COMPARING MOTOR LEARNING AND MU SUPPRESSION UNDER SHORT-TERM PHYSICAL AND OBSERVATIONAL PRACTICE IN ADULTS: A PILOT STUDY

by

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Abstract

Repeated physical practice is not always the optimal approach in rehabilitation, especially in individuals with severe motor-related problems. Research has shown the effectiveness of observational practice as a motor learning tool in various rehabilitation settings. However, little is known about the neurophysiological mechanisms underlying this mode of learning and whether similar behavioral and neurophysiological changes occur during physical and observational practice. The purpose of this study was to compare short-term physical and observational practice during the acquisition and retention of a novel motor task and to evaluate how each type of practice modulates EEG mu rhythm (8-13Hz).

Thirty healthy individuals were randomly assigned to one of three groups: (1) physical practice (PP); (2) observational practice (OP); and (3) no practice (NP). The experiment consisted of three phases: training, testing (observing 10 minutes following training), and retention (performing 24 hours following training). Two behavioural measures (as indexed by total time and error) and brain responses (as indexed by mu suppression at the central regions) were examined. The results revealed: (1) that when comparing the PP group during their first exposure to the task to the OP group during their first exposure to the task, the OP group was significantly faster than the PP group, did not differ from the PP group in terms of error, (2) significant bilateral suppression of mu rhythm during PP and significant left lateralized mu suppression during OP, (3) significant bilateral mu suppression during observation after PP compared to that after OP and NP.

Overall, the study demonstrates that OP induces neurophysiological (i.e., mu suppression) and behavioural (i.e., reduced total time) changes similar to that occur during PP. However, the different pattern of activation during the two types of practice suggests that OP does not activate the same brain areas activated during PP; rather, it triggers a subset of brain regions. Therefore, OP may be a good proxy for PP under conditions where PP is not possible. This is the first study to investigate changes in mu rhythm as a function of both PP and OP.

Preface

This study was conducted in collaboration with my thesis committee at UBC: Dr. Nicola Hodges and Dr. Jill Zwicker. I completed the study under the supervision of Dr. Naznin Virji-Babul. The flower-tracing task was used in this study with full permission from Dr. Lara Boyd. I was responsible for developing the study design, the research question, hypotheses and objectives, completing ethics application, recruiting participants, collecting, analyzing, and interpreting the data, and drafting this written document.

Ethics

This research study met the criteria for a Minimal Risks Human Ethics application. Approval was granted for this study on October 4th, 2016 (Certificate # H16-02396).

Conflict of Interest Declaration

The researchers and members of the thesis committee report no conflict of interest.

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List of Abbreviations

ANOVA: Analysis of Variance

AOT: Action Observation Treatment

BESA: Brain Electrical Signal Analysis

BOLD: Blood Oxygen Level Dependent

C3: Central Left Electrode

C4: Central Right Electrode

CBH: Centre for Brain Health

CCWFF: Clockcounterwise Force Field

CI: Confidence Interval

CWFF: Clockwise Force Field

cm: Centimetre

CZ: Central Medial Electrode

EEG: Electroencephalography

EMG: Electromyography

FF: Force Field

FFT: Fast Fourier Transform

fMRI: Functional Magnetic Resonance Imaging

Hz: Hertz

ICA: Independent Component Analysis

IPL: Inferior Parietal Lobule

KR: Knowledge of Results

M: Mean

MABC: Movement Assessment Battery for Children

MNS: Mirror Neuron System

MSI: Mu Suppression Index

NP: No Practice

OP: Observational Practice

PP: Physical Practice

RMANOVA: Repeated Measures ANOVA

RT: Reaction Time

SD: Standard Deviation

STS: Superior Temporal Sulcus

SRT: Serial Reaction Time

TMS: Transcranial Magnetic Stimulation

UBC: University of British Columbia

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Chapter 1: Introduction

1.1 Problem & rationale

It is well established that repeated physical practice is the most effective strategy to acquire a motor skill (Adams, 1971; Schmidt, 1975; Fitts, 1964). However, many individuals with serious neurological impairments cannot engage in physical rehabilitation (Bassolino, Sandini, & Pozzo, 2015). Developing alternative options to physical practice to help regain motor function, especially during the initial stages of recovery would be of benefit for people with motor-related problems. Observational practice is one approach that has been shown to facilitate both immediate performance and long-term learning in a wide range of behavioral and cognitive tasks (Bandura, 1986; McCullagh & Weiss, 2001; Hodges, Williams, Hayes, Breslin, 2007).

Amongst a variety of rehabilitation strategies aiming at restoring motor function, action observation treatment (AOT) has shown to have a positive impact on the recovery of motor function after stroke (Eltert et al., 2007; Celnik, Webster, Glasser, & Cohen, 2008), cerebral palsy (Buccino et al., 2012), and Parkinson's disease (Pelosin et al., 2010). However, despite the extensive research on the observation of simple movements, little is known about the neurophysiological processes underlying observational practice. Specifically, there is a lack of studies that have investigated the changes in brain responses as a function of visual training, and the mechanisms by which these changes could influence motor learning. Given the well-established benefits of observational practice, investigating the underlying processes by which this approach operates would provide valuable information toward more optimized applications for rehabilitation.

1.2 Literature review

1.2.1 Motor learning

1.2.1.1 Motor learning and motor performance

Motor learning is defined as a relatively permanent change in motor behavior that is due to the interaction with the environment and is not related to developmental factors (Magill, 1989; Schmidt & Lee, 2005; Singer, 1980; Wolpert, Ghahramani, & Flanagan, 2001). It is known to come about in two different phases: short-term learning, in which rapid performance improvements arise, followed by a slower long-term learning in which additional improvements take place incrementally (Floyer-Lea & Matthews, 2005; Maslovat, Hayes, Horn, & Hodges, 2010).

Because learning is consistently mistaken for performance, it is important to note the differences between the two concepts (Magill, 1989; Schmidt & Lee, 2005). Motor performance is an observable behavior that could be measured through four general characteristics: improvement, consistency, persistence, and adaptability. In contrast, motor learning is not observable, and hence it can be only inferred from performance. Specifically, learning is assessed by evaluating improvement and consistency during acquisition, persistence during retention, or adaptability during skill transfer. There are two different measures by which the four features of performance could be evaluated: (1) outcome measures such as reaction time, error measures, and time to completion; and (2) production measures such as displacement, velocity, and brain activation (Magill, 1989; Schmidt, & Lee, 2005). Figure 1 summarizes the relationship between learning and performance. Physical practice and observational practice are two approaches of motor learning that have gained a great deal of attention.

1.2.2 Comparison of the effects of physical practice and observational practice on motor learning

1.2.2.1 Physical practice

1.2.2.1.1 Behavioural evidence

Physical practice is the most efficient approach to learn a motor skill as asserted by early theories of motor learning (Adams, 1971; Schmidt, 1975; Fitts, 1964). Numerous studies have shown the impact of physical training on the acquisition of motor skills from neurophysiological and behavioural perspectives. From a behavioural perspective, different performance measures including decreased **reaction time** and/or a decrease in the **number of errors** during acquisition, retention, and skill transfer have been considered direct indices of the effects of physical practice on motor learning (Schmidt & Lee, 2005; Magill, 1989).

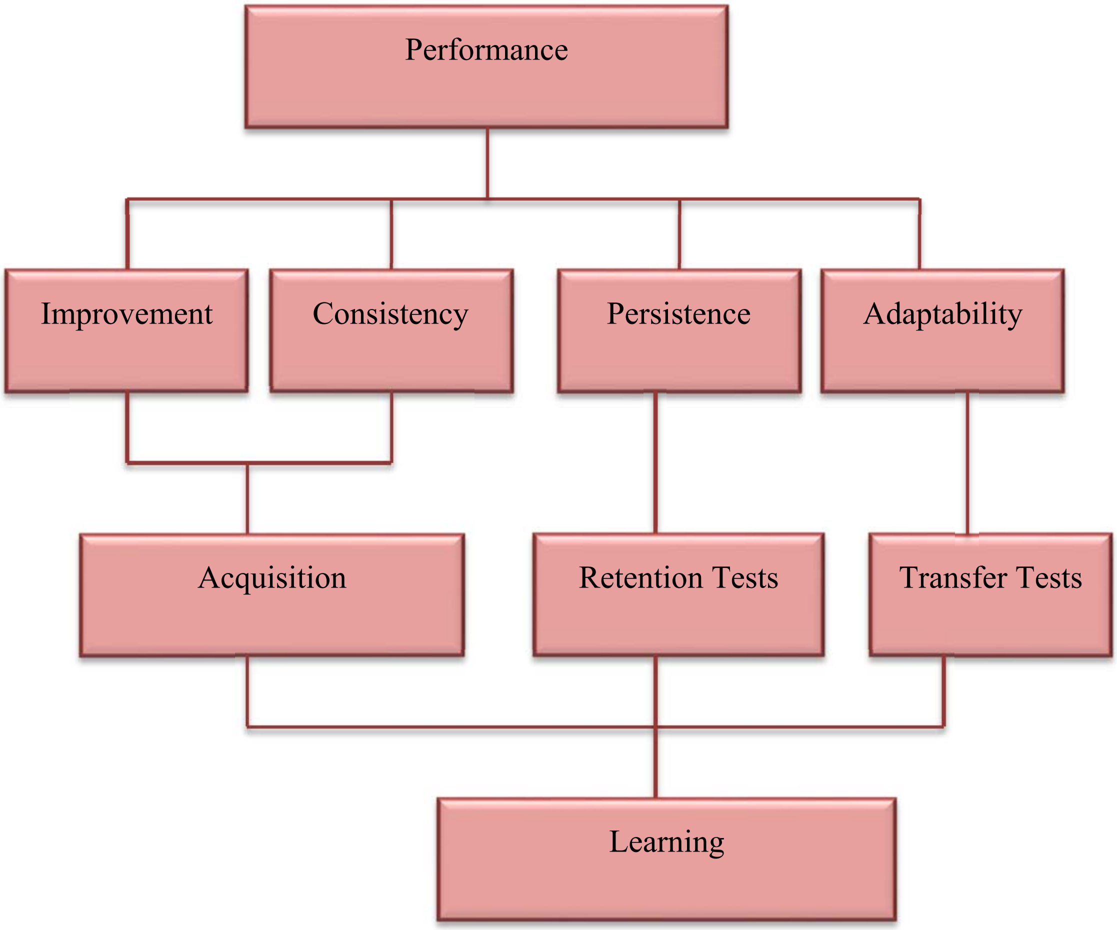

Figure 1. A schematic of the relationship between learning and performance.

1.2.2.1.2 Neurophysiological evidence

Neurophysiologically, physical practice of a new motor skill has been associated with changes in the primary motor cortex (M1) excitability, changes in the somatotopic representations of the limb areas in the motor cortex, decreased activation in the dorsolateral prefrontal, anterior cingulate, posterior parietal, and cerebellar cortices, and with increased activation in the right cerebellar dentate nucleus, left putamen, and left thalamus (Classen, Liepert, Hallett, & Cohen, 1999; Kleim, Barbay, & Nudo, 1998; Floyer-Lea & Matthews, 2005, Lohse, Wadden, Boyd, & Hodges, 2014; Hardwick, Rottschy, Miall, & Eickhoff, 2013). Long-term learning, in contrast, is found to be associated with increased activation in the left primary somatosensory and motor cortices and in the right putamen (Floyer-Lea & Matthews, 2005).

1.2.2.2 Observational practice

Despite the well-established effectiveness of physical practice, it is not always feasible to use this approach for motor learning purposes. Learning by observing a model whether this model is a parent, a coach, or a teacher has been shown to facilitate motor skills acquisition (De Maeght & Prinz, 2004). This type of learning has been described using a range of terms including observational modeling, observational learning, vicarious learning, demonstration, imitation, and copying (Williams, Davids, & Williams, 1999; Maslovat et al., 2010).

It is noteworthy, however, to distinguish between observational practice and observational learning as each term is associated with specific schedules and processes (Vogt, &

Thomaschke, 2007). Observational *learning* refers to the process by which viewers learn about different aspects of the action through the observation of a model and use this feedback to modify their own motor responses based on the model's actions. In this mode of learning, visual demonstration is alternated with physical practice (i.e., observe, perform, observe). In contrast, under observational practice contexts, learners simply observe but do not engage in physical practice. Growing evidence from behavioural and neurophysiological studies supports the effectiveness of observational practice and considers it, under certain conditions, to be on par with physical practice (Vogt, 1995).

