tDCS.**

| | | No Cue | Double Cue | Center Cue* | Spatial Cue | Incongruent Cue | Congruent Cue |
|---|---|---|---|---|---|---|---|
| Anode | Pre (ms) | 559.6 (12.5) | 508.6 (12.5) | 516.2 (13.8) | 483.5 (14.1) | 606.7 (13.6) | 506.5 (13.5) |
| | Post (ms) | 556.5 (11.1) | 489.17 (7.8) | 535.7 (9.7) | 476.7 (9.9) | 611.4 (11.6) | 502.4 (10.8) |
| | Aftereffect (%) | 1.0 (1.5) | -2.0 (1.3) | 4.2 (1.6) | -0.5 (1.4) | 0.9 (1.1) | -0.6 (1.3) |
| Sham | Pre (ms) | 587.6 (16.6) | 515.5 (12.4) | 543.7 (16.9) | 493.3 (14.9) | 626.2 (16.9) | 518.9 (13.2) |
| | Post (ms) | 574.7 (12.4) | 501.2 (10.5) | 530.6 (13.9) | 479.9 (9.3) | 625.8 (18.6) | 507.0 (9.4) |
| | Aftereffect (%) | -1.8 (1.9) | -2.6 (1.6) | -1.2 (1.3) | -1.3 (1.4) | -0.0 (1.6) | -2.1 (1.4) |

* indicates significant difference in aftereffect (%) between anode and sham tDCS

**Table 4.2. Grand median (±SE) of reaction time (RT, ms) and aftereffects (%) for the attention effects before and after anodal and sham tDCS.**

| | | Alerting Effect | Orienting Effect* | Executive Effect |
|---|---|---|---|---|
| Anode | Pre (ms) | 50.9 (6.2) | 32.7 (4.1) | 100.2 (7.7) |
| | Post (ms) | 67.3 (6.6) | 59.1[§] (4.3) | 108.9 (6.2) |
| | Aftereffect (%) | 47.0 (16.8) | 87.1 (20.0) | 13.1 (8.0) |
| Sham | Pre (ms) | 72.1 (8.8) | 50.4 (7.3) | 107.3 (6.0) |
| | Post (ms) | 73.5 (8.5) | 50.8 (6.6) | 118.8 (11.6) |
| | Aftereffect (%) | 11.8 (11.0) | 8.1 (11.2) | 10.3 (8.1) |

* indicates significant difference in aftereffect (%) between anode and sham tDCS;
[§] indicates significant difference in RT (ms) between pre and post stimulation

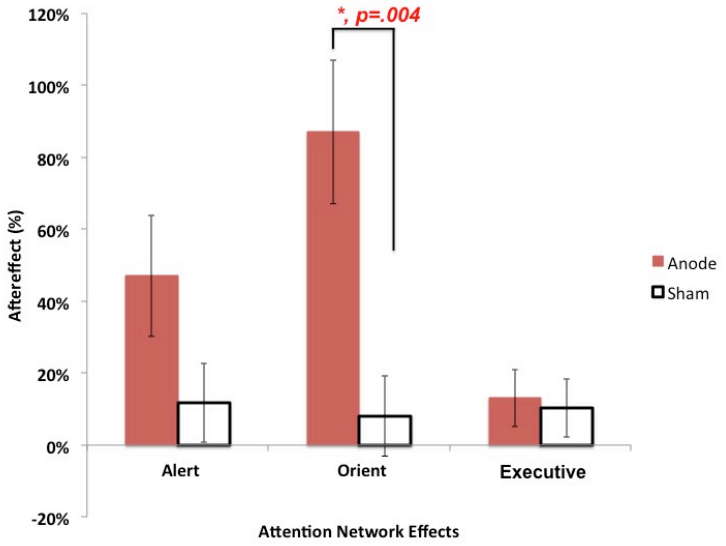


**Figure 4.4. Aftereffects (%) in the alerting, orienting, and executive effects in the anode and sham conditions.** * indicates the significant difference between anode and sham stimulation.

## Discussion

The purpose of this study was to examine the effects anodal tDCS over the right PPC had on the attention network. The results suggested a significant enhancement to the orienting attention after the anodal tDCS, but not in the alerting or executive attention networks. The findings agreed with our hypothesis on the critical role of PPC in orienting attention and the anodal tDCS was effective at enhancing the behavior.

The ANT orienting effect was enhanced by approximately 87% after a 20-minute anodal stimulation. Previous studies had found evidence for the involvement of the parietal cortex in the orienting attention through other neurophysiological tools such as fMRI (Corbetta, Kincade, & Shulman, 2002), TMS (Chica, Bartolomeo, & Valero-Cabre, 2011) and intermittent theta burst stimulation (iTBS) (He et al., 2013). Roy et al. (2015) reported a significant improvement in reorienting attention after the application of anodal tDCS. Previous findings, together with our data, suggest that a 1.5 mA anodal stimulation could enhance activity in the neurons of the right PPC when compared with a sham stimulation.

Interpretations of this finding should be cautious, as the baseline values of the orienting effect prior to stimulation were noticeably different between the anodal and shame conditions (32.7 ms and 50.4 ms, respectively). Despite having a lower baseline value in the pre-anodal condition, a greater orienting effect was still observed in the post-anodal than in the post-sham stimulations (59.1 vs. 50.8 ms). We also noticed that the increased orienting effect was attributed to the slower median reaction time toward central cues after anodal tDCS, which was increased by 4.2% after anodal tDCS but decreased by 1.2% after sham tDCS; the aftereffects between the anodal and sham

stimulations were also significant.

We hypothesized that all reaction times would be improved after anodal tDCS but that did not occur when subjects responded to central cues after anodal tDCS. Several limitations were considered. For one, inter-subject variability was high. Within the orienting effect, the range of aftereffect was 190.0% for anodal tDCS, compared to 123.5% for sham tDCS. And although most of the subjects improved their orienting effects after tDCS, there were subjects who had no improvement or had a poorer performance after anodal tDCS. This high variability suggested there might be both responders and non-responders toward anodal tDCS. In particular, different subjects could have distinct brain structures, functional connectivity or tolerate the stimulation to various extents. Depending on only ANT behaviors without verifying them through other neuroimaging techniques was the limitation of this study. In this study, the same researcher placed the anodal electrode over the right PPC on every subject, based on the 10-20 EEG international system, and marked the brain site on the swim cap in order to localize the same location for the second visit. However, due to the lack of a neural navigation system and a subject-specific head model, we could not quantitatively confirm the stimulation sites between two visits or among subjects.

This study did not include tDCS with cathode stimulation nor measure any potential effect caused by the reference electrode. Results from our pilot study suggested that no effect was found after cathode tDCS stimulation when compared to sham tDCS although previous studies suggested cathodal tDCS over PPC could disrupt visuospatial processing (Schweid, Rushmore, & Valero-Cabre, 2008) or induced a neglect-like effect (Giglia et al., 2011). Further, we could not detect any cathode effects caused by the

reference electrodes over the left supraorbital ridge. Although most of the studies did not consider the reference electrode influencing the cognitive behavior, this cathodal reference electrode could impact the direction of the direct currents and induce inconsistent cognitive behaviors.

Lastly, the ceiling effect of cognitive performance could play a role in young healthy adults. The accuracy rate of the ANT test was above 96% for all the subjects for either pre- or post- test, for both the anodal and sham conditions. There may be very little room to improve for such a relatively easy task; due to the enhancement nature of the anodal tDCS, the aftereffects could thus be limited. Jones and Berryhill (Jones & Berryhill, 2012) also suggested that the parietal cortex contributes to visual working memory to a different degree depending on the task difficulty.

## Conclusion

This study investigated the anodal and sham tDCS over the right PPC on performances of the ANT test. The results suggested that the orienting effect among three attention networks was significantly improved after anodal tDCS. However, due to the inter-subject variability, unspecified brain target, missing cathode condition, and potential ceiling effect, further studies should be conducted to clarify and validate the positive anodal tDCS effects in the orienting attention.

## Bridge

Chapter IV demonstrated that anodal tDCS over the right PPC enhanced the orienting attention, suggesting that the aftereffects of anodal tDCS are effective and may

be used to modulate cortical excitability for a locomotor behavior. In the next chapter, we applied anodal tDCS over the right PPC to the experimental paradigm we established in Chapter II, which was to perform a visuospatial attention task during the approaching phase of the obstacle- crossing behaviors. We hypothesized that the right PPC was critical to visuospatial attention during locomotion, and that the cognitive and motor performances would be enhanced after anodal tDCS.

# CHAPTER V

# EFFECTS OF TRANSCRANIAL DIRECT CURRENT STIMULATION (tDCS) OVER RIGHT POSTERIOR PARIETAL CORTEX (PPC) ON VISUOSPATIAL ATTENTION AND OBSTACLE CROSSING IN HEALTHY YOUNG ADULTS

This work has been prepared for publication. On-Yee Lo contributed to the concept of the studies, recruited subjects, collected data, wrote analysis software, performed data analysis, and prepared the initial manuscript. Dr. Li-Shan Chou contributed to the concept of the study, provided editorial support, and critically reviewed and revised the manuscript.

## Introduction

Visual perception of spatial relationships among objects is important for navigation during gait. Safe navigation can be challenging for high-risk fallers; more than half of falls occur during locomotion while encountering an environment-related hazards, such as being tripped by an obstacle. Recent dual-task studies demonstrate that the control of locomotion is a cognitive-demanding task rather than an automatic motor activity (Al-Yahya et al., 2011; Woollacott & Shumway-Cook, 2002; Yogev-Seligmann et al., 2008). These findings suggest that the central control of locomotion is not limited within the spine but also involve the cortex for higher-level information processing. Among the higher-level cognitive functions, visuospatial attentional resources are closely related to balance control and anticipatory control in human locomotion (Catena, van Donkelaar, & Chou, 2007; Drew et al., 2007; Lo et al., 2015; Owens, 2008; Van

Donkelaar et al., 2005). Visuospatial attention refers to an ability to select absolute and relative spatial information of objects in the visual field. Take obstacle crossing for example, individuals who ineffectively utilize spatial information can mistakenly estimate the appropriate raised-height of their legs and get tripped by an object.

Previous studies suggested that the posterior parietal cortex (PPC) contributes to planning and integrating an estimated location of the body and the object for modifying gait during locomotion (Andujar et al., 2010; Beloozerova, 2003; Marigold & Drew, 2011; Marigold, Andujar, Lajoie, & Drew, 2011). Andujar et al. (2010) recorded 121 neurons from the PPC of two cats and found that 84% of the neurons significantly increased their activity while stepping over an obstacle on a treadmill compared to 53% of the neurons while walking unobstructed on a treadmill. These neurons were found to be firing prior to crossing over the obstacle, indicating the role of the PPC in the planning of gait modification during the approaching phase rather than the crossing phase. When comparing neural activities in the PPC and the motor cortex, 60% of the PPC cells were involved in gait modification whereas only 16% of the motor cortex cells were. Furthermore, the same amount of PPC cells discharged during the task, regardless of contralateral or ipsilateral limb, whereas these limb-independent cells were not observed in the motor cortex during the the obstacle-crossing task. These findings suggest that the PPC works at a higher level than the motor cortex in planning visually-guided locomotor modifications. Marigold et al. (2011) also recorded neurons in the PPC of the cats and further realized that the PPC contributed to motor planning not only with constant but also with intermittent visual inputs. The cats were able to step over the obstacle when their eyes were occluded, suggesting that the cats were able to retain the memory of the

motor plan, and that the PPC is more involved in integrating visual and motor information rather than in analyzing visual characteristics of the obstacle. In addition, both the old and new neural frameworks suggest that the PPC plays a critical role in mediating visuospatial processing (Kravitz et al., 2011; Mishkin, Ungerleider, & Macko, 1983). Kravitz et al. (2011) reviewed evidence to support the idea that spatial processing occurs in three pathways for navigation: the parieto-prefrontal, parieto-premotor and parieto-medial temporal pathways, which were all initiated at the PPC.

Finding out how to investigate the role of the PPC in a dynamic and upright position, such as in a walking human, is a challenge. Previous studies have tried to explore cortical involvement during locomotion through the following methods: 1) some recorded neuron activities in the PPC in animal subjects (Andujar et al., 2010; Marigold & Drew, 2011); 2) other studies observed locomotor behaviors in human or animal subjects with damaged PPC (K. Lajoie & Drew, 2007; Philbeck, Behrmann, Black, & Ebert, 2000); 3) others detected changes in regional cerebral-blood-flow (rCBF) via positron emission tomography (PET), or blood oxygenation level dependent (BOLD) signals via functional magnetic resonance imaging (fMRI), after real or imagined walking, with or without obstacles (Jahn et al., 2004; la Fougère et al., 2010; Malouin et al., 2003); 4) other research measured changes in hemoglobin oxygenation via near-infrared spectroscopy (NIRS) during treadmill walking (Holtzer et al., 2011; Miyai, Tanabe, Sase, Eda, Oda, Konishi, Tsunazawa, Suzuki, Yanagida, & Kubota, 2001b); 5) other researchers analyzed electrocortical activity via high density electroencephalography (HD-EEG) while walking on a treadmill (Gwin et al., 2011; Lau et al., 2014); or 6) some analyzed EEG patterns while treadmill-walking in a virtual

reality environment (J. Wagner, Solis-Escalante, & Scherer, 2014). The above methods, however, could not sufficiently measure any direct or causal contribution of the PPC to the control of walking in healthy human subjects.

Transcranial direct current stimulation (tDCS) serves as a tool with the potential to probe specific brain sites while subjects are walking outside of a scan room or outside of a treadmill. tDCS is a non-invasive brain stimulation method and the after-effects generated by an anodal tDCS can elevate long-lasting cortical excitability for up to 90 minutes (Nitsche & Paulus, 2001). Jayaram et al. (2012) applied anodal tDCS over the cerebellum and reported an enhanced rate of locomotor adaptation on a split-belt treadmill. Kaski et al. (2012) applied anodal tDCS over the primary motor cortex of the leg and the premotor cortex and noticed a significant increase in forward trunk displacement and gait velocity after stepping from a moving platform, suggesting an enhancement of the motor adapting ability. Evidence from clinical tDCS studies supports the positive effects of applying anodal tDCS to individuals with stroke (Feng et al., 2013; Schlaug et al., 2008; Tahtis, Kaski, & Seemungal, 2014), Parkinson's disease (Benninger et al., 2010; Broeder et al., 2015) and other neurological diseases (Floel, 2014; Fox et al., 2014). These recent studies mainly targeted the motor cortex or cerebellum because tDCS is relatively new as a research tool. Using the aftereffects from tDCS over the right PPC is an innovative method for further understanding the neurophysiological mechanism of visual perception during over-ground locomotion in humans.

The purpose of this study was to investigate the underlying neurophysiological mechanism of the visuospatial attention process during locomotion. In particular, we adopted the established paradigm described in Chapter II (Lo et al., 2015) and the same

tDCS protocol used in Chapter IV to explore the performance in visuospatial attention and obstacle crossing before and after stimulating right PPC. We hypothesized that after anodal tDCS, both visuospatial attention and obstacle-crossing performances would be improved, as demonstrated by a higher accuracy rate in the responses to the visuospatial attention task and by the maintenance of greater toe-obstacle clearances for the leading and trailing limbs while responding to the visuospatial attention task during the approaching phase of locomotion.

## Methods

### *Subjects*

Ten healthy young adults (4 males/6 females, age: 24.1 ± 4.7 y/o) participated in the study. The Snellen and the Ishihara tests were applied to confirm that individuals had normal or corrected-to-normal vision and no color blindness, respectively. Individuals with any history of neuromuscular diseases, head injury, seizure or other medical condition that could affect locomotion or induce adverse reactions to brain stimulation were excluded. The recruited subjects were right-handed and right-footed, as determined by the Edinburgh Handedness Inventory (Oldfield, 1971) and a report of the self-selected leg when kicking a ball. The experimental procedure was approved by the Institutional Review Board at the University of Oregon and the subjects signed an informed consent form prior to participation.

*Experimental Protocol*

Subjects performed three tasks in random order immediately before and after 20 minutes of brain stimulation. The three tasks included a visuospatial attention task performed in a static standing position (VA only), walking and crossing over an obstacle (OC only), and performing the visuospatial task while obstacle crossing (OC+VA) (Figure 5.1). The visuospatial task (VA) and obstacle crossing (OC) tasks are described in the following paragraphs. Each subject visited the lab twice for one anode and one sham stimulation, in random order.

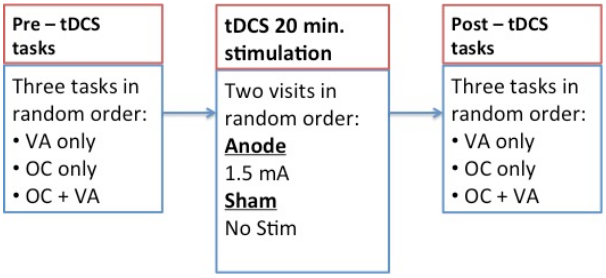


**Figure 5.1**. **Experimental protocol**. Each subject performed three tasks in random order immediately before and after tDCS stimulation. Two laboratory visits were required for one anode and one sham stimulation condition, respectively.

*Visuospatial Attention Task*

A simplified version of a visuospatial attention (VA) task was adopted from our previous study (Lo et al., 2015) for this experiment. Two targets, one red C [RGB: 255, 0, 0] and one orange-red C [RGB: 255, 50, 0], were randomly placed at the top or bottom of an image projected onto the floor (Figure 5.2a). Each C pointed toward one of the four directions relevant to the walking or standing direction: toward (Front), opposite (Back), left (Left) or right (Right), and could be located at either the top or bottom of the projected area. The instruction for the VA task was to identify the directional opening of

the red C as soon as the visual image was flashed (200ms). The red C could appear at each direction and location once so that there would be eight trials (4 directions * 2 locations) in total for the visuospatial attention task. Figure 5.2 displays the projected image for one of the eight possible trials. In this trial, the correct response would be "back" because the bottom red C was open toward the opposite direction of the walking or standing direction. The subject had to accurately respond to this briefly-appearing image by orienting attention toward the correct target (red-C) and ignoring the distractor target (orange-red C). Visual stimuli were implemented using SuperLab Pro (Cedrus Corp., San Pedro, CA) and an LCD projector (NEC Corp., Japan). All projected C stimuli were 2.5 inches long, 2.5 inches wide and the openings of the gaps were 0.5 inches. The total projection area on the floor was 26 inches wide by 34 inches long.

The subjects responded in the visuospatial attention task during either standing or obstacle-crossing conditions. In the standing condition, the visual image was projected two steps in front of the subject. In the obstacle-crossing condition, the visual image was projected two or three steps in front of the subject prior to crossing over the obstacle.

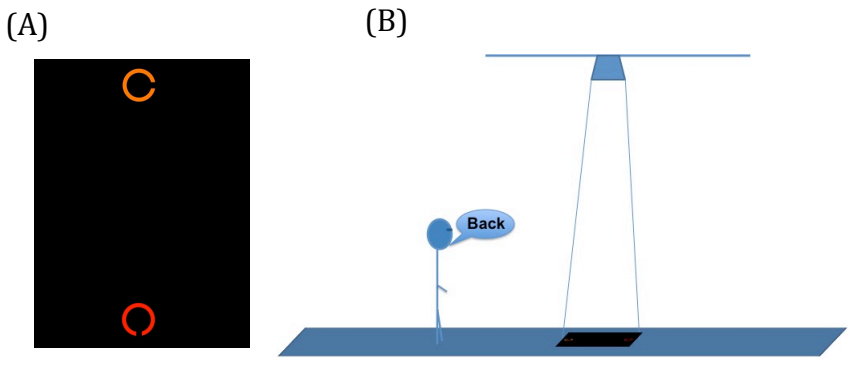


**Figure 5.2. Example of the simplified visuospatial attention task**. (A) One example trial of the visuospatial attention (VA) task. The subjects had to identify the opening direction of the red C (the bottom one) and ignore the distractor orange-red C (the top one). (B) For example, in this case, the subject would answer "back" because the bottom red C was directed toward the back of the subject.

### *Obstacle Crossing Paradigm*

The obstacle-crossing paradigm is similar to that described in Chapter II (Lo et al., 2015). A PVC pipe crossbar (0.5 inches diameter, 1.3 m long) was set up at 10% of the subject's height to be the obstacle and it was placed directly after the VA task projection area. The subject began walking from a location approximately 7 meters away from the obstacle, proceeded towards the obstacle, stepped over it, and continued walking toward the end of the walkway at a self-selected speed. Each subject performed eight trials of this obstacle-crossing-only task. The same researcher placed twenty-nine markers on bony landmarks for every subject and two retro-reflective markers on both sides of the obstacle (Hahn & Chou, 2004). A ten-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA) was used to collect the marker trajectory at a sampling frequency of 60 Hz. The data were further processed and filtered with a low-pass, fourth-order Butterworth filter and a cutoff frequency of 8 Hz in Cortex software (Motion Analysis Corp., Santa Rosa, CA).