1.2.2.2.1 Behavioural evidence

Behaviourally, research has shown the benefits of observational practice in learning motor skills using two paradigms: observation only paradigms, in which various observation conditions are compared, and practice paradigms, in which different types of practice are compared. Using the first paradigm, Matter and Gribble (2005) examined the influence of observation on the learning of a force field (FF) task, in which a robotic device controlled the direction of the actor's arm movement. They tested two groups of participants while they observed a video of a model learning an FF task either in a clockwise direction (CWFF) or a counter clockwise force field (CCWFF), and a third control group in which participants did not observe anything. Participants were then tested in the CWFF condition. The group that observed the CWFF learning made significantly less error (i.e., fewer **curved movement trajectories)** than the control participants who did not observe any learning. However, the group that observed the CCWFF did significantly worse than the control group.

Similarly, Heyes and Foster (2002) showed that compared to a no-observation condition, observing a live skilled actor performing a serial reaction time (SRT) task was more effective in learning sequence information. Additionally, Badets and colleagues have conducted several studies on the effect of the knowledge of results (KR) on learning during observational practice. This group compared different observational conditions with various KR contexts and showed that the absolute and relative timing of movement sequence could be acquired through simple observation without the aid of overt practice (Badets, and Blandin, 2004; Badets & Blandin, 2005; Badets, Blandin, Wright, & Shea, 2006).

Aiming to compare the effects of practice type on the performance of cyclical movement sequences, Vogt (1995) tested four experimental groups under the following conditions: observational practice, mental practice, and physical practice with and without visual feedback. The author found no difference between the four groups in learning the movement form. Even for parameters that were thought to be dependent on physical practice, the author reported that the consistency of both the timing and the tempo was similar between the four conditions. Similarly, Heyes and Foster (2002) used reaction time (RT) as a measure of learning and found that the observational practice group performed as fast as the physical practice group in a SRT task. Using the physical practice group as a learning model in a sequence-timing task, Hayes and his coauthors found that the observational practice group performed as well as the physical practice group in learning both the movement time and its kinematics (Hayes, Timmis, & Bennett, 2009; Hayes, Elliott, & Bennett, 2010). In addition, a number of studies have shown that the factors known to influence physical practice, such as feedback and practice schedule, have a similar impact on observational practice (Badets & Blandin, 2004; Badets & Blandin, 2005; Badets et al., 2006; Wright, Li, & Coady, 1997).

Overall, behavioural studies have demonstrated that observational and physical practice lead to similar behavioural motor outcomes. This comparable level of performance could be acquired after a short period of time up to 7 minutes (Gatti et al., 2013; Heyes & Foster, 2002). However, these studies have provided different explanations regarding the processes by which the similar behavioural outcomes come about, with some studies supporting motor involvement in observation (Heyes & Foster, 2002; Matter and Gribble, 2005; Vogt, 1995; Hayes et al., 2009, 2010), and others attributing this similarity to cognitive underlying processes (Badets & Blandin, 2004; (Badets & Blandin, 2005; Badets et al., 2006).

Nevertheless, using different measures of learning, other behavioural studies have shown that the two types of practice could lead to different behavioral outcomes. Using after-effects as a measure of learning, Ong and Hodges (2010) found that after-effects were present after physical practice but not after observational practice. In motor learning, the after-effect is considered a compensatory response or a mirror image of a distorted trajectory that occurs after the removal of an induced distortion (Gandolfo, Mussa-Ivaldi, & Bizzi, 1996). The absence of after-effects after observational practice has led the authors to conclude that the two modes of learning may implicate distinct brain networks. In a similar vein, it has been shown that contrary to physical practice, observational practice is more effective for learning multiple skills (Larssen, Ong, & Hodges, 2012). The authors suggested that this may be because the observational method does not require the observer to update the neural representation of the observed task to meet the demands of the new one. Based on these results, the authors argued that observational practice and physical practice might involve different mechanisms and that cognitive processes may mediate the information transfer during observational practice.

1.2.2.2.2 Neurophysiological evidence

The mirror neuron system (MNS)

While behavioural studies have provided different explanations for the underlying processes by which observational practice facilitates motor skill acquisition, neurophysiological studies support the notion of a shared neural representation between action observation and action execution. These studies have been stimulated by the discovery of the mirror neuron system (MNS). This system consists of a unique class of visuomotor neurons called mirror neurons that are activated in response to both execution of an action and observation of that action (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996)

Monkey studies

Monkey studies have provided direct evidence of the MNS through single-neuron recordings, by which the activity of specific neurons could be measured. Mirror neurons were first discovered in the premotor cortex (area F5) of the macaque monkeys (Di Pellegrino et al., 1992; Gallese et al., 1996; Rizzolatti et al., 1996). After discovering (area F5), numerous studies have demonstrated other brain regions that constitute the mirror circuit including the inferior parietal lobule (IPL) and the superior temporal sulcus (STS), although the latter is activated only during action observation (Fogassi et al., 1996). One important functional feature of mirror neurons is the congruence between their motor and visual properties. Using this congruence as a defining criterion, mirror neurons are divided into two categories: strictly congruent neurons and broadly congruent neurons. Strictly congruent neurons discharge in response to identical executed and observed actions, whereas broadly congruent neurons require, to be active, the observed action to duplicate the observed movement (Gallese et al., 1996; Fabbri-Destro, & Rizzolatti, 2008).

Humans Studies

Due to ethical considerations, single-cell recording in humans is not possible, although some recent studies have employed it in specific settings such as that undertaken in patients with epilepsy (Ojemann, Creutzfeldt, Lettich, & Haglund, 1988; Kreiman, Koch, & Fried, 2000; Quian Quiroga, Mukamel, Isham, Malach, & Fried, 2008). However, indirect evidence from various brain imaging techniques has shown that, similar to monkeys, humans have an action observation–action execution mirror circuit. Since the discovery of this system, there has been a growing interest in its proposed role in many social and neural phenomena, including the mirror neuron theory of action understanding, leading to a paradigm shift in thinking about action recognition. According to Rizzolatti, Fogassi, and Gallese (2001), this ground-breaking theory emphasizes that "there is an analogy at the cortical levels between the mechanisms that mediate action observation with those involved with action execution" (p. 667). In other words, observing an individual executing an action triggers a motor activation similar to that which occurs when the observer performs a similar action. This similarity allows for understanding others' actions without more complex cognitive inferences (Rizzolatti & Sinigaglia, 2010).

Functional magnetic resonance imaging (fMRI) has revealed a wide range of brain areas that are activated during both observation and execution of actions including the inferior frontal sulcus (Iacoboni et al., 2005; Kaplen & Iacoboni, 2006; Dinstein et al., 2007; Kilner, Neal, Weiskopf, Friston, & Frith, 2009), the ventral and dorsal premotor cortex (Iacoboni et al., 2005; Dinstein et al., 2007; Gazzola & Keysers, 2009; Filimon, Rieth, Sereno, & Cottrell, 2014; Buccino et al., 2001), the intraparietal cortex (Dinstein et al., 2007; Shmuelof & Zohary, 2005), the superior and inferior parietal lobule (Chong, Cunnington, Williams, Kanwisher, & Mattingley, 2008; Filimon et al., 2014; Gazzola & Keysers, 2009), as well as the occipital cortex, the middle temporal cortex, the somatosensory cortex, the middle cingulate cortex, the supplementary motor cortex, and the cerebellum (Gazzola & Keysers, 2009; Iacoboni et al., 2005).

Although transcranial magnetic stimulation (TMS) studies have not confirmed the existence of the MNS per se, they have provided evidence for a shared neural mechanism underlying action observation and execution. These studies described motor facilitation during the observation of actions that is specific to the hand muscles involved in the execution of these actions (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Strafella & Paus, 2000; Gangitano, Mottaghy, & Pascual-Leone, 2001, 2004; Baldissera, Cavallari, Craighero, & Fadiga, 2001; Burgess, Arnold, Fitzgibbon, Fitzgerald, & Enticott, 2013; Craighero, Zorzi, Canto, & Franca, 2014). Electroencephalographic (EEG) studies have provided additional support to the notion of the action-observation matching system. These studies have demonstrated that both performance and observation of hand movements induce a decrease in EEG signals at the frequency range of (8-13Hz) over the sensorimotor cortex (Babiloni et al., 2002; Muthukumaraswamy, Johnson, & McNair, 2004; Pineda, Allison, & Vankov, 2000; Woodruff & Maaske, 2010).

Concerning the hemispheric activation, many fMRI studies that used right-handed participants and first-person observation have revealed a *lateralized left or right hemispheric effect* during both action execution and observation (e.g., Left: Shomuelof & Zohary, 2005; Gazzola & Keysers, 2009; Right: Chong et al., 2008; Kaplen & Iacoboni, 2006). With the same handedness and perspective specifications, the majority of EEG studies that examined the hemispheric effect reported *bilateral* suppression during both observation and execution (e.g., Muthukumaraswamy et al., 2004; Pineda et al., 2000; Streltsova, Berchio, Gallese, & Umilta, 2010; Woodruff & Maaske, 2010).

1.2.2.3 Cognitive and motor mediated processes underlying observational practice

The question as to how observational practice enhances motor learning is a subject of ongoing debate in the motor learning literature. Two theoretical explanations have been proposed concerning the underlying processes associated with this mode of learning: the cognitive mediating learning and the motor-mediated learning (Maslovat et al., 2010). Cognitive mediating learning (also known as late mediation) suggests that the transfer of information during observational practice occurs by the aid of cognitive processes without the involvement of the motor system (Vogt, 2002; Vogt & Thomsachke, 2007). This account is based on Bandura's social cognitive theory in which he claimed that the cognitive representation of an observed action serves as a mediator between the model and the observer (Bandura, 1986).

Motor mediating learning (also known as early mediation) emphasizes that observation automatically activates the motor representations of the observed action in the observer's brain, allowing for action understanding, and hence learning, to occur (Vogt, 2002; Vogt & Thomsachke, 2007). As mentioned earlier, behavioural studies have provided support for both proposals, suggesting that information transfer during observational practice could be acquired through either process or, perhaps, a combination of both. To shed more light on the underlying processes concerning the information transfer during observational practice, the current study has examined both the neurophysiological and behavioural measures of learning concurrently.

1.2.3 Electroencephalography (EEG)

1.2.3.1 What is EEG?

Although fMRI has contributed significantly to identifying the neural networks implicated in the human MNS, the blood oxygenation level-dependent (BOLD) response to a stimulus is much more delayed in time than the electrophysiological responses, and hence it does not allow for "fine-grained temporal analyses of brain activity" (Neubauer & Fink, 2009, p.

1006). The delayed response, along with its higher cost, has limited its broader use in examining brain activation during the observation and execution of movement.

Because of its affordable cost and high temporal resolution, EEG is a widely used method to investigate the modulation of brain activity during physical and observational practice. It is a non-invasive technique that measures brain electrical activity through a set of electrodes that are placed on the scalp to record the voltage changes (μV) in a millisecond scale associated with a specific cognitive or motor task (Gevins, Leong, Smith, Le, & Du, 1995; Roach, & Mathalon, 2008). The link between EEG changes and behaviour has been of a great interest for many disciplines since the discovery of the first human EEG signals. Alpha waves at the frequency range of 8-12 Hz were the first EEG signals to be described by the German physiatrist Hans Berger (Gastaut & Bert, 1954; Buzsáki, & Draguhn, 2004; Cochin, Barthelemy, Lejeune, Roux, & Martineau, 1998). Because the magnitude of the electrical activity of a single neuron is very small, EEG signals reflect the synchronized activity of thousands of neurons (Cooper, Winter, Crow, & Walter 1965). This activity is measured in power units, which are the squared magnitude of the actual voltage. The transformation of these signals from the time domain to the frequency domains is attained through a mathematical calculation called Fast Fourier Transform (FFT) (Akin, 2002).

1.2.3.2 EEG frequency bands

It has been shown that EEG signals at different frequency bands are linked to certain brain states and activities. EEG frequency bands are divided into five groups as follows from the slowest to the fastest (Figure 2).

- **Delta (0.5 – 3.5 Hz):** Delta band is the primary frequency during deep sleep (Steriade, McCormick, & Sejnowski, 1993). This band is also linked to motivation, learning, and reward (Knyazev, 2007).
- **Theta (3.5 – 7.5 Hz):** Theta is associated with a wide range of cognitive processing, such as memory encoding and recall (Jensen & Lisman, 2005), as well as emotional arousal (Knyazev, 2007).
- **Alpha (7.5 – 12.5 Hz):** Alpha activity reflects the cortical activation during the brain awake-resting state (Pineda, 2005) as well as working memory (Palva, & Palva, 2007).
- **Beta (12.5– 30 Hz):** The activity of this band is mainly associated with motor activity (Kilner et al., 2009). In addition, it has been shown to increase in magnitude with increasing mental effort (Dolce & Waldeier, 1974; Papanicolaou, Loring, Deutsch, & Eisenberg 1986).
- **Gamma (30-60 Hz):** Gamma oscillations are linked to a wide range of activities, including attentional effects, sensorimotor integration, movement preparation, memory formation, and conscious awareness (Engel, & Fries, 2010).