### *Transcranial Direct Current Stimulation (tDCS)*

The transcranial direct current stimulation (tDCS) paradigm is similar to that described in Chapter IV. A 1 x 1 line tDCS low-intensity stimulator (Sotetix Medical Inc., New York, NY) was used to deliver direct currents. We targeted the right posterior parietal cortex (PPC), so we placed the anode electrode over P4 according to the international 10-20 EEG system and placed the reference electrode above the left supraorbital ridge. A constant current of 1.5 mA was delivered for 20 minutes in the anodal condition, and no constant current was delivered besides the first and last 30 seconds, at the sham condition. Two 5 x 7 cm EASYpads$^{TM}$ (Soterix Medical Inc., New

York, NY) soaked with approximately 14 ml saline per sponge served as the electrodes. In addition to answering the screening questionnaire before the experiment, each subject filled out another questionnaire to monitor for any possible adverse reactions.

*Data Analysis*

The dependent variables of interest were: 1) accuracy rate of the VA task, 2) toe-obstacle clearances of the leading and trailing limbs, 3) aftereffects in the accuracy rate of the VA task, 4) aftereffects in the toe-obstacle clearances for the leading and trailing limbs, 5) dual-task cost (DTC) in the accuracy rate of the VA task, and 6) DTC in toe-obstacle clearances of the leading and trailing limbs. In addition to determining DTC within either pre-stimulation and post-stimulation conditions, respectively, we further calculated the post-stimulation DTC based on the single task in the pre-stimulation condition in order to eliminate the effects caused by the cognitive task and stimulation. According to our previous findings, the trailing limb was significantly decreased but not the leading limb so we reported these changes in the trailing limbs.

The accuracy rate of the VA task was calculated based on the accurate responses divided by the total responses for each condition. Toe-obstacle clearances were measured to be the vertical distance between the markers placed on the obstacle and the swinging foot between the 2nd and 3rd metatarsals (toe marker) when the foot was directly above the obstacle. The aftereffects of tDCS were analyzed with the following formula: ***Aftereffects (%) = (Post-stimulation performance – Pre-stimulation performance) / Pre-stimulation performance * 100%.*** A positive aftereffect on the accuracy rate refers to a better performance in answering the VA task while a negative aftereffect refers to a worse performance in answering the VA task after the anodal or sham stimulation. A

positive aftereffect on the toe-obstacle clearance refers to a higher toe-obstacle clearance, while a negative aftereffect refers to a lower toe-obstacle clearance after anodal or sham stimulation.

Dual-task costs (DTC) were calculated based on the following formula: ***Dual-task cost (DTC, %) = (Dual-task performance – Single task performance) / Single task performance * 100%.*** A positive DTC in the accuracy rate of the VA task refers to a better performance in answering the VA task during an obstacle-crossing task than in standing alone, and a negative DTC value refers to a worse performance in the dual-task condition. A positive DTC in the toe-obstacle clearance refers to a higher foot raise while concurrently performing the VA task and the obstacle-crossing task, while a negative DTC value refers to a lower toe-obstacle clearance during a dual-task scenario.

In addition to normalizing the DTC within pre-stimulation or post-stimulation, we normalized the post-stimulated dual-task cost based on the pre-stimulated single task performance - for accuracy rate and toe-obstacle clearance - through the following formula: ***Dual-task costs in Post-stimulated dual-task performance normalized by Pre-stimulated single task performance ($DTC_2$, %) = (Post dual-task performance – Pre single task performance)/ Pre single task performance * 100%.*** The pre single-task performance was selected as the baseline for normalizing the post dual-task performance, as this value was not affected by either cognitive task or stimulation.

Paired t-tests were used to detect the significance in the abovementioned dependent variables either 1) between anodal and sham conditions, 2) between pre- and post- stimulation conditions or 3) between single and dual-task conditions.

## Results

### *Accuracy Rate of the Visuospatial Attention Task*

There was no significant difference between anode and sham conditions in the pre- or post- stimulated accuracy rates of the VA task, either with or without an obstacle-crossing task (Table 5.1). However, the dual-task cost (DTC) in the accuracy rate of the VA task was significantly different between anode (16.0±10.9%) and sham (-13.6±7.8%) conditions after stimulation *($p = .04$*) (Table 5.1, Figure 5.3). DTC changed from -3.5±6.5% to 16.0±10.9% after anodal stimulation and from 0.0±7.7% to -13.6±7.8% after sham stimulation; however, the changes between pre- and post-stimulation were insignificant for anode (*$p = .14$)* or sham *($p = .23$)* conditions (Table 5.1, Figure 5.3).

Figure 5.4 displays the post-stimulation DTC by using two normalization methods. Both methods appeared to show the same direction of trends but only the method that was normalized by the post-VA alone can significantly differentiate anode from sham stimulation. Aftereffects in the accuracy rate tended to improve while subjects were performing the VA and obstacle-crossing tasks after the anode stimulation (10.7±6.8), compared to the sham stimulation (-4.7±7.8), but the difference between anode and sham was not significant (*$p = .16$).* Aftereffects in the accuracy rate were also insignificant between anode and sham while performing VA alone (*$p = .12$)* (Table 5.1, Figure 5.5).

### *Toe-Obstacle Clearance*

No significant differences were found in toe-obstacle clearances between anode and sham conditions (Table 5.2). Before stimulation, toe-obstacle clearances were similar between the anode and sham groups for leading (Anode: 15.8±0.4 cm vs. Sham: 15.7±0.7

cm) and trailing (Anode: 19.4±1.8 cm vs. Sham: 19.5±1.5 cm) limbs during obstacle crossing, suggesting a similar baseline performance. After stimulation, subjects in both the anode and sham groups tended to increase the leading toe-obstacle clearance (aftereffects: Anode: 4.4±5.8 % and Sham: 2.3±7.0 %) and decrease the trailing toe-obstacle clearance (aftereffects: Anode: -9.5±4.8 % and Sham: -6.6±2.9%).

Compared to single task obstacle crossing, the leading toe-obstacle clearance tended to increase and the trailing toe-obstacle clearance tended to decrease when obstacle crossing and the VA task were performed simultaneously (Table 5.2). After stimulation, the leading toe-obstacle clearance appeared to be the same (Anode: 16.5±0.9 to 16.9±1.5 cm and Sham: 17.2±0.8 to 17.3±2.0 cm) and the trailing toe-obstacle clearance decreased slightly (Anode: 18.4±1.9 to 17.3±2.0 cm and Sham: 16.8±1.6 to 15.2±1.6 cm). Dual-task cost (DTC) analysis revealed smaller changes in the anode condition than in the sham condition, either before or after stimulation, for both the leading and trailing limbs.

The post-OC+VA results suggested that the trailing toe-obstacle clearance tended to decrease after either anode or sham stimulation (Table 5.2, Figure 5.6). The trailing toe-obstacle clearance decreased from 19.4±1.8 cm, with no stimulation nor VA task, to 17.3±2.0 cm after anode stimulation and with a VA task ($p = .45$). The trailing toe-obstacle clearance decreased from 19.5±1.5 to 15.2±1.6 cm after sham stimulation and with a VA task ($p = .06$). The results suggested that after an anodal stimulation a smaller reduction in the trailing toe-obstacle clearance (-.11±.06 %) was observed when compared with the sham stimulation (-.22±.04 %). The post-OC+VA DTC appeared to show the same trend whether the post-OC+VA performance was normalized by the pre-

OC only (Anode: -.11±.06 % and Sham: -.22±.04 %, *p*=*.15*) or the post-OC only data (Anode: -4.7±5.5 % and Sham: -17.2±5.1 %, *p*=*.13*) (Table 5.2, Figure 5.7).

**Table 5.1. Mean (±SE) accuracy rate of the VA task (%) during standing (VA only) and obstacle crossing (Obstacle Crossing+VA) before (Pre-) and after (Post-) anode or sham tDCS stimulation.** Aftereffects and dual-task costs were also reported.

| | | VA Only | Obstacle Crossing +VA | Dual-task Cost* |
|---|---|---|---|---|
| **Anode** | **Pre (%)** | 85.0±3.1 | 81.3±5.0 | -3.5±6.5 |
| | **Post (%)** | 80.0±5.7 | 87.5±3.2 | 16.0±10.9 |
| | **Aftereffect (%)** | -5.1±7.6 | 10.7±6.8 | |
| | **DTC of Post-OC+VA normalized by Pre-VA only (%):** 3.3±3.3 | | | |
| **Sham** | **Pre (%)** | 81.3±2.8 | 80.0±5.0 | 0.0±7.7 |
| | **Post (%)** | 88.8±4.4 | 75.0±5.9 | -13.6±7.8 |
| | **Aftereffect (%)** | 9.6±4.9 | -4.7±7.8 | |
| | **DTC of Post-OC+VA normalized by Pre-VA only (%):** -5.8±9.0 | | | |

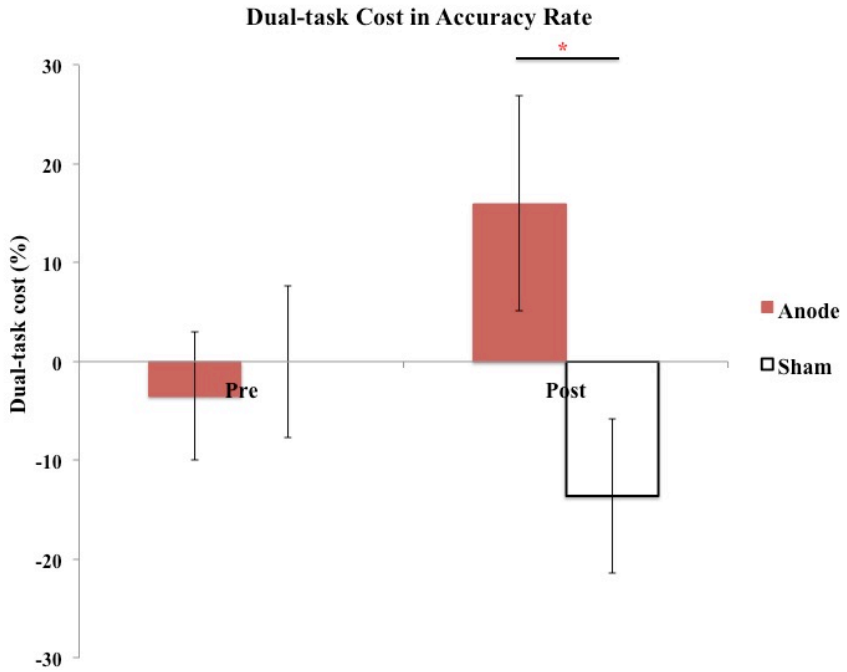


**Figure 5.3**. **Dual-task cost (DTC, %) in accuracy rate at pre- and post- stimulation for anode and sham conditions.** * indicates a significant difference in DTC after stimulation between anode and sham conditions.

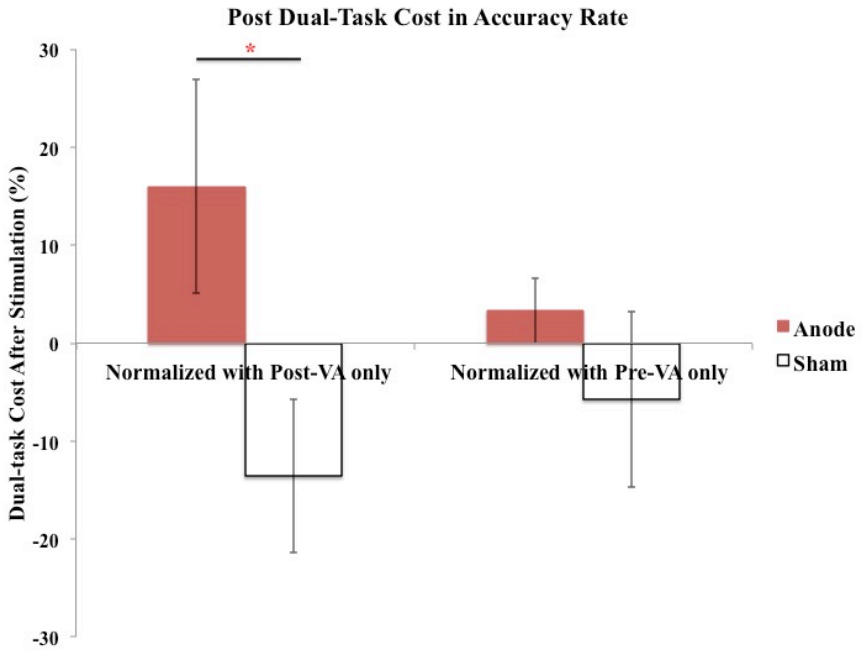


**Figure 5.4**. **Two normalized methods to calculate dual-task costs after stimulation.** One was normalized by the accuracy rate of the visuospatial attention (VA) task only after stimulation (left, Normalized with Post-VA only) and the other one was normalized by the accuracy rate of the VA task only before stimulation (right, Normalized with Pre-VA only). * indicates a significant difference between anode and sham conditions.

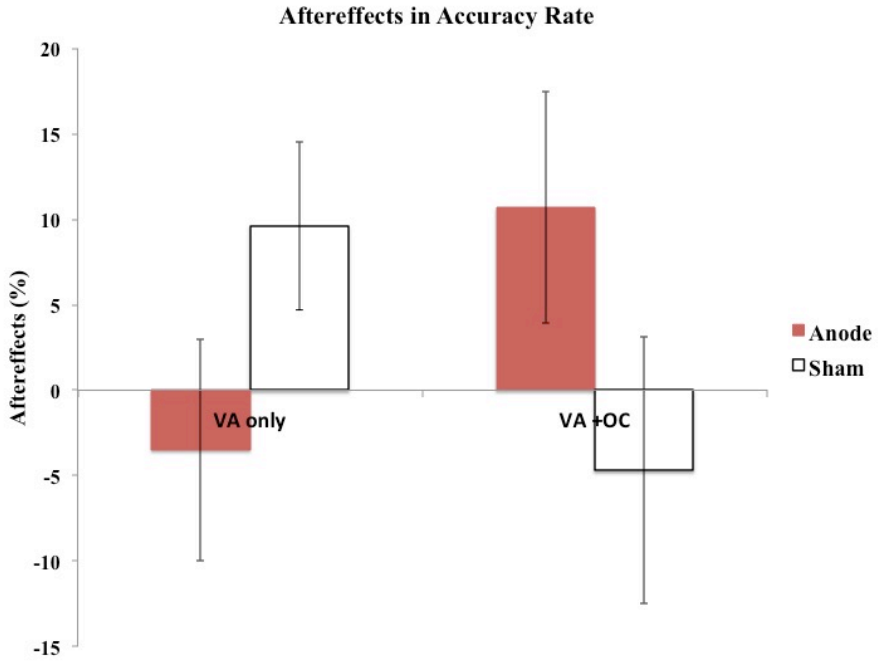


**Figure 5.5**. **Aftereffects in accuracy rate of the visuospatial attention (VA) task (%) during standing (VA only) or obstacle crossing (VA+OC) for anode and sham conditions.** There was no significant difference between anode and sham conditions for VA only or VA+OC.

**Table 5.2. Mean (±SE) toe-obstacle clearances of the obstacle crossing alone (OC only) and obstacle crossing with the VA (OC+VA) task before (Pre) and after (Post) anode or sham tDCS stimulation.** Aftereffects, dual-task costs (DTC), and DTC of post-OC+VA normalized by Pre-OC only in the trailing limb were also reported.

| | | Obstacle Crossing Only | | Obstacle Crossing + VA | | Dual-task Cost (DTC, %) | |
|---|---|---|---|---|---|---|---|
| | | *Lead* | *Trail* | *Lead* | *Trail* | *Lead* | *Trail* |
| **Anode** | **Pre (cm)** | 15.8±0.4 | 19.4±1.8 | 16.5±0.9 | 18.4±1.9 | 4.5±5.3 | -5.0±5.4 |
| | **Post (cm)** | 16.3±1.1 | 17.9±2.1 | 16.9±1.5 | 17.3±2.0 | 0.5±3.3 | -4.7±5.5 |
| | **Aftereffect (%)** | 4.4±5.8 | -9.5±4.8 | 1.6±3.8 | -6.7±4.9 | | |
| | **DTC of Post-OC+VA normalized by Pre-OC only (%, trail limb):** | | | | | -.11±.06 | |
| **Sham** | **Pre (cm)** | 15.7±0.7 | 19.5±1.5 | 17.2±0.8 | 16.8±1.6 | 11.1±3.5 | -12.8±4.1 |
| | **Post (cm)** | 15.9±1.2 | 18.4±1.7 | 17.3±2.0 | 15.2±1.6 | 8.0±2.8 | -17.2±5.1 |
| | **Aftereffect (%)** | 2.3±7.0 | -6.6±2.9 | 0.0±3.9 | -8.6±4.7 | | |
| | **DTC of Post-OC+VA normalized by Pre-OC only (%, trail limb)**: | | | | | -.22±.04 | |

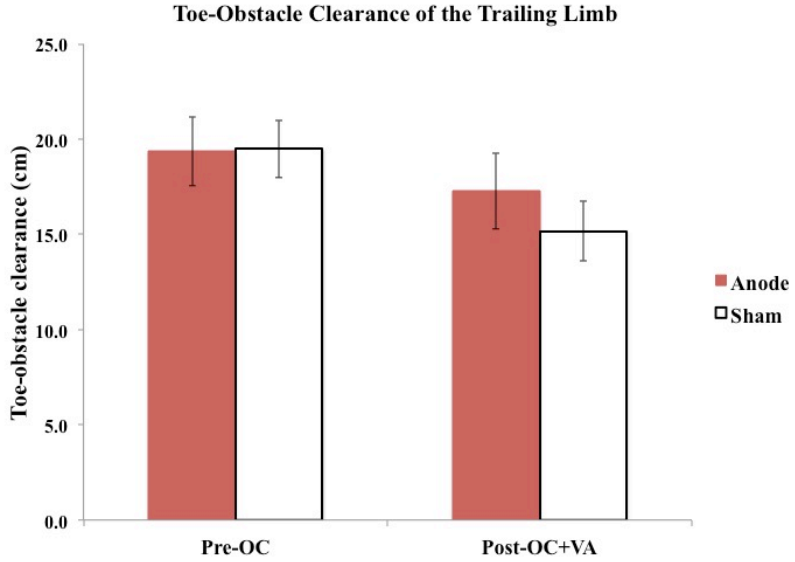


**Figure 5.6**. **Toe-obstacle clearance of the trailing limb (cm) in obstacle crossing alone before stimulation (Pre-OC, left) and after both stimulation and adding the visuospatial attention (VA) task (Post-OC+VA, right).** Toe-obstacle clearances tend to decrease less in anode condition (19.4±1.8 to 17.3±2.0 cm, *p=.45*) compared to sham *(*19.5±1.5 to 15.2±1.6 cm, *p=.06)* condition.

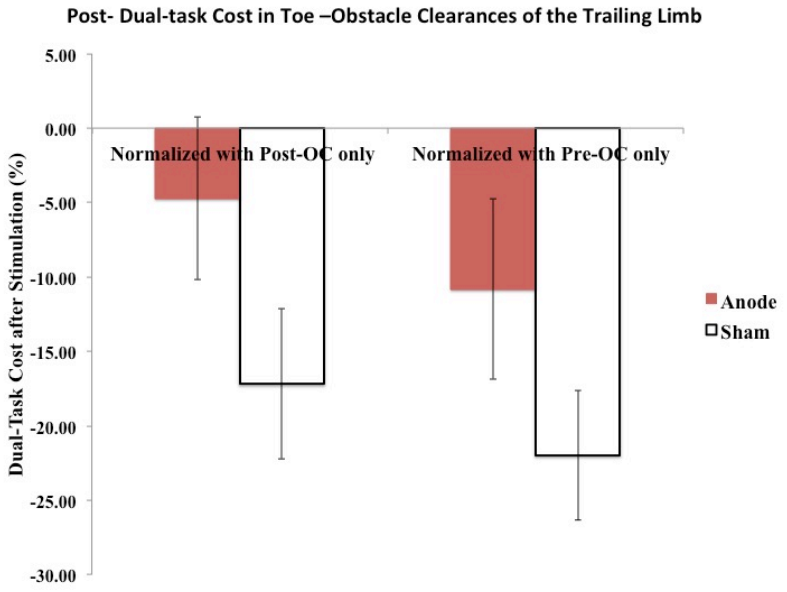


**Figure 5.7. Two normalized methods to calculate dual-task costs after stimulation.** One was normalized by the toe-obstacle clearances during obstacle crossing only after stimulation (left, Anode: -4.7±5.5 % v.s. Sham: -17.2±5.1 %, *p=.13*) and the other one was normalized by obstacle crossing only before stimulation (right, Anode: -.11±.06 % v.s. Sham: -.22±.04 %, *p=.15*). Both methods appeared to show the same trend but no significant difference was detected between anode and sham conditions for both methods.