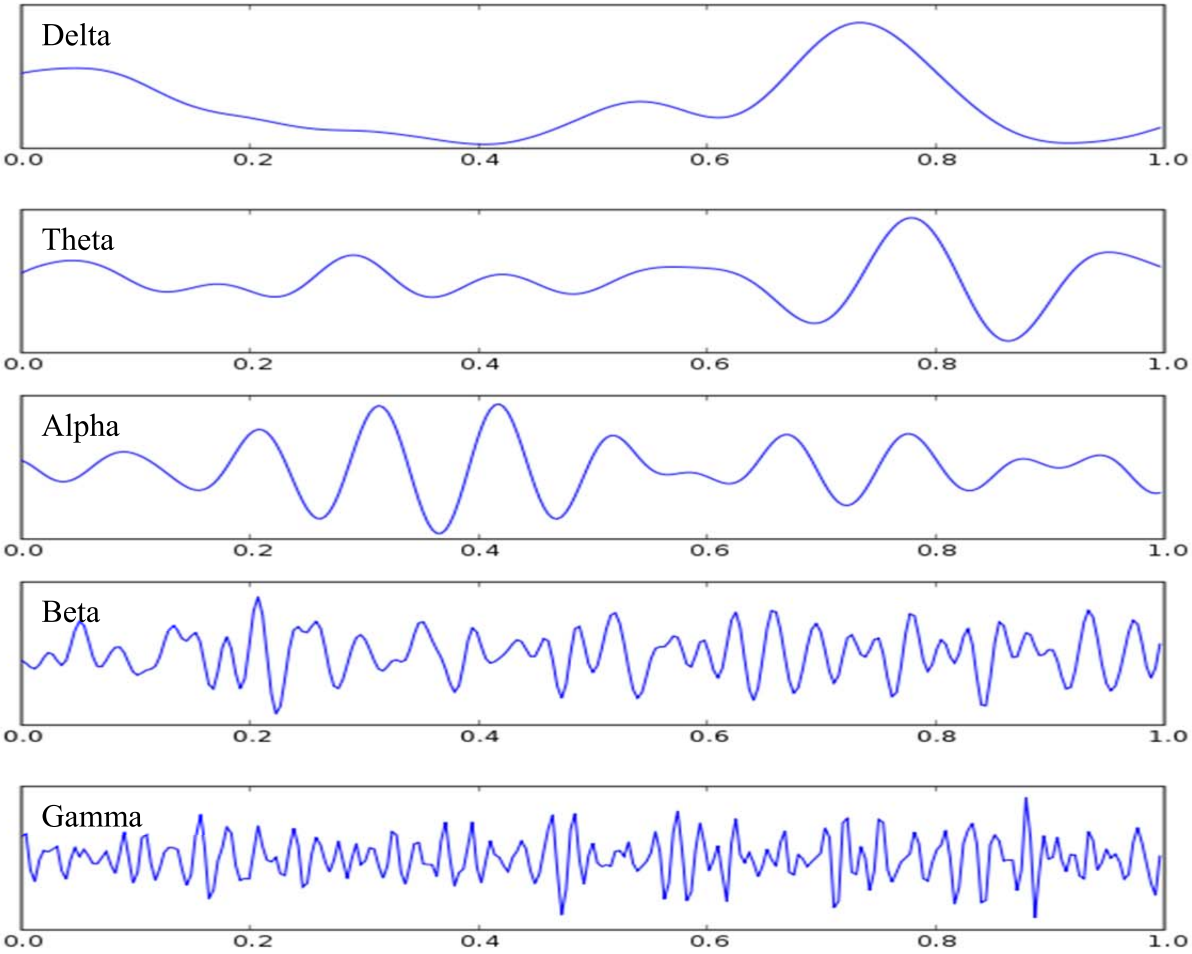

Figure 2. EEG frequency bands.

1.2.3.3 Mu suppression

Among these bands, alpha band or mu rhythm is the most relevant to the MNS activity as it has been shown that this rhythm is suppressed during both observation and execution of movement (Muthukumaraswamy et al., 2004; Perry & Bentin, 2009; Streltsova et al., 2010). This rhythm consists of EEG oscillations at the frequency range of 8-13Hz, which arise from the somatosensory cortex (Cochin et al., 1998; Perry & Bentin, 2009). This suppression [also called event-related desynchronization (ERD)] across both action execution and observation has been considered a neural signature of mirror neuron activity in humans (Rizzolatti & Craighero, 2004).

The relationship between the MNS activity and mu rhythm was first proposed by Eric Altschuler in 1997, and thereafter by others (Oberman et al., 2005; Muthukumaraswamy, et al., 2004). The validity of mu suppression as a marker of the MNS activation has been verified by studies that have used both EEG and fMRI simultaneously (Arnstein, Keysers, Maurits, Gazzola, 2011). The authors have showed a correlation between mu suppression and BOLD signal in the areas associated with mirror neurons. Mu suppression occurs primarily over the central sites of the brain, specifically at the lateral central electrodes (C3-left central, and C4-right central) and medial central electrode (CZ), which record the activity of the sensorimotor cortex (Pfurtscheller, Neuper, Andrew, Edlinger, 1997).

1.2.3.4 Mu suppression and motor learning

In relation to motor learning, a few recent EEG studies have examined brain responses during physical practice and/or observational practice (Kiefer, Cremades, & Myer, 2014; Wong et al., 2014; Nakano, Osumi, Ueta, Kodama, & Morioka, 2013). In a study by Kiefer et al. (2014), participants completed a pretest in which they performed repeated trials of a novel mirror star-tracing task. They were then assigned to one of three groups: a whole practice group who performed the whole task, a part practice group, who performed separate parts of the task, and a control group who received no practice. Subsequently in the post-test, all groups performed 50 trials of the same task. The author found that compared to the pretest, all groups during the posttest exhibited reduced suppression over the central and occipital electrodes at the frequency band of 8-10Hz. Similarly, Wong et al. (2014) studied the relationship between motor familiarity and EEG responses during the performance of seven trials of a computerized version of a mirror-drawing task. The authors reported a significant decrease in alpha power at the frequency range of 8-11Hz at the frontal regions with each subsequent trial. They also found that this decrease in suppression was associated with an increase in task familiarity. Nakano et al. (2013) recorded EEG signals during the observation, preparation, and performance of five trials of a ball-rotating task. The authors found across all the three conditions, the suppression in the fifth trial was significantly greater than that in the first trial.

Although some of these studies have associated their results with motor learning, their designs did not reflect learning, as it is hard to draw a conclusion about learning based on a few trials of performance. Moreover, the studies that used enough execution trials have not examined the changes in mu responses as a function of visual practice. Finally and more importantly, some of these studies have not shown that learning had actually occurred. As previously defined, learning is a relatively permanent change in behaviour; thus, to examine this change, learners need to be tested again on the same task (i.e., retention) or some other variation of it (skill transfer). Despite the fact that learning could be inferred from performance during the first acquisition of a motor task, this assessment of learning could be misleading (Magill, 1989). A more accurate account of the "relative permanent change" is obtained by retesting participants minutes or days following practice (Magill, 1989; Etnier, Whitwer, Landers, Petruzello, Salazar, 1996).

Taken together, these studies fall short of providing a clear picture of the relationship between learning and mu suppression during short-term practice. To our knowledge, no study to date has compared the changes in mu suppression that occur throughout the entire learning experience for both physical and observational practice. The majority of studies on mu suppression and learning have compared the effects of both physical and observational practice during subsequent observation only. Specifically, they examined the influence of motor experience (short-or long-term) on mu rhythm during the observation of motor skills.

1.2.3.5 Effects of previous experience on mu rhythm modulation

A great body of EEG research has provided evidence for the role of previous motor experience/practice (whether long-term or short-term) on modulating mu rhythm activity during observation of motor skills.

1.2.3.5.1 Long-term experience

Mixed results have been reported on the relationship between long-term experience and mu rhythm during the observation of motor skills. Orgs, Dombrowski, Heil, and Jansen-Osmann (2008) presented professional dancers and non-dancers with video clips of dance movements and everyday movements. Their results showed that expert dancers exhibited significantly more suppression at the frequency band 7.5 -13Hz compared to non-dancers, with no difference between the two groups during the observation of everyday movements. Similarly, Behmer and Jantzen (2011) studied musicians and non-musicians while they listened to music, observed videos of musical performance of others, and watched a static image of the corresponding sheet music. The authors found that, compared to non-musicians, musicians exhibited significantly stronger mu suppression at the frequency band 8-13Hz during the observation of sheet music and actual musical performances.

However, other researchers found that long-term experience is associated with reduced MNS activation (Babiloni et al., 2009). These authors compared elite gymnasts to non-gymnasts during the observation of video clips of gymnastic actions. They showed that relative to baseline, gymnasts exhibited less suppression in the alpha frequency band compared to non-gymnasts.

These mixed results could be because these studies tested individuals with years of experience, which may have introduced pre-existing differences among participants.

1.2.3.5.2 Short-term experience

To avoid potential pre-existing individual differences in expertise, the amount of practice given for participants has been controlled in studies investigating the effect of short-term practice. These studies associated more experience with increased suppression. Quandt and his colleagues trained one group of participants to observe videos of novel drawing movements (Quandt, Marshall, Bouquet, Young, & Shipley, 2011). Participants had to imitate half of these movements after watching them, while only watching the other half. This created two training conditions: combined visual and motor experience condition and visual experience only condition. The following day, participants observed videos of the same drawing movements along with a novel set of drawing actions. The authors found that during subsequent observation, the suppression at the upper alpha at the frequency range of 11-13 Hz was stronger during the observation of imitated (i.e., more experience) actions compared to the other two conditions.

In another study, Quandt and his team provided participants with sensorimotor experience with different objects that varied in weight (Quandt, Marshall, Shipley, Beilock, & Goldin-Meadow, 2012). Participants then watched video clips of a model producing gestures for those objects. The researchers demonstrated that observers displayed *greater* suppression across the lower (8-10Hz) and the upper (11-13Hz) alpha band when observing a gesture for a previously experienced object in contrast to a non-experienced one. Cannon et al. (2014) tested three groups of participants: performers, who were trained to use a claw-like tool to pick up a toy, observers, who had only visual experience with the same tool use, and novices, who had neither physical nor visual experience with the task. The authors found that during ensuing observation, performers exhibited the strongest suppression at the frequency range of 8-13Hz compared to observers and novices.

In summary, studies that examined the relation between short-term experience and mu rhythm activity have neither examined how visual or active motor experience/practice with a novel motor learning task modulates this rhythm during actual practice nor how it influences subsequent motor performance.

1.3 Purpose, objectives, and hypotheses

1.3.1.1 Purpose

The overarching purpose of this study is to compare short-term physical and observational practice during the acquisition and retention of a novel motor task and to evaluate how EEG mu rhythm is modulated during each type of practice.

1.3.1.2 Objectives

The objectives of this study are:

1. To examine the effects of observational practice of a novel flower-tracing task on outcome measures of motor performance and learning.

2. To compare the modulation of mu rhythm during physical and observational practice/training of a novel flower-tracing task.
3. To examine whether previous short-term physical practice modulates mu rhythm responses during observation.

1.3.1.3 Hypotheses

1. **During the first 10 trials of the retention phase, the performance of the OP group (indexed by number of errors and total time) will be significantly better than that of the NP group; in addition, the PP group will have the best performance.**
2. During training, relative to the resting baseline, mu rhythm will be suppressed at all the central electrodes (i.e., C3, CZ, and C4) for both the physical practice and the observational practice groups.
3. **During subsequent observation, previous physical practice will result in the highest magnitude of mu suppression at all central electrodes; in addition compared to no practice, previous observational practice will result in greater magnitude of mu suppression.**

Chapter 2: Methods

2.1 Participants

Thirty healthy individuals (Male = 9, Female = 21; $M_{age} = 26.2$ yr, *SD* = 5.72 yr, age range $[19 - 40 \text{ yr}]$ were recruited from the community via distributed flyers (Appendix A), social media invitations (Facebook, Craigslist), and word-of-mouth (snowball sampling). Using the Research Randomizer website (https://www.randomizer.org), participants were randomly equally assigned to one of three groups: physical practice group (*N* = 10, Male = 3, $M_{age} =$ 26.60 yr, *SD* = 7.18 yr), observational practice group (*N* = 10, Male = 3, $M_{age} = 24.40$ yr, *SD* = 3.37 yr), and no practice group (*N* = 10, Male = 3, $M_{age} = 27.70$ yr, *SD* = 6 yr). All participants were right-handed as confirmed using the ten-item version of the Edinburgh Handedness Inventory (Oldfield, 1971) (Appendix B). They reported normal or corrected-to-normal vision, no motor problems, and no known neurological disorders (Table 1).