## Discussion

The purpose of this study was to investigate how anodal tDCS stimulation over the right posterior parietal cortex (PPC) alters obstacle crossing behaviors, especially when subjects were distracted by a visuospatial attention (VA) task. We hypothesized that after anodal tDCS was applied over right PPC, subjects enhanced their cognitive performance by improving the accuracy of the VA task, and enhanced motor performance by decreasing toe-obstacle clearance in the dual-task task. Our results suggested that the anodal tDCS significantly enhanced the dual-task cost (DTC) in response to the visuospatial attention (VA) task while obstacle crossing, as compared to sham stimulation. A non-significant trend of a smaller reduction in trailing toe-obstacle clearance was observed after anodal tDCS when compared to sham tDCS.

*Accuracy Rate of the Visuospatial Attention Task*

Accuracy rates for the VA task were similar before anode or sham stimulation while standing (Anode: 85.0±3.1% vs. Sham: 81.3±2.8 %, $p=.38$) or in approaching an obstacle while walking (Anode: 81.3±5.0 % vs. Sham: 80.0±5.0 %, $p=.86$). After the anodal stimulation, the accuracy rates decreased to 80.0±5.7 % (5.1±7.6 %; $p=.45$) for the VA only condition but increased to 88.8±4.4 % (9.6±4.9 %; $p=.16$) after the sham stimulation. Subjects could perform similarly or better in their second attempt, so it is reasonable that the accuracy rate improved after the stimulation in the sham condition. In fact, eight out of ten subjects remained the same or improved after the sham condition. However, the trend did not appear after anodal stimulation in the accuracy rate of VA-only, although we would expect the accuracy rate to be improved more in the post-anodal tDCS when compared to post-sham tDCS. Indeed, five out of ten subjects regressed in answering in the VA task while standing after anodal tDCS, including one subject who responded with only a 37.5 % accuracy rate after the anodal stimulation as compared to a 75 % accuracy rate before stimulation. Although most previous studies suggested that anodal tDCS enhanced cognitive performance, few studies reported negative or mixed effects after anodal tDCS (Berryhill & Jones, 2012; Berryhill, Peterson, Jones, & Stephens, 2014; Jones & Berryhill, 2012) potentially due to task difficulty or some unidentified factors. In addition to the mixed tDCS effects, the insignificant changes in the accuracy rate of the VA task during standing may result from the ceiling effect, insufficient trials of the VA task (only 8) or the sample size.

When answering the VA task becomes challenging -- subjects had to answer the VA task immediately prior to crossing an obstacle -- the anodal stimulation might benefit

cognitive performance. The baseline in accuracy rates remained similar prior to both stimulations (Anode: 81.3±5.0 % vs. Sham: 80.0±5.0 %, $p=.86$). After anodal tDCS, subjects tended to enhance their performance, raising the accuracy rate up to 87.5±3.2% while the averaged accuracy rate was 75.0±5.9 % after the sham condition. Eight out of ten subjects improved or remained constant after anodal stimulation, whereas only three slightly improved and two remained the same after the sham stimulation. Although these differences in accuracy rates were not statistically significant, the dual-task costs after stimulation could be statistically distinguished between the anodal and sham stimulations.

Before the anodal or sham stimulation, more than half of the subjects in both conditions demonstrated negative or zero dual-task costs (DTC) for answering the VA task during obstacle crossing, suggesting a worsened or similar cognitive performance when combining two tasks together, as compared to answering the VA task while only standing. After anodal stimulation, DTC in accuracy rate was enhanced by an average of 16.0±10.9 %. When looked at in individual performance, eight out of ten subjects improved their DTC. However, after sham stimulation, DTC in the accuracy rate diminished by an average of -13.6±7.8%. Only two individuals performed slightly better in answering the VA task while obstacle crossing, and the rest of the subjects either performed worse or remained at the same DTC in the accuracy rate. These findings suggest that after anodal tDCS the ability to perform the VA task during obstacle crossing is enhanced after normalizing it with the single task performance, and this enhanced cognitive performance was significantly better than with the sham stimulation. However, we have to be cautious about interpreting the data because the post-single task baseline, the averaged accuracy rate in VA only, is difficult to compare between post-anodal and

post-sham stimulation (Anode: 80.0±5.7 % vs. Sham: 88.8±4.4 %). Thus we then normalized the post-DTC with a pre-VA only performance to avoid any tDCS effects. A similar trend of findings appeared as an increased DTC of 3.3±3.3 % after anodal stimulation, compared to a decreased DTC of -5.8±9.0 % following sham stimulation.

In summary, we were able to differentiate anodal from sham effects when comparing the DTC in accuracy rate for the VA task after stimulation. The ability to perform the VA task while approaching an obstacle during walking is likely to be enhanced after anodal tDCS stimulation, but this did not occur while performing the task during standing. Our results suggest that the anodal tDCS over right PPC might enhance the visuospatial attention function as the task becomes more challenging.

*Toe-Obstacle Clearance*

For obstacle crossing only performance, the baseline data were consistent over the two visits for leading and trailing limbs (Table 5.2). This suggested that although the subjects were tested on different days the baseline performance in obstacle crossing was comparable and the values could be used as a reference for comparison. No significant differentiations were observed between anodal and sham tDCS effects on toe-obstacle clearances of the leading or trailing limbs. However, several trends were noted from further examination of an individual's performance.

Prior to stimulation, we noticed that the leading toe-clearance tended to increase while the trailing toe-clearance tended to decrease when performing a VA task while obstacle crossing, as compared to the obstacle-crossing only task. However, none of these changes were statistically significant. It is reasonable to expect no changes in the leading toe-obstacle clearance as our earlier study reported that only the trailing toe-clearance

was significantly reduced when performing a VA task with obstacle crossing (Lo et ,al 2015). Indeed, the trailing toe-clearance in this study tended to decrease. The smaller sample size and a greater variability could be the contributing factors to these differences.

After the stimulation, no significant changes were found in the leading toe-obstacle clearance for OC only in either the anode or sham condition. The trailing toe-obstacle clearance exhibited greater pre- and post-stimulation differences (when compared to the leading limbs) for OC only. However, none of the abovementioned dependent variables appeared to have any statistically significant difference.

We further examined each individual's data in trailing toe-obstacle clearances in pre-OC only and post-OC+VA in the anode and sham conditions as presented in Table 5.3. The average trailing toe-obstacle clearances of the Pre-OC only and Post-OC+VA tasks, respectively, were compared for each subject. We noticed that after sham stimulation, seven out of ten subjects significantly decreased their trailing toe-obstacle clearances when the VA task was added during obstacle crossing as compared to the obstacle crossing only instance. If we counted the data from all eight trials individually in the statistical analysis, there would be a significant reduction in Post-OC+VA (15.2±0.6 cm) from Pre-OC (19.5±0.6 cm, $p < .001$) after sham stimulation. This finding suggests that as the sample size increases the variance in the data reduces, and the trend could be more clearly demonstrated that the trailing toe-obstacle clearance reduces when an individual responds to the VA task when approaching an obstacle during gait.

One of the purposes for this study was to investigate the obstacle crossing behavior after anodal tDCS over the right PPC. We hypothesized that anodal stimulation would result in a smaller decrease in the trailing toe-obstacle clearance during obstacle

crossing while simultaneously responding to the VA task, which would reduce the risk of tripping. Our data tend to support this hypothesis. Only 30% of the subjects significantly reduced their toe-obstacle clearances while performing OC+VA task (compared to 70% in the sham condition). Most of the subjects did not demonstrate significant differences in trailing toe-obstacle clearances between Pre-OC and Post-OC+VA. When we performed the statistical analysis accounting for all individual trials from all subjects, a significant difference could be detected between Pre-OC and Post-OC+VA conditions (Post-OC+VA: 17.3±0.8 cm from Pre-OC: 19.4±0.7 cm, $p=.041$). However, this reduction after anodal tDCS was smaller than the reduction after sham tDCS. This finding suggests that although trailing toe-obstacle clearance may still decrease after adding the VA task during obstacle crossing, the anodal tDCS on the right PPC may have a beneficial effect in maintaining a greater trailing toe-obstacle clearance.

**Table 5.3. Mean (±SE) for toe-obstacle clearances of the trailing limbs for obstacle crossing only before stimulation (Pre-OC) and adding the VA task after simulation (Post-OC+VA) for each subject.** "+" indicates toe-obstacle clearance increased from Pre-OC to Post-OC+VA and "-" refers to reduced toe-obstacle clearance. A *p-value* less than .05 was highlighted in red, indicating a significant difference between toe-obstacle clearances of trailing limbs between Pre-OC and Post-OC+VA.

| | **Anode** | | | | **Sham** | | | |
|---|---|---|---|---|---|---|---|---|
| **Subject** | **Pre-OC** | **Post-OC+VA** | ***+ or -*** | ***p-value*** | **Pre-OC** | **Post-OC+VA** | ***+ or -*** | ***p-value*** |
| **1** | 15.2±0.9 | 9.1±0.3 | - | *< .001* | 10.8±1.0 | 8.9±0.4 | - | *.093* |
| **2** | 30.3±2.0 | 26.4±2.0 | - | *.190* | 27.1±1.7 | 20.3±1.2 | - | *.005* |
| **3** | 16.6±1.4 | 20.4±0.0 | + | *.015* | 17.8±0.6 | 14.9±0.7 | - | *.007* |
| **4** | 16.2±0.5 | 12.8±0.7 | - | *.002* | 15.7±0.4 | 11.9±0.3 | - | *< .001* |
| **5** | 18.9±0.7 | 17.2±0.8 | - | *.137* | 18.6±0.7 | 13.5±0.7 | - | *< .001* |
| **6** | 12.8±0.9 | 11.7±0.6 | - | *.353* | 19.9±1.7 | 18.5±0.5 | - | *.448* |
| **7** | 23.6±1.1 | 15.9±1.7 | - | *.002* | 23.0±1.7 | 12.4±0.6 | - | *< .001* |
| **8** | 23.9±0.7 | 21.6±1.1 | - | *.087* | 24.7±1.3 | 25.6±0.9 | + | *.581* |
| **9** | 23.5±2.0 | 26.7±1.6 | + | *.221* | 21.2±1.6 | 14.1±0.7 | - | *.001* |
| **10** | 12.8±0.6 | 11.0±0.7 | - | *.059* | 16.2±1.2 | 11.7±1.1 | - | *.014* |
| **All** | **19.4±0.7** | **17.3±0.8** | **-** | ***.041*** | **19.5±0.6** | **15.2±0.6** | **-** | ***< .001*** |

In addition, we examined changes in the trailing toe-obstacle clearances between OC+VA and OC only, and normalized the toe-obstacle clearances in post-OC+VA to values obtained from post-OC only and pre-OC only, respectively. When normalizing to the post-OC only condition, the DTC was -4.7±5.5 % after anodal stimulation compared to -17.2±5.1 % after sham stimulation. Through normalizing to the pre-OC only condition, the DTC was -.11±.06 % after anodal stimulation compared to -.22±.04 % after sham stimulation. Although no significant differences were detected between the anodal and sham conditions when using average values form each subject, the DTC was significantly different between anode and sham stimulation if data from individual trials were accounted separately (both $p < .001$). This could suggest a meaningful trend that trailing toe-obstacle clearances were reduced less after the application of anodal tDCS.

Taking the accuracy rate of the VA task and the trailing toe-obstacle clearance data together, there is a trend that applying 1.5 mA anodal tDCS stimulation over the right PPC for 20 minutes could enhance cognitive and motor performances when the task was challenging enough and the measurement was precise and normalized. Anodal tDCS of the posterior parietal cortex can potentially modulate neural excitability underneath the electrodes and also modulate cognitive and motor behaviors through the paradigm we presented. However, exactly how these behavioral effects were influenced could not be answered in this study due to the lack of any neural navigation device. We could not clarify whether these behavioral effects are due to the direct effects of the stimulated area, the interactive network effects or both. We also do not know if there was any dynamic trade-off within and across neural levels due to the coexistence of anodal and cathodal electrodes. Brem et al. (2014) proposed a net zero-sum proposition to interpret

neuroenhancement caused by noninvasive brain stimulation. They argued that brain resources were limited and followed the conservation of energy principle. After anodal tDCS, the enhanced performance may result from "changes in distribution and/or amplitude of processing power, reduction of neuronal interference processes, and/or changes in how fast processing power can be re-distributed." We tried to identify and measure the functions that were closely related to the contribution of right PPC during gait and did not measure other functions which may also be affected by this brain site, either positively or negatively. Therefore, it is possible that our potential enhancement resulted from sacrificing other functions or was assisted by them. Further, there may be other, better indicators to detect enhancement caused by anodal tDCS over the right PPC, but we could not identify one better suited for a navigation performance during over-ground walking.

*Limitations*

Due to the lack of a neural navigation device, we were not able to precisely identify brain sites for each subject. We followed the guidelines of the 10-20 EEG system, marked the brain site on a swimming cap, and had the same researcher applying stimulation every time. There was still a high variability among subjects and within visits due to shape and localization differences. Future studies such as combining tDCS with a high-density electroencephalogram (HD-EEG) and a computerized head model could enhance the precise localization.

The posterior parietal cortex (PPC) serves a hierarchically higher position in the planning and execution of visually guided locomotion as compared to the motor cortex. It has been difficult to identify an appropriate dependent variable, either cognitive or motor-

related, to directly examine the role of PPC during gait. The obstacle-crossing paradigm we proposed and selected seems promisingly in detecting overall visuospatial function during gait, but this paradigm could not be used to differentiate or determinate the precise functions of the whole task, such as orienting, reorienting, or managing conflicting attention throughout walking, nor the timing of each function. Further studies could consider utilizing a virtual reality environment and manipulating various scenarios to examine all aspects of visually-guided locomotor behavior.

Inter-subject variability was the main challenge for this study. Even as we tried to place the electrodes on the exactly same sites on different people, there was little chance that the current flowed in exactly the same direction and affected the same tissues. Even if the current flowed in the exact same direction and targeted the same tissues, it is possible for subjects to respond differently or without any response. Utilizing advanced head modeling software and a real-time neural navigation system will hopefully help improve the consistency of the effects.

In addition, we had a small sample size, and realized potential learning and ceiling effects in this study. We tried to randomize the sequence of VA only, OC only, OC+VA for both pre and post performances, as well as the sequence of anodal and sham visits. Also, according to their status as healthy young adults, the subjects could have achieved their maximized performance and anodal tDCS might not further enhance their performance. Applying anodal tDCS on an aging population or on individuals with neurological impairments could better enhance their cognitive or motor performance.

## Conclusion

This study investigated the effects of anodal and sham tDCS over the right PPC on the accuracy rate in a visuospatial attention task and toe-obstacle clearances as individuals were distracted by a visuospatial attention task as they approached an obstacle during walking. Our results suggested that the aftereffects of the anodal tDCS stimulation potentially enhanced cognitive and motor performance while young healthy adults were interacting with a challenging obstacle-crossing task.

# CHAPTER VI

# CONCLUSION

## Findings Summary

This dissertation investigated the role of visuospatial attention during locomotion and how neural substrates of the attention network contribute to gait behaviors. Two layers of approaches were conducted to achieve the proposed aims. The first layer was to observe cognitive and motor behaviors by using an obstacle crossing (goal-oriented gait) combined with a visuospatial attention task as a functional paradigm. The second layer was to apply transcranial direct current stimulation (tDCS) over the hub of visuospatial processing and attentional control, the posterior parietal cortex (PPC), to probe the topography in the cortical mechanism of the visuospatial attention networks in gait.

In the first study, the visuospatial attention task was employed in the approaching or crossing phase of the obstacle crossing. The task's instruction was to identify the directional opening of a red C among distractor orange-red Cs. Subjects had to walk toward and cross over an obstacle and respond to the test as soon as they saw it. The results showed that toe-obstacle clearance was reduced for the trailing leg when the visuospatial attention task was completed during the approaching phase, but it remained the same when the visuospatial attention task was completed during the crossing phase. In addition, the accuracy rate of the visuospatial attention task tended to be higher when the relevant stimuli were projected at the locations closer to the obstacle. The findings suggested that the interaction between visuospatial attention and locomotion occurs in both a spatially- and temporally- dependent manner.

In the second study, we examined how different visual attention tasks interfered with obstacle crossing. Subjects performed either 1) a visual Stroop task via an iPod Touch app, or, 2) a visuospatial attention task during obstacle crossing. Instead of reducing toe clearances, every subject significantly increased the toe clearances of both leading and trailing limbs while engaging in the visual Stroop task with obstacle crossing. These findings demonstrated that disturbing different components of the attention network (i.e. orienting attention in study one and conflicting attention in study two) could lead to various gait strategies, implying that task-directed gait trainings should be considered for intervention.

In order to modulate cortical control during walking, we applied two sections of non-invasive brain stimulation (anodal and sham, at least one week apart) via a transcranial direct current stimulation (tDCS) device with 1.5 mA for 20 minutes each. The effective window after anodal stimulation is suggested to lead to a depolarization of resting membrane potential and to cause action potentials to discharge more readily for at least 30 minutes. Therefore, we could investigate the aftereffects on cognitive and gait performance in a cable-free environment outside a scanner room.

We targeted the right posterior parietal cortex (PPC) due to its critical role in visuospatial processing and orienting attention. We conducted two studies (studies three and four) by stimulating the same brain site. In the third study, the subjects performed the Attention Network Test (ANT) before and after stimulation. The results suggested that the orienting effect was significantly enhanced after anodal stimulation but not after sham stimulation (i.e. the inactive form of stimulation). The aftereffect (%, post-pre/pre*100%) in the orienting component of attention was significantly higher in the anodal than in the

sham condition, while the aftereffects in the alerting or conflicting components did not reach a statistically significant level between anodal and sham conditions. The findings indicate that anodal tDCS over the right PPC could enhance orienting attention.

In the fourth study, the subjects performed an obstacle-crossing task with or without the visuospatial attention task before and after anodal tDCS over right PPC. The results appeared to show that after anodal tDCS stimulation, the dual-task cost in the accuracy rate of the visuospatial attention task was significantly improved in the anodal condition, as compared to sham condition. The toe-obstacle clearance of the trailing limb, instead of being reduced in the dual-task condition (which was found in the first study and in the sham condition), remained similar to that of the pre-stimulation condition with anodal tDCS stimulation. Taken together, these results demonstrate that anodal tDCS over right PPC could enhance visuospatial attention and boost the ability to manage distracted obstacle crossing.

## Future Research

Applying noninvasive brain stimulation in isolation or in combination with another rehabilitation program is promising, and well-designed clinical trials are in high demand. In particular, we should identify responders and consider personalized dose and montage to achieve maximum effects. Advances in modeling and real-time neuronavigation techniques can help us accomplish this goal.

APPENDIX A

INFORMED CONSENT FORM: EFFECTS OF VISUAL ATTENTION DURING OBSTACLE CROSSING AND LEVEL WALKING

**INTRODUCTION**

You are invited to participate in a research study conducted by Dr. Li-Shan Chou of the University of Oregon, Department of Human Physiology. We hope to gain a better understanding of the underlying mechanisms of the visual attention during obstacle crossing and level walking, which would help to develop effective treatments aimed at balance control improvement reducing odds of falls. You are selected as a possible participant because you are a healthy individual with an age between 18 and 40 years.

If you decide to participate, you will be asked to engage in the following testing sessions. The data collection will take approximately 2 hours. All of the data collected is coded and therefore maintains all personal confidentiality.

**TESTING SESSIONS**

Preparation session

At the beginning, you will be asked to change into a short and a tank top. Your age, height, and weight will be measured. Besides, length of your feet, medio-lateral dimensions of your ankle joints, knee joints and pelvic width will also be measured. This will take approximately 5 minutes.

Reflective marker placement

A set of 29 reflective markers will be placed on bony landmarks of your body. It will take 10 minutes.

Visual Task

A visual task will be instructed. Several stimuli will be displayed on the floor or on the screen. You will be asked to respond what you see on the display. After you are familiar with the visual task, you will be asked to perform the same task during quiet standing and during walking and obstacle crossing. The instruction and the visual task during quiet standing will take 10 minutes.

Obstacle-Crossing Walking Task

You will be asked to walk and cross over an obstacle with or without a visual task. The obstacle can be presented as a PVC pipe bar or be projected from the projector. The obstacle can be shown expectedly or unexpectedly. You will be walking over ground and crossing over an obstacle for several times until you feel comfortable walking with the markers and with your self-selected speed. This practice walking trials will take 10 minutes. After you are comfortable, you will cross the obstacle and walk over ground with the visual task together. It will take 60-75 minutes depending on how many trials the visual task provides.