The experiment was conducted over two days, and participants received a $10 Starbucks gift card as remuneration for each day of their participation. Informed consent was obtained from all participants according to the ethical guidelines of the University of British Columbia (UBC) (Appendix C).

Table 1. Study inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Age of 19-40 years Right-handed	Vision impairment (uncorrected) Psychiatric diagnoses Neurodegenerative disorders Substance abuse Neurological or muscular deficits that affect vision

Inclusion Criteria	Exclusion Criteria
	or manual control Personal of family history of epilepsy.

2.2 Study protocol

Interested individuals who responded to the recruitment material were screened for meeting the study criteria through email or phone communications. Eligible volunteers were invited to visit the Perception-Action Lab at the Djavad Mowafaghian Centre for Brain Health (CBH) at UBC. Prior to their arrival, participants were randomly assigned to one of three groups: physical practice (PP), observational practice (OP), and no practice (NP). In order to provide the participants with more information about the study, they were given written consent forms and were invited to discuss any questions or concerns.

To obtain reliable signals from the EEG electrodes, invited participants were requested to refrain from using hair products (e.g., gels, hairspray) prior to coming into the lab. Before placing the EEG net, the participant's head circumference was measured to determine the proper net size to use. The EEG net used in this study was a 64-channel HydroCel Geodesic EEG Sensor Net (EGI, Eugene, OR). The appropriate net was then placed on the participant's head, with the vertex (CZ) electrode placed midway between ears, and midway between the nasion and inion. Once the net was fixed, the participant was seated in front of a 60 cm desktop monitor at a distance of approximately 60 cm in a dimly lighted room.

2.3 The task

The motor task was a computerized version of the flower trail task used by the Movement Assessment Battery for Children (MABC) to assess motor functioning (Henderson & Sudgen, 1992). The flower figure was displayed on a computer screen using custom Labview 7.1 software (National Instruments Co, Austin, TX). When the volunteers were at rest, the flower was shown in red. When they were instructed to go, the flower was outlined in green. Participants were instructed to trace the figure between the two solid lines of the flower trail (Figure 3) as accurately and as fast as possible in a clockwise direction using a joystick. Each time the participant crossed beyond the two lines, it was considered an error. Once he/she completed each trial/trace, the number of errors made along with the time it took him/her to complete the trial were displayed on the screen.

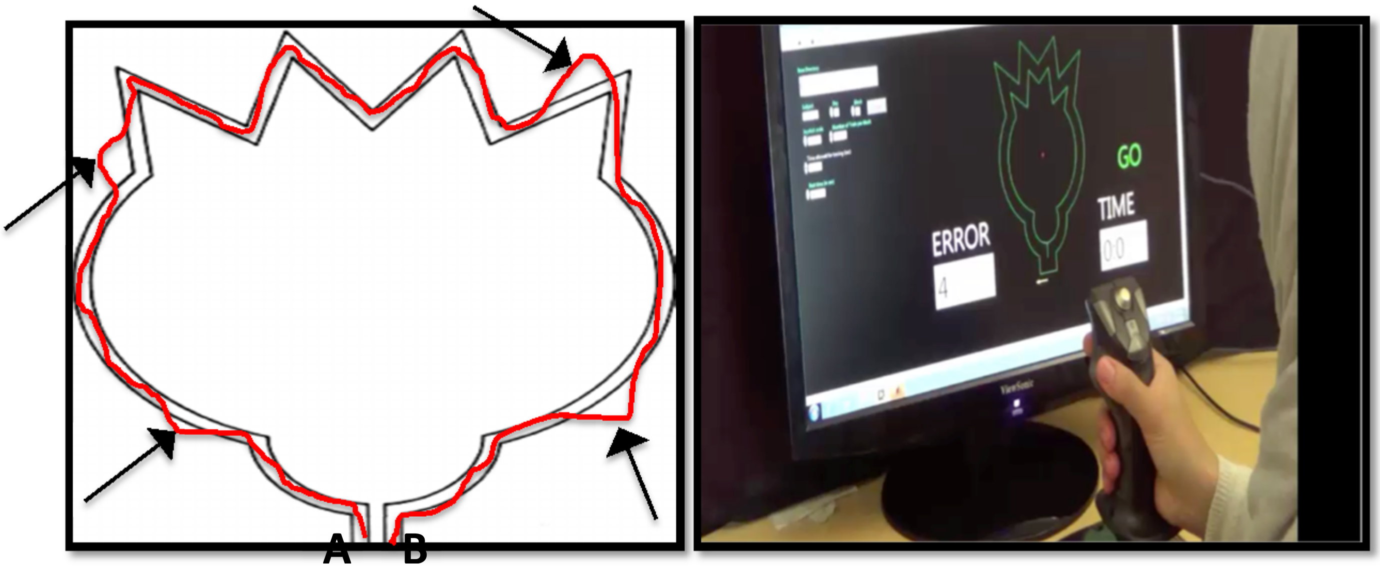

Figure 3. The flower-tracing task. Each arrow represents an error. The total tracing time starts at A and ends at B.

2.4 Experiment stages and experimental groups

2.4.1 Baseline

To determine the baseline for EEG data, participants were seated still and brain activity was recorded for 3 minutes while they were viewing a blank screen. The experiment was divided into three stages: Training session, testing session, and retention session (Figure 4):

2.4.2 Training session

2.4.2.1 Physical practice (PP) group

Participants in this group were first familiarized with the joystick by tracing a cross on the computer screen for 60 seconds. Then they performed three blocks of a flower-tracing task with a total of 45 trials (15 trials per block). To allow participants to rest, there was a 2-minute break between blocks. In order for EEG signals to return to baseline, a 10-second inter-trial-interval was applied (Pfurtscheller & Da Silva, 1999). Participants were instructed to trace the flower figure between the two solid lines using the joystick as accurately and as fast as possible.

Prior to the experiment, a different group of participants (Male = 2, Female = 4; $M_{age} = 23$, *SD* = 3. 21) were tested to determine the learning curve of the task. They performed 60 trials divided equally between three blocks (30/block). The results showed that the participants' performance leveled out around the 45th trial (Appendix D), and that it took the performers approximately 35 seconds to complete one trace/trial.

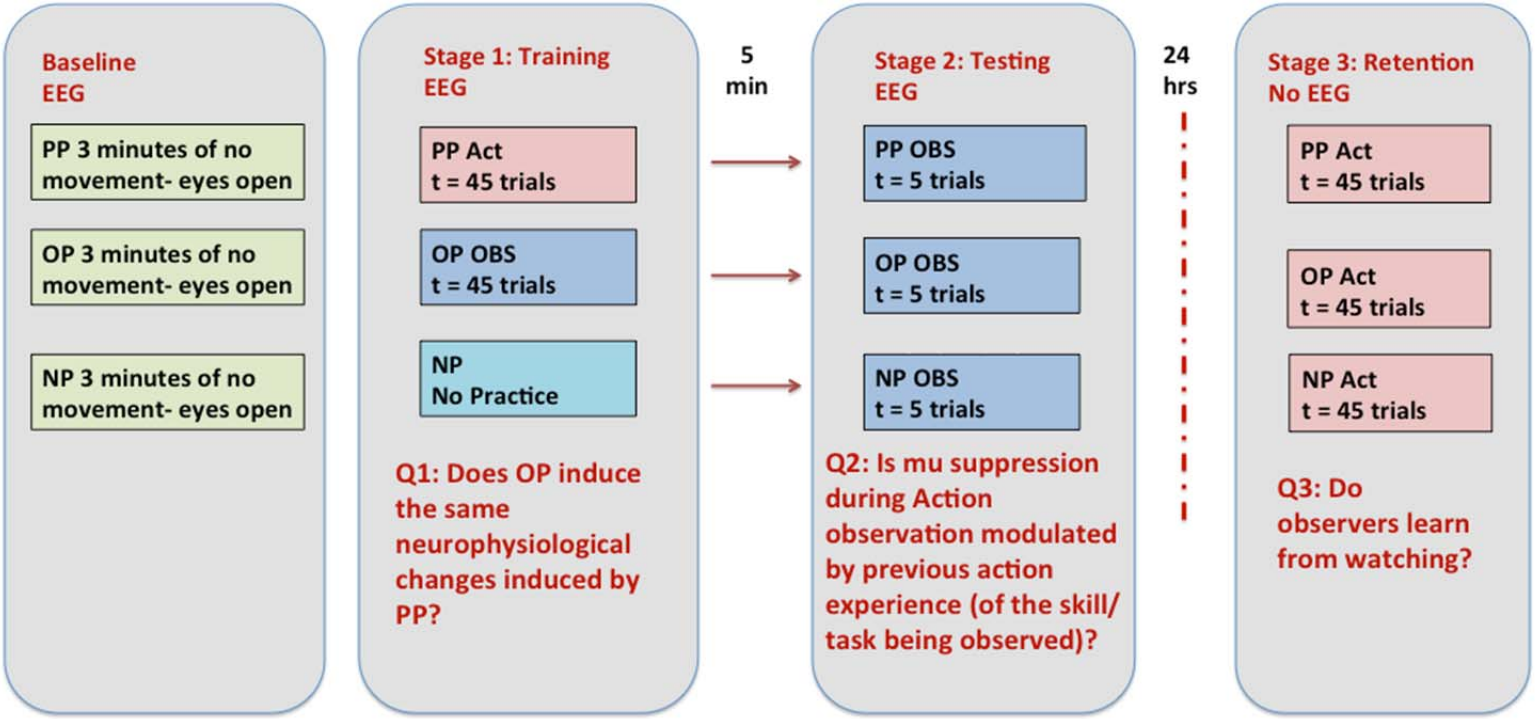

Figure 4. Schematic of the study design. EEG Electroencephalography, PP Physical practice, OP Observational practice, NP No practice, OBS Observe.

Based on these results, the number of trials was decided to be 45 trials, and the time window for each trace was set at 35 seconds. If the participant failed to finish within 35 seconds, the trial was terminated automatically. Each time the participant crossed beyond the two lines, it was considered an error. Once he/she completed each trial/trace, the number of errors made along with the time it took him/her to complete the trial were displayed on the screen.

EEG signals were collected throughout the training phase.

2.4.2.2 Observational practice (OP) group

All participants in this group watched the same video clips depicting the learning experience of a novice model performing the same tracing task. Each clip represented a trial, with a total of 45 trials/clips divided equally into three blocks (15 trials per block). Similar to the PP group, the blocks were separated by a 2-minute break with a 10 second-inter-trial washout interval of a blank screen. The video clips used in the observation trials were recorded at a resolution of 1,280× 720 pixels and a frame rate of 60 Hz. Additionally, they were shot from a first-person perspective (figure 5) as research has linked this perspective to better learning (Ishikura & Inomata, 1995) and stronger hemispheric activation (Jackson, Meltzoff, and Decety, 2006; Pilgramm et al., 2010), compared to the third-person perspective. To ensure that motion did not influence the observation data, the observers were instructed to refrain from any movement and their overt behaviour was monitored via a video camera. They were also instructed to pay attention to the model's movement, as they would be doing the same task the following day. Research has shown that observation with the intention to reproduce the movement results in an increased MNS activation (Iacoboni et al., 1999; Buccino et al., 2004; Frey & Gerry, 2006).

Figure 5. A picture showing what the participants in the OP group observed during the training session.

To ensure that attention was paid to the recordings, participants were asked to verbally state the tracing time or/and the number of errors made by the model at the end of each trial. These questions were randomized so the observers did not identify the pattern and focus on observing one measure on the screen.

2.4.2.3 No practice (NP) group

Participants in the (NP) group did not receive physical or observational training. After measuring their brain activity during baseline, they were moved to the next stage (i.e., testing session) immediately.

2.4.3 Testing session

Five minutes after the training session, participants in each group viewed a video of the same model observed by the OP group performing the last five trials of the learning experience.

EEG signals were collected for the three groups. Similar to the OP group, all participants during this session were instructed to stay still movement and to pay attention to the model's performance.

2.4.4 Delayed retention

Twenty-four hours after the training session, participants in the three groups performed 45 trials of the same task (15 trials per block). Each time the participant crossed beyond the two lines, it was considered an error. Once he/she completed each trial/trace, the number of errors made along with the time it took him/her to complete the trial were displayed on the screen. The participants received the same instructions given to the PP group during the training session. EEG signals were not recorded.