We will remove your markers after the experiment and the total time for the experiment takes 2 hours.

**RISKS AND DISCOMFORTS**

This study may include risks that are unknown at this time. We expect that there will be no more risk for you during these tests than there normally is for you when outside of the laboratory. However, you may feel fatigue during or after the testing. Our staff member will check with you frequently and provide any required assistance. You will be given frequent breaks as requested. There is also the possibility of discomfort involved in removing adhesive tape (used for marker) from skin at the end of the experiment. Although you personally will not receive any benefits from this research, based on results of this study more effective therapies, rehabilitation programs, or balance assistive devices for the prevention of falls in a number of patient populations may be designed and implemented.

Access to the records will be limited to the researchers; however, please note that regulatory agencies and the Institutional Review Board and internal University of Oregon auditors may review the research records. All information will be kept confidential. Computer data files, laboratory notes and videotapes will be archived in a locked filing cabinet. All records will be stored with a code number, not your name and will be kept by the principal investigators in the locked and security regulated Motion Analysis Laboratory.

**COMPENSATION**

You will receive $20 for your participation in this study. This is to help defray the costs incurred for participation such as parking and transportation as well as your time. If you withdraw from the study without completing all procedures, the compensation will be pro-rated based on the rate of $10/hour and with the maximum payment of $20 per participation.

Your participation is voluntary. Your decision whether or not to participate will not affect your relationship with the Department of Human Physiology or University of Oregon. You do not waive any liability rights for personal injury by signing this form. In spite of all precautions, you might develop medical complications from participating in this study. If such complications arise, the researchers will assist you in obtaining appropriate medical treatment. In addition, if you are physically injured because of the project, you and your insurance company will have to pay your doctor bills. If you are a University of Oregon student or employee and are covered by a University of Oregon medical plan, that plan might have terms that apply to your injury. If you have any questions about your rights as a research subject, you can contact the Research Compliance Services, 5237 University of Oregon, Eugene, OR 97403, (541) 346-2510. This office oversees the review of the research to protect your rights and is not involved with this study.

If you decide to participate, you are free to withdraw your consent and discontinue participation at any time. If you have any questions, please feel free to contact Dr. Li-Shan Chou, (541) 346-3391, Department of Human Physiology, 112C Esslinger Hall, University of Oregon, Eugene OR, 97403-1240. You will be given a copy of this form to keep. Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your

consent at any time and discontinue participation without penalty, that you will receive a copy of this form, and that you are not waiving any legal claims, rights or remedies.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal claims, rights or remedies.

Print Name _____

Signature _____

Date _____

APPENDIX B

INFORMED CONSENT FORM: SMARTPHONE USE WHILE WALKING

**INTRODUCTION**

You are invited to participate in a research study conducted by On-Yee Lo (Advisor: Prof. Li-Shan Chou) of the University of Oregon, Department of Human Physiology. We hope to gain a better understanding of the underlying mechanisms of smartphone use while walking upon gait behavior during over-ground walking, obstacle-crossing and in adaption to an unexpected stimulus, which would help to develop a quantified understanding of the underlying mechanisms of distracted locomotion. You are selected as a possible participant because you are a healthy individual aged 18-40 years. However, if you do not pass the screening test, you will be excluded from participation in this study.

If you decide to participate, you will be asked to engage in the following screening and testing sessions that span two days. The total data collection will take approximately 2 hours. All of the data collected is coded and therefore we maintain all personal confidentiality.

**SCREENING SESSION**

At the beginning, you will be asked to complete this consent form and the "Smartphone Usage and Healthy History Questionnaire". If you answer yes in any of the questions under Health History Questionnaire, you will be excluded from participation in this study. If you pass the screening test, you will continue to the testing sessions. The screening session will take approximately 10 minutes.

**TESTING SESSIONS**

**Visit One:**

*Preparation session*

You will first be directed to change into shorts and a tank top. Your age, height, and weight will then be measured. Further, the length and width of your feet, the medio-lateral dimensions of your ankle joints, knee joints and your pelvic width will also be measured. The entire preparation session will take approximately 10 minutes.

*Reflective marker placement*

A set of 29 reflective markers will be placed on bony landmarks of your body. It will take 5 minutes.

*Practice the Stroop Test*

You will practice the Stroop Test in an iPod Touch. In this Stroop Test, you will state the color of colored words instead of the name of the word that is presented. For example, when you see "Green", you will respond by saying "Black," instead of "Green."

*Walking while Texting and Stroop Test*

You will be asked to walk at your self-selected speed without any concurrent task for 5 trials. Then you will be asked to walk the same course when responding to a text message. You will be asked to respond to each question with a simple one-word answer. You will complete this walking and texting for 5 trials. You will then be asked to walk the course while working on a Stroop test on the iPod Touch. You will complete this walking and

responding to the Stroop test for 5 trials. These three conditions will be in random order. All of the walking trials will take a total of 10 minutes.

*Obstacle-Crossing Walking Task*

You will be asked to walk and cross over an obstacle at your self-selected speed without any concurrent task for 5 trials. The obstacle will be presented as a PVC pipe bar. Then you will walk and cross over an obstacle while texting or responding to the Stroop test. You will perform 5 trials for walking and texting and another 5 trials for walking and responding to the Stroop test. These conditions will be in random order. All of the obstacle crossing trials will take a total of 10 minutes.

*Sitting While Texting and Sitting While Responding to the Stroop Test*

You will be asked to sit and to answer simple questions through text and to complete 5 trials of the Stroop test. This will take a total of 5 minutes.

*Marker Removal*

Markers will be removed from subjects after completing the aforementioned tasks.

**Visit Two:**

*Preparation session*

At the beginning, you will be asked to change into shorts and a tank top.

*Reflective marker placement*

A set of 29 reflective markers will be placed on bony landmarks of your body. It will take 5 minutes.

*Sitting While Texting and Sitting While Responding to the Stroop Test*

You will be asked to sit and to answer simple questions through text and to complete 5 trials of the Stroop test. This will take a total of 5 minutes.

*Walking*

You will be asked to walk across the floor for 5 trials without any obstacles. This will take approximately 5 minutes.

*Distracted Walking Stimulus Adaption*

A line will be projected onto the ground. You will have to walk and then stop right in front of the projected line for 5 trials. Afterwards, you will walk for 10 trials without any distractions. The line will be randomly projected onto the ground and every time it shows up, you will have to stop in front of it; if it does not show up, you can just walk to the other side of the room. After that, you will be given an iPod Touch and will have to preform the Stroop Task while walking. The line will randomly be projected onto the ground and you will also have to stop in front of the projected line whenever you see it. This will occur for another 10 trials. This part will take a total of approximately 30 minutes.

*Marker Removal*

Markers will be removed from subjects after completing the aforementioned tasks

The total time for this experiment is roughly 2 hours. We expect 1 hour per visit.

**RISKS AND DISCOMFORTS**

We expect that there will be no more risk for you during these tests than there normally is for you when walking around outside of the laboratory. However, you may feel fatigue during or after the testing. A staff member will check in with you frequently and provide any required assistance. You will be given frequent breaks as requested. There is also

the possibility of discomfort involving the removal of adhesive tape (used for the motion markers) from the skin at the end of the experiment. Although you will not receive any personal benefits from this research, the full results can help to create a better understanding of distracted walking, especially texting while walking, which can create better educational programs for college-age students.

All information will be kept confidential. Computer data files, laboratory notes and videotapes will be archived in a locked filing cabinet. All records will be stored with a code number, not your name, and will be kept by the principal investigators in the locked and security-regulated Motion Analysis Laboratory.

**COMPENSATION**

You will receive $10 per hour for your participation in this study. This is to help defray the costs incurred for participation such as parking and transportation as well as your time. If you do not complete a full session (2 visits, 2 hours) of testing, the amount will be pro-rated. Your participation is voluntary. Your decision of whether or not to participate will not affect your relationship with the University of Oregon Department of Human Physiology or the general university campus. You do not waive any liability rights for personal injury by signing this form. In spite of all precautions, you might develop medical complications from participating in this study. If such complications arise, the researchers will assist you in obtaining appropriate medical treatment. In addition, if you are physically injured because of the project, you and your insurance company will have to pay your medical bills. If you are a University of Oregon student or employee and are covered by a University of Oregon medical plan, that plan might have terms that apply to your injury. If you have any questions about your rights as a research subject, you can contact the Office for Protection of Human Subjects, 5237 University of Oregon, Eugene, OR 97403, (541) 346-2510. This office oversees the review of the research to protect your rights and is not involved with this study. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time. If you have any questions, please feel free to contact On-Yee Lo or Dr. Li-Shan Chou, (541) 346-3391, Department of Human Physiology, 112 Esslinger Hall, University of Oregon, Eugene OR, 97403-1240. You will be given a copy of this form to keep.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal claims, rights or remedies.

Print Name _____

Signature _____

Date _____

APPENDIX C

INFORMED CONSENT FORM: BRAIN FUNCTION, VISUAL SPATIAL

ATTENTION

AND WALKING

**Introduction**

You are invited to participate in a research study conducted by Dr. Li-Shan Chou of the University of Oregon, Department of Human Physiology. We hope to gain a better understanding of the underlying brain function involved in the interaction between visual attention and walking, especially obstacle crossing. You are selected as a possible participant because you are a healthy individual with an age between 18 and 40 years. You will be assigned to one of three groups receiving tDCS stimulation of the posterior parietal cortex, prefrontal cortex or primary motor cortex.

If you decide to participate, you will be asked to engage in the following screening and testing sessions. Two visits to the Motion Analysis are required. In each visit, the total time for the experiment will take 3 hours. All of the data collected is coded and therefore maintains all personal confidentiality.

**Screening Session**

After reading this informed consent document, and asking any questions you have about the study, you will be asked to fill out a Pre-Participation Screening Questionnaire and a Brain Stimulation Safety Screening Questionnaire. These questionnaires will be completed during the first visit only to ensure your satisfaction of all inclusion criteria and safety in study participation. Based on your responses to questionnaire questions, your eligibility to participate in this research study will be determined. This screening session will take about 20 minutes.

If you are a female subject and have been assigned to the primary motor cortex (TMS) group, to ensure your safety, you will be required to take a urine pregnancy test (a test kit will be provided to you). This is to confirm that you are not pregnant at the time of study participation. You can choose not to take the pregnancy test; however, you will be excluded from participation in this study.

**Testing Sessions and Number of Visits**

If you pass the Screening Session, two lab testing sessions in the Motion Analysis Laboratory will take place. Each visit (lab testing session) will take 3 hours. The following procedures will be carried out during each of your lab visits.