2.5 Model characteristics

Similar to the performers in the PP group, the model in the video clips of the OP group was right-handed and was a novice to the task. The handedness of the model was determined based on the studies that have shown that observing same-handed models from a first person perspective is associated with better learning (Blandin, Lhuisset, & Proteau, 1999; Boutin, Fries, Panzer, Shea, & Blandin, 2010; Gruetzmacher , Panzer, Blandin, & Shea, 2011; Heyes & Foster, 2002; Osman, Bird, & Heyes, 2005) and greater activation comparable to that which occurs during PP (Aziz-Zadeh et al., 2006; Aziz-Zadeh et al., 2002; Maeda, Kleiner-Fisman, & Pascual-Leone, 2002; Pilgramm et al., 2010; Shmuelof & Zohary, 2006, 2008). The model received the same verbal instructions delivered to the PP group. She was selected over several performers as she showed the least trial-to-trial variability in performance, yielding the most typical learning curve.

2.6 EEG acquisition

EEG was recorded using a 64-channel Hydrogel Geodesic SensorNet with a Net Amps 300 amplifier at a sampling rate of 500 Hz via EGI software (Net Station, Electrical Geodesics, Inc., Eugene, OR). At the start of the acquisition, impedances values for all EEG channels were less than 50 kΩ. The collected signals were referenced to the vertex (CZ). EEG data collected from each participant were processed and analyzed using the software, Brain Electrical Source Analysis® Research.86. Data were low-pass-filtered at 4 Hz and high-pass-filtered at 40 Hz, and a notch filter of 60 Hz was included for purposes of artifact detection and eye blink identification (Woodruff & Massake, 2010). Eye movements were corrected using Independent Component Analysis (ICA) procedure. The remaining artifacts exceeding ± 120 µV in amplitude in the central electrodes were rejected.

Because mu oscillations occur in brief periods from 0.5 second to 2 seconds (Niedermeyer, Goldszmidt, & Ryan, 2004), the first 2 seconds of each trial were segmented for all the experimental conditions. For the baseline segment, the data were averaged across three-minute period. Given that the focus of the experiment was on mu rhythm at the frequency range of 8-13 Hz, the integrated power in this range for both the experimental conditions and the baseline was computed using a Fast Fourier transform (FFT).

2.7 Outcome measures

The primary outcome measures of this study were physiological measures represented by EEG mu rhythm at the frequency band 8-13Hz, and behavioural measures indexed by total time and error.

2.7.1 Physiological measures: Mu Suppression Index (MSI)

Relative mu rhythm, or the Mu Suppression Index (MSI), has been used as an index of the mirror neuron system activation because it adjusts for the variability in absolute mu power that may result from individual differences, such as scalp thickness and electrode impedance (Perry, Troje, & Bentin, 2010). The MSI is a change score of absolute mu power (8-13Hz) between a baseline and an experimental condition. It was calculated as:

$$\mathrm{MSI} = \log \frac{\text{mu power experimental}}{\text{mu power baseline}}$$

Because the ratio data are inherently skewed, the log was employed for the purposes of parametric analysis (Perry et al., 2010). Any log value below zero was considered suppression/desyncronsation and any value above zero was a display of synchronization. The MSI was calculated for each participant (using rest as baseline) for the electrodes C3, CZ, and C4 according to the international 10-10-system montage (Figure 6). These central electrodes record the activity of the sensorimotor cortex (Pfurtscheller et al., 1997).

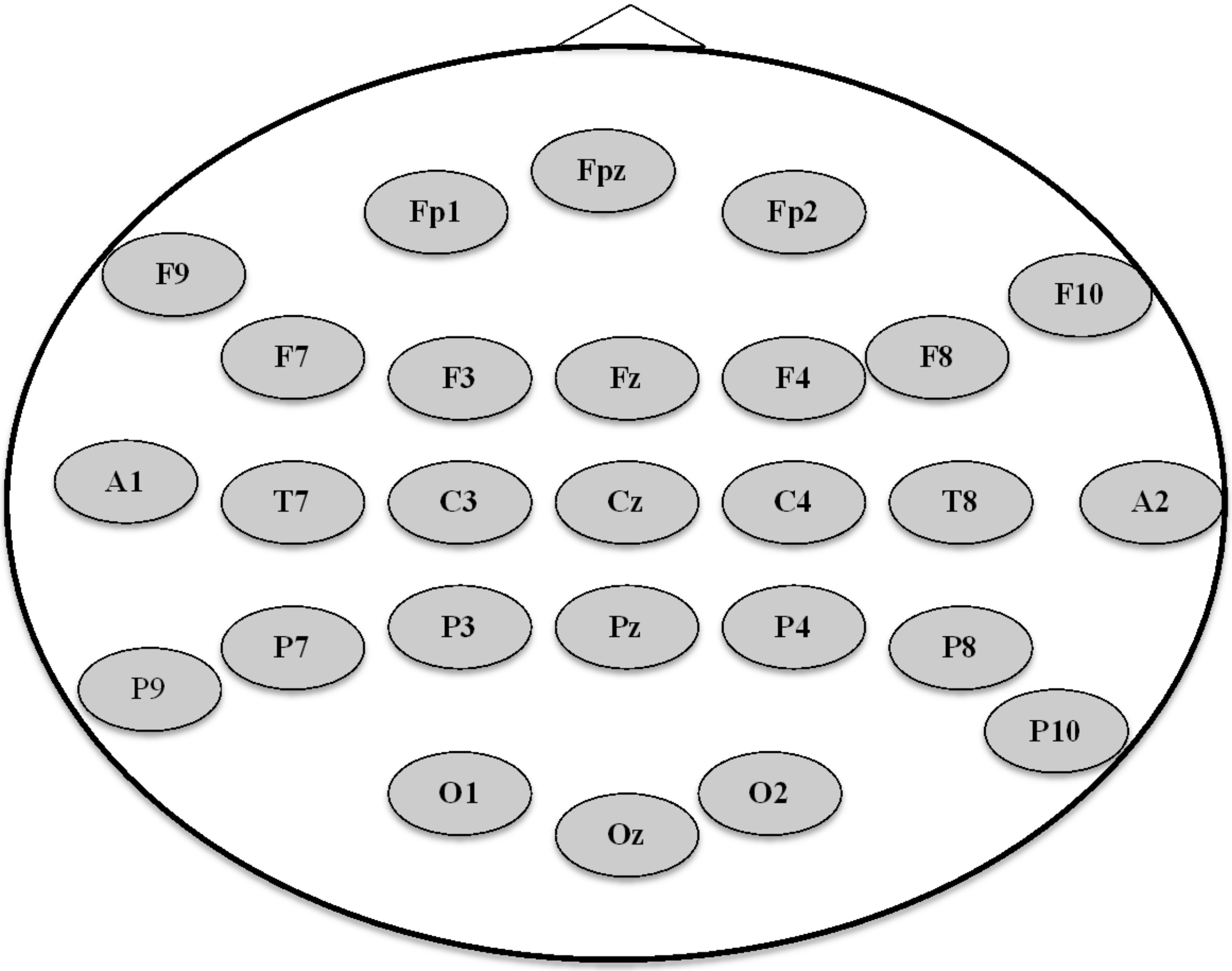

Figure 6. 10-10 montage for electrode placement.

2.7.2 Behavioural measures

Two specific behavioural measures were used to assess learning: (1) error, which was denoted as the number of times the participant crossed out of the flower figure's bounds; and (2) total trace time, which was described as the time it took the participant to complete each trace/trial.

2.8 Data analysis

2.8.1 Statistical analysis

2.8.1.1 Participant characteristics

The significance level for this study was set at $\alpha = .05$. Prior to conducting the main analyses, a one-way [group: PP, OP, NP] ANOVA was performed to test whether the three groups differed significantly in age. With regard to sex, each of the three groups consisted of three males and seven females.

2.8.1.2 Hypotheses

The dependent variables for the behavioural analysis were the average tracing time and the average number of errors per trial, whereas the dependent variable for the physiological analysis was the mean MSI. SPSS software was used to conduct statistical analyses of the data. A statistician was consulted to ensure that appropriate analyses were performed.

Hypothesis 1: During the first 10 trials of the retention phase, the performance of the OP group (indexed by number of errors and total time) will be significantly better than that of the NP group; in addition, the PP group will have the best performance.

To test hypothesis 1, two separate 3 [group: PP, OP, NP] × 10 [trial: T1, T2… T10] mixed design ANOVA were conducted to compare (1) the average number of errors and the (2) the average tracing time in each of the first 10 trials of retention for the three groups. Trial was the within-subjects factor, and the group was the between-group factor. All effects met the assumptions of mixed ANOVA except for the sphericity assumption; therefore, Greenhouse-

Geisser test was used. A post hoc test with Bonferroni correction was conducted to examine the main effects and interactions.

Hypothesis 2: During training, relative to the resting baseline, mu rhythm will be suppressed at all the central sites (i.e. C3, CZ, and C4) for both the PP and OP groups.

To test hypothesis 2, first the MSI was calculated as per the equation shown previously, with positive values representing synchronization and negative values indicating suppression. Second, because the suppression at each electrode was associated with three blocks of training, a 2 [group: PP, OP] × 3 [electrode: C3, CZ, C4] × 3 [block: B1, B2, B3] mixed design ANOVA was performed to test whether there was a significant difference in the MSI between the three blocks in each group. Electrode and block were the within-subjects factors, and the group was the between-groups factor. All the assumptions of mixed ANOVA were met. Third, three single sample t-tests were computed for each condition/group over C3, CZ, and C4 to decide whether the MSI associated with each electrode in each group is significantly less than zero.

It was hypothesized that the MSI during training for both groups will be significantly less than zero at all three electrodes. The data met the assumption of normality. The three comparisons within each group (i.e., C3, CZ, and C4) were considered a source of a family wise error; therefore, to control for multiple comparisons, Bonferroni correction was used and the significance level for each group was set as $\alpha/3 = .017$.

Hypothesis 3: During subsequent observation, previous physical practice will result in the highest magnitude of mu suppression at all central electrodes; in addition compared to no

practice, previous observational practice will result in greater magnitude of mu suppression.

To test hypothesis 3, first, a single sample t-test was run to decide if the MSI associated with each electrode in each group is significantly less than zero. All effects met the normality assumption. Second, a 3 [group: PP, OP, NP] × 3 [electrode: C3, CZ, C4] mixed design ANOVA was performed to compare MSI at C3, CZ, and C4 in each group. Electrode was the within-subjects factor, and the group was the between group factor. All effects met the assumptions of mixed ANOVA.

Chapter 3: Results

3.1 Participant characteristics

The one-way ANOVA showed that there was no significant difference in age between the three groups, F (2, 27) = .856, p = .436. In addition, the groups did not differ in sex as each group consisted of three males and seven females.

3.2 Behavioural results

Hypothesis 1: During the first 10 trials of the retention phase, the performance of the OP group (indexed by number of errors and total time) will be significantly better than that of the NP group; in addition, the PP group will have the best performance.

3.2.1 Performance of PP, OP, and NP groups during retention

3.2.1.1 Error

Figure 7 displays the average number of errors across the 10 trials for each of the three groups. Overall, the number of errors for each group decreased across trials, with the PP group having the smallest number of errors. The results of the conducted mixed ANOVA revealed a significant main effect for both the trial, [F (5.19, 139.99) = 9.96, p < .001, partial $\eta^2 =. 27$, and the group, F (2, 27) = 10.85, p < .001, partial $\eta^2 = .45$]. However, there was no significant interaction between the trial and the group, [F (10.37, 139.99) = .927, p = .513, ns]. A post hoc analysis of the main effect for the group showed that, overall, the PP group had significantly less error than both the OP and NP groups. Surprisingly, there was no difference in the number of errors between the OP and NP groups. See Appendix E for the means and standard deviations of the number of errors associated with each trial for the three groups. For the changes in the number of errors for each participant during the first 10 trials of retention, see Appendix F.

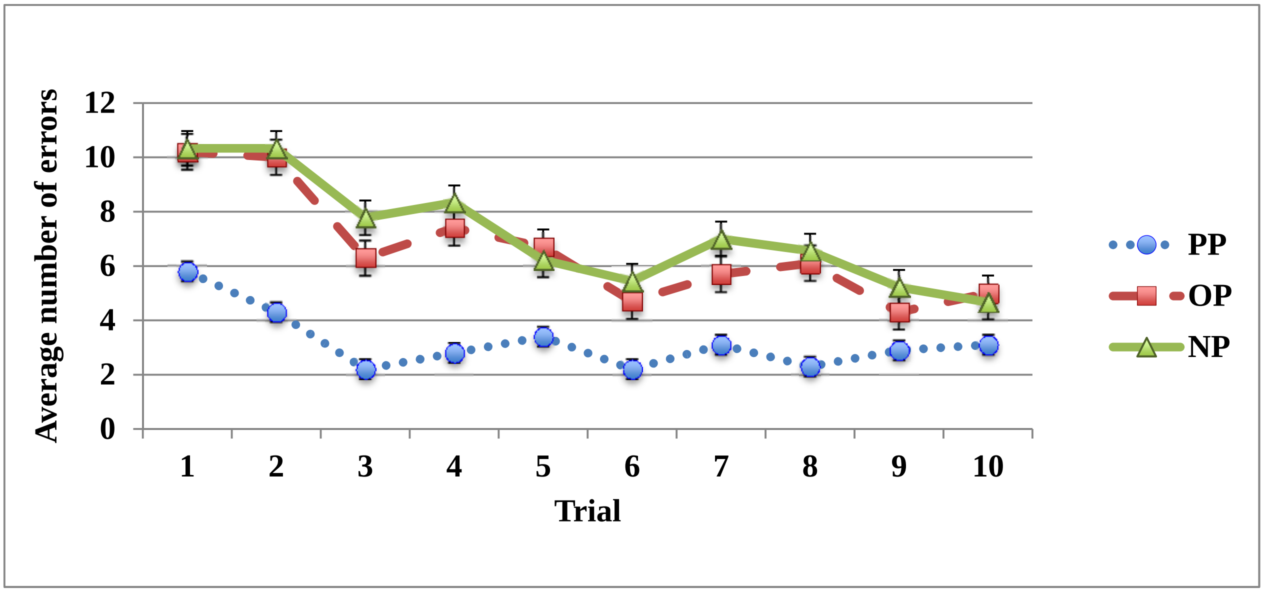

Figure 7. Average number of errors for PP, OP, and NP groups for each of the first 10 trials in retention. Error bars represent standard error of the mean SE.

3.2.1.2 Time

Figure 8 displays the average tracing time across the ten trials for each of the three groups. Overall, the average tracing time for each group decreased across the trials. The results of the mixed ANOVA revealed a significant main effect for the trial, [*F* (5.76, 155.54) = 4.82, *p* < .001, partial η^2 =. 15]. However, both the main effect for the group, [*F* (2, 27) = .794, *p* = .462, *ns*], and the interaction between the group and the trial [*F* (11.52,155.54) = 1.09, *p* = .373, *ns*] were not significant. The non-significant main effects for the group indicated that there was no difference in the average tracing time between the three groups. See Appendix E for the means and standard deviations of the tracing time associated with each trial for the three groups. For the changes in the total tracing time for each participant during retention, see Appendix F.

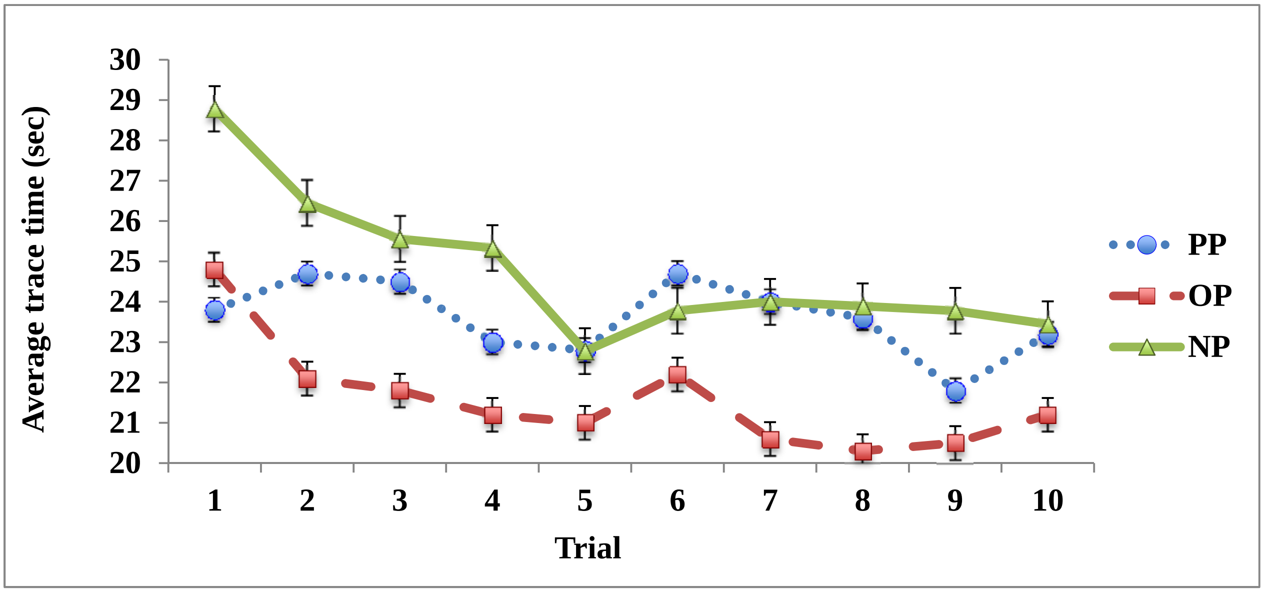

Figure 8. Average tracing time for PP, OP, and NP groups for each of the 10 trials in retention. Error bars represent standard error of the mean SE.

3.2.2 Performance of the PP group during training and the OP and NP groups during retention

Given that the OP and NP groups were not significantly different in performance during the retention phase, I assumed that the comparable level of performance might be because both groups had been exposed to the task visually during the testing stage. It is possible that the observed five trials during the testing session have been sufficient to provide some cues of learning for the NP group. Consequently, comparing this group to the OP group would not provide an accurate answer as to whether or not OP has an advantage over the lack of PP. Given that the PP group had not been exposed to the task before training, comparing the OP and PP groups during their first physical encounter with the task would serve a better comparison to determine whether or not observers learned from observation. It was predicted that the OP group in the first 10 trials of retention would be faster and make fewer errors than the PP group in the first 10 trials of training.

3.2.2.1 Error

Figure 9 shows the average number of errors across the ten trials for each of the three groups. Overall, the number of errors for each group decreased across the trials. A 3 [group: PP, OP, NP] × 10 [trial: T1, T2… T10] mixed design ANOVA was conducted to compare the average number of errors for each of the first 10 trials of training made by each group. Trial was the within-subjects factor, and the group was the between-group factor. All effects met the assumptions of mixed ANOVA except for the sphericity assumption; therefore, Greenhouse-Geisser test was used.

The results revealed a significant main effect for the trial, [F = (5.53, 149.40) = 13.99, $p < .001$, partial η^2= .34], indicating that, on average, the number of errors decreased significantly with trial. However, neither the main effect for the group, [F = (2, 27) = 1.83, p = .180, *ns*], nor the interaction between the group and the trial, [F (11.07, 149.40) = .315, p = .982, *ns*] were significant. See appendix E for the means and standard deviations of the average number of errors associated with each trial for the three groups.

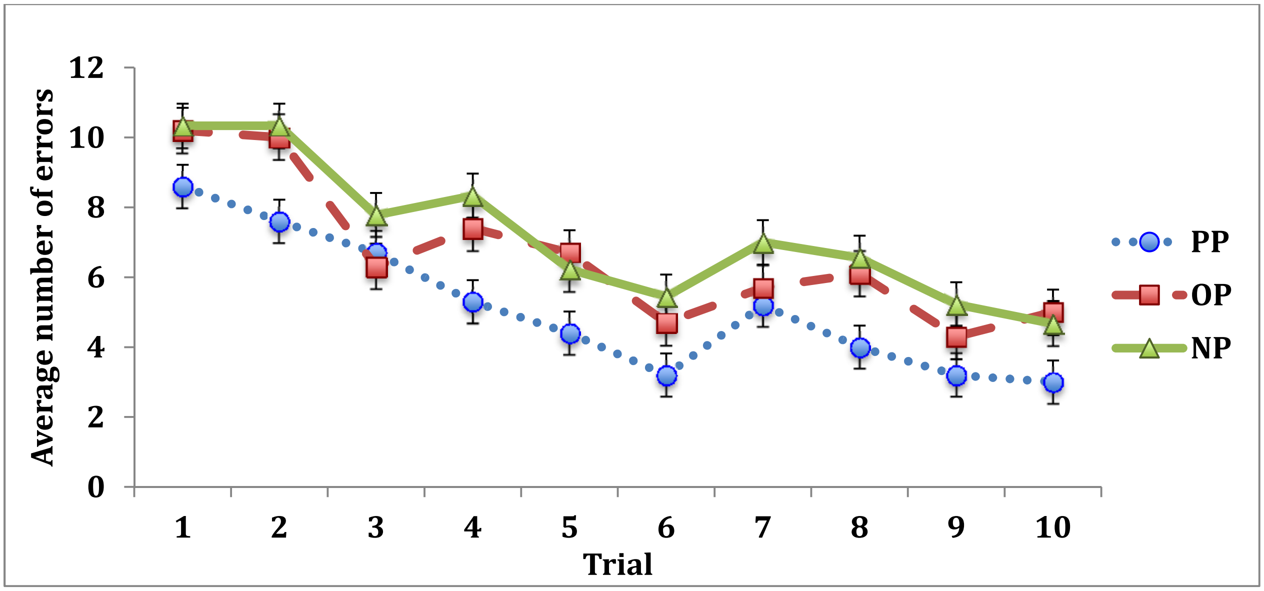

Figure 9. *Average number of errors for PP group for each of the first 10 trials of training, and for OP and NP groups for each of the first 10 trials of retention. Error bars represent standard error of the mean SE.*

3.2.2.2 Time

Figure 10 displays the average tracing time across the ten trials for each of the three groups. The same mixed ANOVA was performed to compare the three groups in tracing time. All effects met the assumptions of the mixed ANOVA except for the sphericity assumption; therefore, Greenhouse-Geisser test was used. The results revealed significant main effects for both the trial, [F = (4.92, 132.86) = 6.13, $p < .001$, partial η^2 = .19], and the group, [F = (2, 27) = 4.46, $p < .001$, partial η^2= .25]. However, there was no significant interaction, [F (9.84, 132.86) = .437, p = .92, *ns*]. A post hoc analysis of the main effect for the group with Bonferroni correction showed that the OP group spent, on average, 6.29 seconds less than the PP group to complete the task. Moreover, there was no significant difference in the average tracing time between the OP and the NP groups nor between the PP and the NP groups. See appendix E for the means and standard deviations of the average tracing time associated with each trial for the three groups.

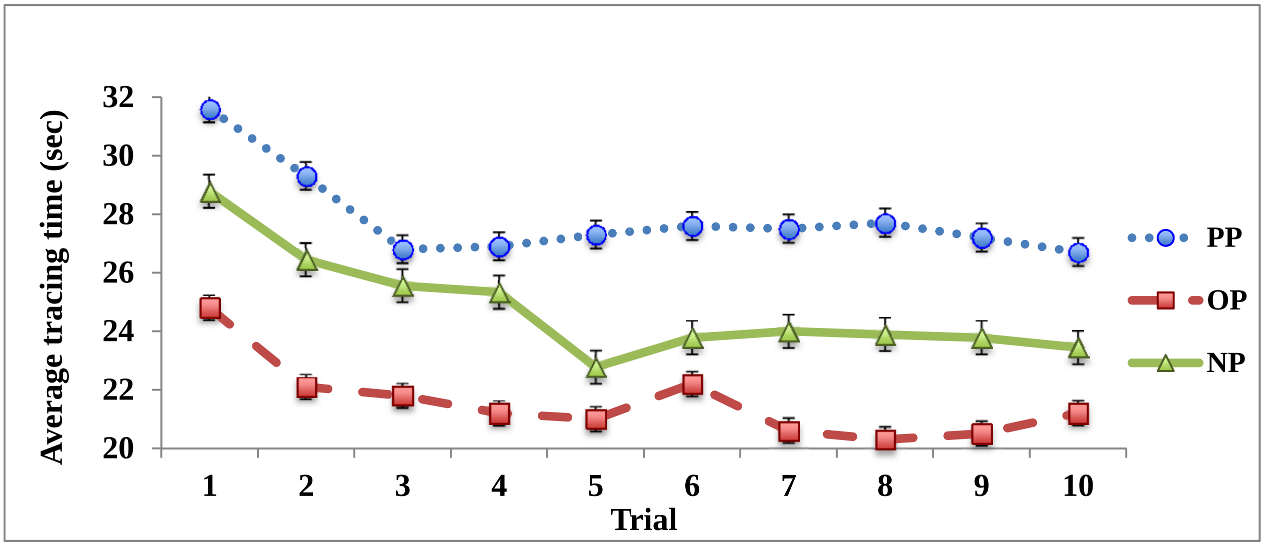

Figure 10. Average tracing time for PP group for each of the first 10 trials of training, and for OP and NP groups for each of the first 10 trials of retention. Error bars represent standard error of the mean SE.

3.3 Neurophysiological results

Hypothesis 2: During training, relative to the resting baseline, mu rhythm will be suppressed at all central sites (i.e., C3, CZ, and C4) for both the PP and OP groups.