Preparation

At the beginning, you will be asked to change into a pair of shorts and a tank top. Your age, height, and weight will be measured. Besides, length of your feet, medio-lateral dimensions of your ankle joints, knee joints and pelvic width will also be measured. Then, a set of 29 reflective markers will be placed on bony landmarks of your body. This will take about 10 minutes.

Visual Task

A visual task will be instructed. Several stimuli will be displayed on the floor or on the screen. You will be asked to respond what you see on the display. After you are familiar with the visual task, you will be asked to perform the same task during quiet standing and during walking and obstacle crossing. It will take approximately 5 minutes to perform the visual task while standing quietly.

N-Back Task

If you are assigned to the prefrontal cortex group, you will also perform the N-Back task and receive an additional $10, which is to compensate for the additional 30 minutes beyond the previously noted 3 hour time commitment for the lab testing session. The N-Back consists of a sequence of a random numbers. You will recognize the repetition of a number from n numbers ago. For example, if n = 2, and the number sequence is 1,2,1, you will have to answer "yes" when you hear the "1" again since the 1 is repeated from 2 numbers ago. Each n-back task takes about 2 minutes. 2-back, 3-back, and 4-back will be examined during sitting and walking. The sequence of the numbers will be played from speakers and the response of the subjects will be recorded from microphones.

Level Walking and Obstacle-Crossing Tasks

You will be asked to walk along a 10-meter walkway and cross over an obstacle with or without a visual task. The obstacle will be presented as a PVC pipe bar. You will be walking over ground and crossing over an obstacle for several times until you feel comfortable walking with the markers and with your self-selected speed. After you are comfortable, you will cross the obstacle and walk over ground with the visual task together. These tasks will take about 20 minutes and will be conducted before and after the tDCS stimulation.

You will need to perform the above-mentioned visual and walking/obstacle crossing tasks twice per visit, before and after the transcranial direct current stimulation (tDCS; described below).

Confirmation Tests – Attention Network Test (ANT) or Transcranial Magnetic Stimulation (TMS)

You will receive either ANT test or TMS test depending on your assigned group to measure the effects of the transcranial direct current stimulation (tDCS) at three different times – immediately before the tDCS, after the tDCS stimulation, and at the end of your visit. Either the ANT or TMS test will be provided depending on your group. Each test will take about 10 minutes.

If you receive the ANT test (for posterior parietal cortex and prefrontal cortex groups), you will fixate on a cross in the center of a computer screen and respond as quickly as possible by pressing one of two arrow keys indicating the direction (left or right) of a central arrow presented either directly above or below the cross. Approximately a total of 10 minutes is needed for this session. The Attention Network (ANT) will be used to assess the alerting, orienting and executive components of attention. The alerting effect is examined by determining the reaction time (RT) difference between trials in which a warning cue (asterisk) precedes the arrow stimulus vs. trials in which the warning cue does not precede the arrow stimulus. The orienting effect is examined by the RT difference between trials in which the warning cue indicates the location of the arrow stimulus (above or below the fixation cross) vs. trials in which the warning cue does not provide such spatially relevant information. Finally, the conflict effect is assessed by the RT difference between trials in which the arrow stimulus is accompanied on either side by two congruent flanker arrows (i.e. arrows pointing in the same direction) vs. trials in which the arrow stimulus is accompanied on either side by two incongruent flanker arrows (i.e. arrows pointing in the opposite direction). Thus, the effect is measured by the RT difference between the two conditions presented for each of the three networks (alerting, orienting and conflict). You will first complete a series of 24 practice trials with visual accuracy feedback; they then completed one block of experimental trials made up of 96 trials (4 precue conditions x 2 target locations x 2 target directions x 3 flanker conditions x 2 repetitions).

If you receive the TMS test (for primary motor cortex group), you will be seated in a chair and two surface electromyography (EMG) sensors will be taped to the surface of your skin on the muscle at the belly of your thigh and calf muscles. Another reference sensor will be placed at the lateral side of the knee. These sensors are used to record electrical activity from your muscle. Once you are comfortable, you will be asked to push as hard as you can with the thigh and calf muscles, separately, so that your maximal voluntary contraction force (MVC) can be measured. You will be asked to repeat this procedure two additional times. Each contraction will last 4-5 seconds, and you will be given one to two minutes of rest (or additional time, if required) between contractions. After testing your maximal voluntary contraction force (MVC), a magnetic stimulation coil will be placed on the head over the brain area that controls the leg. We will start with a low intensity and adjust the location and intensity of the coil until the optimal site for stimulation of the leg muscles is located. This threshold will be determined by the site that gives the largest EMG response in the muscle. And then we will provide 5 stimuli with several intensities above and below the identified threshold. Each stimulus will be separated by 10-15 seconds. This test will take about 10 minutes.

<u>Transcranial Direct Current Stimulation (tDCS)</u>

You will receive tDCS stimulation for a period of 20 minutes after performing the visial & walking/obsctacle crossing tasks as well as one of the confirmation tests. We will then measure your head size and place two sponge electrodes on target brain sites over your scalp. The actual current entering your brain during tDCS is very small and the tDCS settings used in this study have been verified with parameters previously established as being safe to use on human subjects. You may notice mild tingling or other

sensation under the electrodes placed on your scalp. There is a small chance (1%) you will experience a headache, nausea, or insomnia. The effects of tDCS are temporary and it is not know to cause any permanent effects. We will have you report any adverse effects you may experience during tDCS stimulation to the researcher so that we can monitor these symptoms.

All the markers will be removed after the experiment and you will receive a Side Effect Questionnaire. Also, we will keep you in the laboratory for 30 minutes after finishing all testing procedures. This serves as a cool-down/recovery period and allows investigators to ensure that you have returned to normal functioning and could safely depart the laboratory and engage in daily activities.

**Risks or Discomforts of Being in this Study**

This study may have the following risks or discomforts. During the walking and obstacle crossing tasks, we expect there will be no more risk for you than there normally is for you when outside of the laboratory. You may feel fatigue during or after the testing. Our staff member will check with you frequently and provide any required assistance. You will be given frequent breaks as requested.

During or after the transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), you might experience slight aching, itching, tingling, burning sensations under the electrodes or coil, light headache, nausea and discomfort due to the headband have been complained in a minority cases. Our staff member will frequently check with you for any side effects you might experience and stand close to you to provide any required assistance. No long-term side effects have been reported for either TMS or tDCS. In extremely rare cases, TMS has induced seizures (but not for tDCS), particularly in individuals with a history of seizures. However, the use of single-pulse stimulation with several seconds between pulses, as will be used in this investigation, substantially reduces the risk of inducing seizure. . If you experience a seizure or other adverse events resulting from participation in study activities, the investigators will remove you from the study immediately and contact the UO Student Health Center when needed.

There is a possibility of allergic reaction to the tDCS sponge electrodes or to the gel used for EMG electrode placement and contact. However, our staff member will minimize this potential reaction with a non-allergic tDCS sponge electrodes and the gel used for EMG electrodes (EMG only for primary motor cortex group).

There is also a possibility of discomfort involved in removing adhesive tape (used for marker) from skin at the end of the experiment. However, our staff member will minimize the potential discomfort with a non-allergic tape.

**Benefits of Being in this Study**

Although you personally will not receive any benefits from this research, based on results of this study more effective therapies, rehabilitation programs, or balance assistive devices for the prevention of falls in a number of patient populations may be designed and implemented.

**Compensation**

Upon your completion of both study visits, you will receive a total of $60 ($70 for participants in the prefrontal cortex group). This is to help defraying the costs incurred for participation such as parking and transportation as well as your time. If you do not qualify for the study based on screening questionnaires or withdraw from the study without completing all procedures, the compensation will be pro-rated based on the rate of $10/hour and with the maximum payment of $60 (or $70) for per participation.

**Confidentiality**

All information will be kept confidential. In any sort of report we may publish, we will not include any information that will make it possible to identify a participant. Computer data files, laboratory notes and videotapes will be archived in a locked filing cabinet. All records will be stored with a code number, not your name and will be kept by the principal investigators in the locked and security regulated Motion Analysis Laboratory.

**Voluntary Participation/ Withdrawal**

Your participation is voluntary. Your decision whether or not to participate will not affect your relationship with the Department of Human Physiology or University of Oregon. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time, for whatever reason. There is no penalty or loss of benefits for not taking part or stopping your participation.

**Dismissal From the Study**

The investigator may withdraw you from the study at any tie for the following reasons: (1) withdrawal is in your best interests (e.g. side effects or distress have resulted) or, (2) you have failed to comply with the study requirements.

**Compensation for Injury**

You do not waive any liability rights for personal injury by signing this form. In spite of all precautions, you might develop medical complications from participating in this study. If such complications arise, the researchers will assist you in obtaining appropriate medical treatment. In addition, if you are physically injured because of the project, you and your insurance company will have to pay your doctor bills. If you are a University of Oregon student or employee and are covered by a University of Oregon medical plan, that plan might have terms that apply to your injury.

**Contacts and Questions**

If you have any further questions about this study, please feel free to contact the primary investigator conducting this study: Dr. Li-Shan Chou, (541) 346-3391, Department of Human Physiology, 112C Esslinger Hall, University of Oregon, Eugene OR, 97403-1240.

If you have any questions about your rights as a research subject, you can contact the Research Compliance Services, 5219 University of Oregon, Eugene, OR 97403, (541) 346-2510. This office oversees the review of the research to protect your rights and is not involved with this study.

If you experience harm because of this project, you can ask the State of Oregon to pay you. A law called the Oregon Tort Claims Act limits the amount of money you can receive from the State of Oregon if you are harmed. If you have been harmed, there are two University representatives you need to contact. Here are their addresses and phone numbers:

General Counsel
Office of the President
University of Oregon
Eugene, OR 97403
(541) 346-3082

Research Compliance Services
University of Oregon
Eugene, OR 97403
(541) 346 – 2510

**Statement of Consent**

**The investigator has reviewed the consent information with the participant, addressed to any participant questions, and assessed that the participant has a thorough understanding of the activities for which they are agreeing to consent.**

**Signature (Investigator): _____Date: _____**

**Print name (Investigator): _____**

I have read (or have had read to me) the contents of this consent form and have been encouraged to ask questions. I have received answers to my questions. My signature indicates that I understand the information provided above, that I willingly agree to participate, that I may withdraw my consent at any time and discontinue participation without penalty, that I have received (or will receive) a copy of this form, and that I am not waiving any legal claims, rights, or remedies.

**Signature: _____ Date: _____**

**Print Name: _____**

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