The results of the mixed ANOVA revealed neither significant main effects nor significant interactions (Appendix E). The non-significant main effect for the block indicated that for each group, the MSI across all the three blocks was similar. Therefore, for each group, the MSI associated with each electrode was averaged across all three blocks to obtain the mean MSI for the entire training session.

In regard to the single sample t-test, the results showed that during PP, the average MSI at C3 (*N* = 10, *M* = -.25, *SD* = .26), CZ (*N* = 10, *M* = -.24, *SD* = .25), and C4 (*N* = 10, *M* = -.25, *SD* = .18) was significantly less than zero. Similarly, during OP, the results showed that the average MSI at C3 (*N* = 10, *M* = -.16, *SD* = .19) and CZ (*N* = 10, *M* = -.16, *SD* = .12) was significantly less than zero. The MSI at C4 (*N* = 10, *M* = -.02, *SD* = .29), however, was not significantly less than zero. Table 2 displays the results of the performed t-tests. Given that all t-tests ran by SPSS are two-tailed and that the study hypothesis was directional (i.e., one-tailed), in order to obtain *p* values for a one-tailed t-test, the reported *p* values were divided by 2.

Table 2. Single sample t-test results for each electrode for PP and OP groups during tainting session.

	PP (N =10)					OP (N = 10)				
Electrode	*df*	*t*	*d*	*(p/2)*	95% *CI*	*df*	*t*	*d*	*(p/2)*	95% *CI*
C3	9	-3.06	.97	.007*	[-.44, .07]	9	-2.71	.86	.012*	[-.29, .03]
CZ	9	-3.01	.95	.008*	[-.42, .06]	9	-4.08	1.29	.002*	[-.24, .07]
C4	9	-4.39	1.39	.001*	[-.38, .12]	9	-.249	.08	.405	[-.23, .19]

Note. * p < .017

To examine whether the two groups differed in MSI, a 2 [group: PP, OP] × 3 [electrode: C3, CZ, C4] mixed ANOVA was conducted using the training MSI. All effects met the assumptions of mixed ANOVA. Both the main effect for the electrode, [*F* (2, 36) = 1.05, *p* = .333, *ns*], and for the group, [*F* (1, 18) = 2.78, *p* = .113, *ns*] were not significant. Similarly, the interaction between the group and the electrode was not significant, [*F* (2, 36) = 1.36, *p* = .333, *ns*]. Figure 11 summarizes the differences between the groups across the three electrodes.

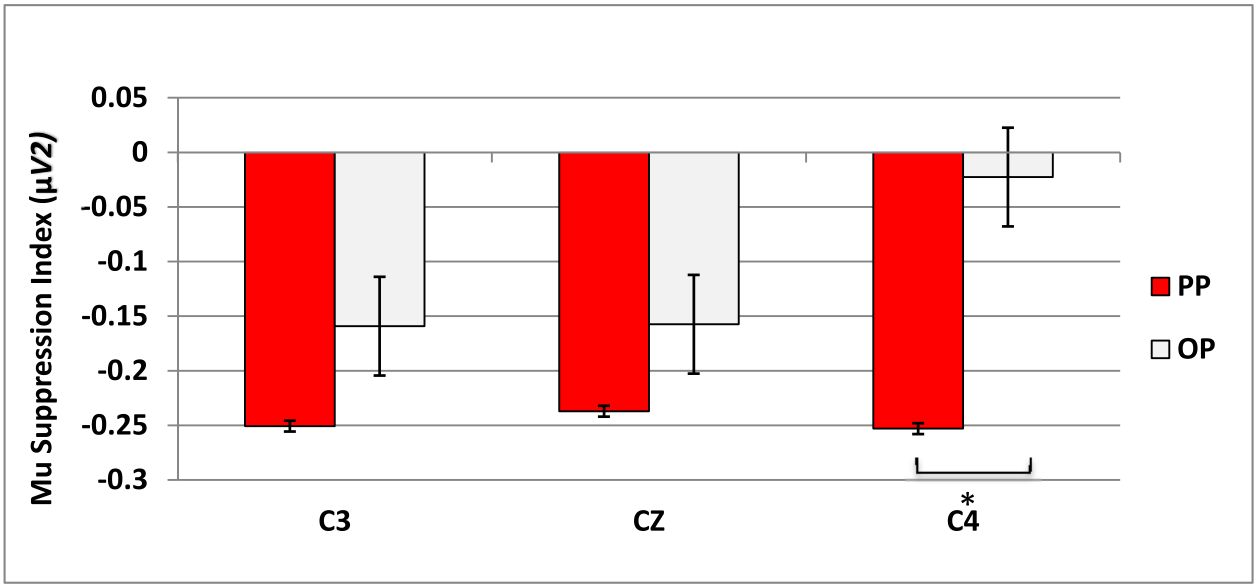

*Figure 11. Mu suppression during PP (3 blocks) and OP (3 blocks) at the central electrodes C3, CZ, C4. Values represent the mean log ratio of mu power at the frequency range of 8-13 Hz in the experimental condition compared to baseline. A ratio of negative value indicates suppression. Error bars represent standard error of the mean SE. *p < .05*

Hypothesis 3: During subsequent observation, previous physical practice will result in the highest magnitude of mu suppression at all central electrodes; in addition compared to no practice, previous observational practice will result in greater magnitude of mu suppression.

Table 3 displays the results of the performed single sample t-tests examining the strength of the MSI. As for the PP group, the results revealed that during observation the average MSI at C3 (*N* = 10, *M* = -.32, *SD* = .26), CZ (*N* = 10, *M* = -.26, *SD* = .26), and C4 (*N* = 10, *M* = -.28, *SD* = .23) was significantly less than the change level of zero. The MSI exhibited by the OP group, however, was significantly less than zero at CZ only (*N* = 10, *M* = -.18, *SD* = .16). Although mu rhythm was decreased in magnitude at C3 (*N* = 10, *M* = -.09, *SD* = .28), the MSI was not significantly less than zero. Mu rhythm was synchronized at C4 (*N* = 10, *M* = .05, *SD* = .34), but this synchronization was not significantly above zero. Mu rhythm in the NP group was synchronized as well at C3 (*N* = 10, *M* = .10, *SD* = .30), CZ (*N* = 10, *M* = .21, *SD* = .18), and C4 (*N* = 10, *M* = .07, *SD* = .26). This synchronization, however, was significantly above zero only at CZ.

The results from the mixed ANOVA revealed a significant main effect for the group, [*F* (2, 27) = 9.68, *p* = .001, partial η2 = .42]. However, there was no significant main effect for the electrode, [*F* (2, 54) = .47, *p* = .625, *ns*], neither the interaction between the group and the electrode, [*F* (4, 54) = 2.52, *p* = .051, ns]. Figure 12 summarizes the differences between the three groups across the 3 electrodes.

Table 3. Single sample t-tests results for each electrode for PP, OP, and NP groups during testing session.

	PP (*N* = 10)					OP (*N* = 10)					NP (*N* =10)				
Electrode	*df*	*t*	*d*	*p*	*CI*	*df*	*t*	*d*	*p*	*CI*	*df*	*t*	*d*	*p*	*CI*
C3	9	3.83	1.21	.002**	[-.51, -.13]	9	-3.21	.30	.185	[-.29, .12]	9	1.05	.33	.162	[-.11, .31]
CZ	9	-3.21	1.01	.006**	[-.44, -.07]	9	-3.48	1.11	.004*	[-.29, -.06]	9	3.62	1.15	.003*	[.08, .34]
C4	9	-3.73	1.18	.003**	[-.45, -.11]	9	.45	.14	.331	[-.20, .29]	9	.826	.26	.215	[-.11, .25]

Note. * p < .017. **p < .001

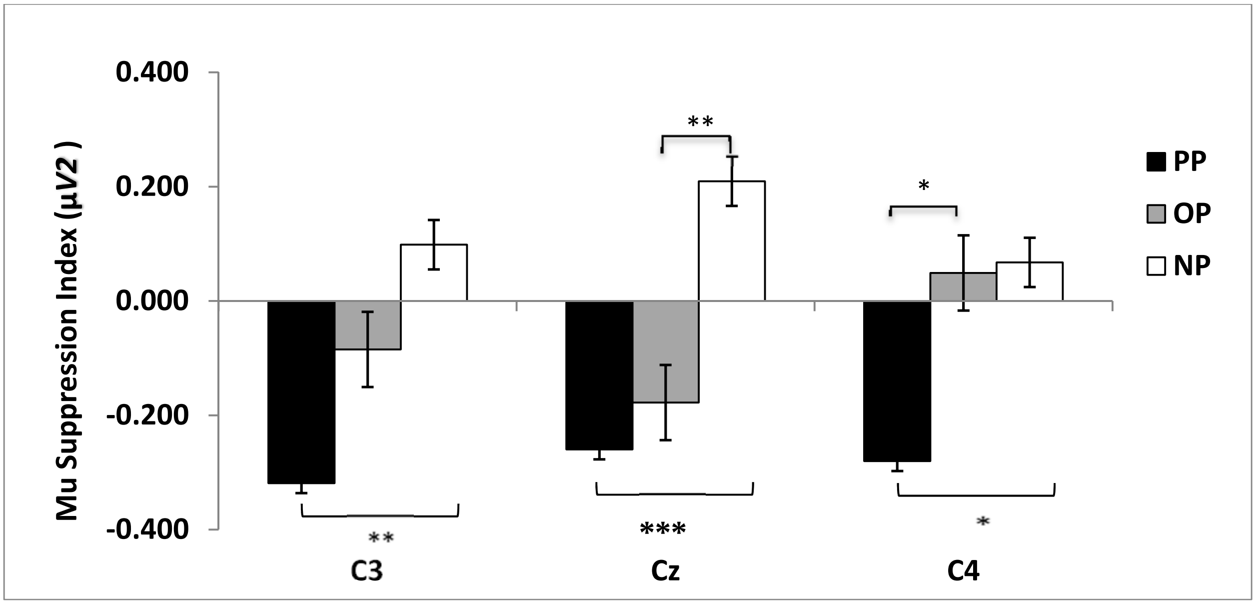

*Figure 12. Mu suppression Index for the PP, OP, and NP groups during the testing session (observation). Error bars represent standard error of the mean SE. *p < .05, *p < .01, ***p < .001.*

3.4 Relationship between neurophysiological and behavioural measures

To evaluate the relationship between learning and mu suppression, performance (i.e., time and error) during retention was correlated with mu suppression during both the training and the testing sessions (Tables 4 & 5). See Appendix G for the graphic representation of the correlations. None of the resulted Pearson bivariate correlations were significant; however, I examined the correlation to see whether there was a trend that may be more pronounced with a larger sample size. Only medium and large correlations (i.e., 0.3 or higher based on Cohen's criteria) are explained below.

3.4.1 Training session

As Table 4 shows, the correlation between error and mu suppression during both OP and PP was smaller than that between mu suppression and time over both hemispheres. Specifically, there was a <u>**medium**</u> mu-time correlation during both types of practice; however, the direction of this correlation depended on the practice type. For PP, the results yielded a <u>**negative**</u> mu-time correlation, indicating that more suppression was associated with faster performance. Conversely, during OP, this correlation was <u>**positive**</u>, suggesting that more suppression correlates with slower performance. The mu-time medium effect during both types of training was more pronounced over the <u>**left**</u> hemisphere compared to the right hemisphere.

3.4.2 Testing session

During the testing session, as Table 5 shows, there was a <u>**medium**</u> <u>**negative**</u> mu-time correlation at all central sites in both the PP and NP groups. This indicates that as mu suppression increased, the tracing time during retention decreased for both groups. However, among the OP group, this relationship was pronounced (medium) only at the medial central site. Interestingly, this correlation was <u>**negative**</u> in contrast to the positive correlation during the training session, suggesting that more suppression during the testing stage was associated with less time during retention. The mu-error relationship during the testing session was evident only in the PP group over <u>**both**</u> hemispheres. This correlation was negative indicating that more suppression during observation was moderately correlated with less error during retention.

Table 4. Correlations between mu suppression at central electrodes (C3, CZ, C4) during training and performance (time and error) during retention for PP and OP groups.

	PP (*N* =10)		OP (*N* =10)	
	Tracing time	Number of errors	Tracing time	Number of errors
	r	r	r	r
MSIC3	-.31	-.04	.33	-.18
MSICZ	-.25	-.11	-.07	-.26
MSIC4	-.01	-.08	-.04	-.26

Table 5. Correlations between mu suppression at central electrodes (C3, CZ, C4) during testing session (observation) and performance (time and error) during retention for PP, OP, and, NP groups.

	PP (*N* = 10)		OP (*N* = 10)		NP (*N* = 10)	
	Tracing time	Number of errors	Tracing time	Number of errors	Tracing time	Number of errors
	r	r	r	r	r	r
MSIC3	-.55	-.54	.05	.20	-.42	-.18
MSICZ	-.40	-.25	-.34	.08	-.46	-.25
MSIC4	-.32	-.32	-.21	-.13	-.38	-.05

Chapter 4: Discussion & Conclusions

The aim of this study was to compare short-term physical and observational practice during the acquisition and retention of a flower-tracing task and to evaluate how each type of practice modulates EEG mu rhythm. To that end, three groups (i.e., PP, OP, and NP) were tested during training, observation, and retention. This study is the first to investigate how mu suppression changes as a function of both observational and physical practice. The majority of studies in this area have not examined the relationship between short-term observational practice and mu rhythm during the actual practice condition. Previous studies typically evaluated changes in mu rhythm only during observation. In this study, mu responses during both practice (observational or physical) and subsequent observation were evaluated. Behavioural changes associated with each mode of practice were also examined.

4.1 Behavioral results

As predicted, the behavioural results showed that during the retention phase, the PP group made the least number of errors compared to the OP and NP groups; however, there was no difference in the average tracing time between the OP and the NP groups. In addition, the NP group performed just as well as the OP group in both time and error. The finding that the NP and OP groups performed similarly to the PP group in terms of time suggests that the learning during observation (be it during the 45 training trials or the five testing trials) was related to time and not to accuracy.

Moreover, the comparable performance of OP and NP groups suggests that the NP group may have learned from the five trials/clips presented during the testing session. Given that this was not a complex task, it is possible that learners did not need to observe all 45 visual trials and that the initial five trials may have been adequate. As shown in the results section, comparing the OP and PP groups during their first actual performance provided a more accurate answer as to whether or not observers learned from observation. The results showed that there was an advantage of OP despite the lack of physical practice; however, it was only in terms of time. During their first physical exposure to the task, the OP group was significantly faster than the PP group, but made, approximately, as many errors as the PP group. Again, it appears that time is the measure that was learned through observation in this task.

Another possible explanation is that the learning in this task, be it during PP or OP, is time-related and not accuracy-related. As additional evidence in support of this assumption, the PP group performed significantly faster during retention compared to the training sessions (Appendix H). There was, however, no difference between the two stages in the average number of errors. Given that delayed retention reflects the persistence of learning, this finding suggests the learning of the temporal aspects of the task was stronger than the learning of the accuracy aspect. The role of observation in enhancing temporal parameters is consistent with previous behavioural studies that have found OP to be as effective as PP in learning the temporal features of motor tasks (Heyes & Foster, 2002; Vogt; 1995).

4.2 Neurophysiological results

The neurophysiological results showed that, compared to baseline, mu rhythm was significantly suppressed over both hemispheres during PP and only over the left hemisphere during OP. However, the magnitude of this suppression did not change as a function of practice, indicating that short-term motor practice, be it overt or observational, does not lead to a change in the magnitude of MNS activation. This result is not consistent with studies that reported changes in the magnitude of MNS activity during practice. Nakano et al. (2013), for example, reported a significant difference in suppression between the first and last trial during the observation of a ball rotation task. Although the authors associated this decrease in suppression with motor learning, it is difficult to draw a conclusion about motor learning based on so few trials.

The unchanged magnitude of mu suppression is also not in line with the neural efficiency hypothesis, which associates improved learning with less cortical activation (Haier et al., 1988). Several lines of evidence have shown that experts exhibit less suppression during the execution and observation of motor skills, suggesting that more experience eventually leads to a more efficient neural processing (Babiloni et al., 2009; Del Percio et al. 2009; 2008). However, contrary to the current study, which focused on short-term practice, these studies tested individuals with years of experience (i.e., long-term) and research has identified different brain networks, with different activation patterns, involved in short-term and long-term motor practice (Floyer-Lea & Matthews, 2005). This may explain the differences in results between the current study and the previously mentioned studies. Moreover, testing experts who differ in the degree of their mastery of a given motor skill may have introduced possible pre-existing differences among participants, and hence any conclusion based on these studies should be made with caution.

As expected, mu suppression during PP was bilateral, suggesting that both hemispheres are active during movement performance. Contrary to our hypothesis, however, mu suppression during OP was higher in magnitude in the left hemisphere compared to the right hemisphere. Given that both the model and the study participants were right-handed, and that the observers watched the movement from a first-person perspective, the bilateral suppression of mu rhythm during PP is consistent with previous studies (e.g. Muthukumaraswamy et al., 2004; Pineda et al., 2000; Strelsova et al., 2010; Woodruff & Maaske, 2010). The lateralized suppression, however, is not in line with the commonly reported bilateral hemispheric effect during action observation (e.g. Babiloni et al., 2002; Mauthukumaraswamy et al., 2004). Nonetheless, this finding is consistent with what Perry and Bentin (2009) found when they examined right-handed participants while observing movements of both right and left hands from a first person perspective (also called egocentric). They showed that mu suppression at the frequency range of 8-13Hz was stronger in the hemisphere contralateral to the hand being observed compared to the hemisphere ipsilateral to the observed hand. Notably, the researchers argued that viewing right hand movements induces greater suppression over the left hemisphere and, vice versa, watching the movement of the left hand triggers stronger suppression over the right hemisphere. Similarly, when Quandt et al. (2013) presented video clips of a right-handed model using a first-person perspective, action observation was associated with greater suppression at the alpha frequency range in the left hemisphere compared with the right hemisphere. In another study, Quandt and his colleagues employed a third-person observation paradigm and found that suppression was greater over the right hemisphere compared with the left hemisphere (Quandt et al., 2012).

The left-lateralized activation reported in this study is also consistent with fMRI studies. These studies have revealed that watching right hand reaching-and-grasping movements from an egocentric perspective elicited larger BOLD responses in the left anterior intraparietal cortex of right-handed observers (Shmuelof & Zohary, 2006, 2008). This contralateral effect, however, was replaced by an ipsilateral response (i.e., the right hemisphere) in the anterior superior parietal lobule when the right-handed observers viewed the right-handed movements form an allocentric perspective (i.e., facing the model) (Shmuelof & Zohary, 2008).

Considering that some studies reported increased left activation of MNS during action execution, it can be argued that the strong suppression over the left hemisphere during OP could be a result of muscle activation. Namely, despite instructions, participants might unintentionally have moved their hand while watching the movements. Nonetheless, muscle activation could not account for the observed left laterality during observation because the suppression during PP was bilateral and involved both the left and right hemispheres with no significant difference between them. Moreover, the observers were continuously monitored via a video camera to ensure that no overt motion occurred, and no overt movement was recorded.

Overall, there is a lack of systematic investigation of the effects of certain factors such as the model's handedness, the observer's handedness, along with the observation perspective on the hemispheric suppression. No study to date has examined how mu suppression (especially the hemispheric effect) is modulated by these three factors together. The primary goal of rehabilitation is to optimize brain activation in damaged areas for more targeted recovery; thus, the relationship between these factors and hemispheric activation is of great importance when considering OP in rehabilitation contexts.

Another important factor in the context of rehabilitation is whether or not the observed movement should be a part of the observer's motor repertoire (i.e., previous active motor experience). In regards to this hypothesis, the results showed that during observation, the PP group exhibited the strongest suppression compared to the NP and OP groups. This suggests that for observation to induce significant suppression, it has to be preceded by active motor experience with the motor skill of interest. This result corroborates with EEG studies that have stressed the role of prior active motor experience (long- or short-term) in modulating mu responses during observation (Quandt et al., 2011, 2012, Canon et al. 2014; Orgs et al., 2008; Behmer & Jazan, 2011).

These results are also consistent with fMRI studies that have examined the effects of expertise on MNS activation during observation of movement. Calve-Marino and her colleagues studied professional and novice dancers and found that professionals exhibited stronger MNS activation during the observation of their domain-specific movements compared to movements outside their domain, whereas novice dancers showed no differences in neural responses between the two types of movements (Calvo-Merino, Glaser, Grezes, Passingham, Haggard, 2005; Calvo-Merino, Grezes, Glaser Passingham, Haggard, 2006).

Although previous PP in this study involved both hemispheres and led to the strongest suppression, previous OP was not entirely futile, as the results revealed a comparable suppression between OP and PP groups at the medial central site (i.e. CZ). The testing session in this study revealed two surprising results: first, the NP group did not exhibit any suppression at all the three central sites. Second, the suppression displayed by the PP group during observation was bilateral, whereas that exhibited by the OP group, albeit not as significant, was left lateralized. The lack of suppression among the NP group during observation is not consistent with studies in this area (Canon et al., 2014).

The results from this study suggest two possible explanations: (1) observation may not always induce suppression and; (2) the amount of visual familiarity during observation is an important factor. Because the link between mu suppression and observation is well documented, it is unlikely that observation would not trigger any suppression. Therefore, it is possible that the five visual trials during the testing session were insufficient to activate MNS in this group. Previous research has shown that the amount of visual familiarity may modulate mu suppression during observation (Ruther, Brown, Klepp, Bellebaum, 2014). Thus, increasing the number of trials during subsequent observation could have resulted in a certain level of suppression across all three groups, with the group that had prior active experience exhibiting the greatest response. More research is needed to clarify the possible link between the amount of visual familiarity (i.e., manipulating the number of visual trials following short-term practice) and the magnitude of mu suppression.

The second surprising result was that the activation during the five visual trials was bilateral after PP and left lateralized after OP. This raises a question of whether observation involves one hemisphere or whether there are other factors mediating the observation-induced hemispheric suppression. Given that the displayed five trials during the testing session reflected the model's near perfect performance, was the bilateral effect a result of previous PP or was it a product of watching a more skilled model? The first assumption suggests that observation preceded with OP and without PP, activates only a subset of brain regions, which also explains the lateralized effect during visual training. The second assumption holds that perhaps watching near-perfect or error-free performances (i.e., skilled model), equally involves both sides of the brain as it "engages cognitive processes similar to those that occur during action execution and physical practice" (Heyes & Foster, 2002, p. 593).

In contrast, observing a novice model who is in the process of learning may be associated with a left hemispheric effect. Behavioural studies that support the use of novice models in learning paradigms showed that watching learning models engages the observer in a problem solving mode in which he/she considers all the relations between the movement patterns and their outcomes to optimize performance (Adams, 1986; Black & Wright, 2000; Buchanan & Dean, 2010; Buchanan, Ryu, Zihlman, & Wright, 2008; Hayes et al., 2010; Lee & White, 1990; McCullagh & Caird, 1990; McCullagh, & Meyer, 1997; Pollock & Lee, 1992). Given the association between the left hemisphere and relational reasoning (Goel & Dolan, 2004; Green et al., 2006; Bunge, Helskog, Wendelken, 2009; Wendelken, Chung, Bunge, 2011), the left lateralized suppression during visual training could be due to watching a novice model compared to a more bilateral effect during the observation of an experienced model.

Given that a skilled model was watched during the testing session, it is reasonable to ask why the suppression exhibited by the OP group was left lateralized. As mentioned earlier, perhaps increasing the number of visual trials would provide a clearer image of the resulted magnitude of mu suppression along with the distribution of this suppression across the two hemispheres. In light of this explanation, it is possible that the bilateral effect during observation reported by many studies in this area was because the observers viewed error-free hand movements, with no learning component. Thus, the model-hemisphere relationship might provide a possible alternative explanation for the lateralization of the suppression during observation in addition to the observation perspective and the observer's handedness. Nevertheless, these are still speculations, and a close examination of all the elements at play would provide further information on the optimal contexts of mu suppression.

4.3 Relationship between behavioural and neurophysiological measures

Although the magnitude of mu suppression for the PP group during training did not change throughout practice, overall, the performance of this group did increase significantly with subsequent blocks, in both time and error (Appendix H). This raises the question as to whether the magnitude of mu suppression is correlated positively with learning. The close examination of mu suppression during both the training and testing sessions and performance during retention indicates that mu suppression is more associated with the temporal aspect of the task rather than accuracy during both PP and OP. Given that time, as previously discussed, is what was learned in this task, it appears that mu suppression is more related to the learned measure. This proposes a possible direct relationship between mu suppression and motor learning. The direction of this relationship, however, depends on the practice type. Namely, more suppression during OP is associated with slower performance, whereas greater suppression during PP is associated with faster performance, suggesting that mu suppression may relate to each mode of learning differently.

Nevertheless, when comparing the groups, the relationship between mu suppression and time-related learning becomes less clear – the pattern of suppression does not echo the pattern of behaviour. The mu responses exhibited by the OP group over the right hemisphere during the training session and that over both hemispheres during the testing session were less stronger than that showed by the PP group. Similarly, the mu responses displayed by the NP group over both hemispheres during the testing session were less in magnitude than that of the PP group. However, all the three groups spent approximately the same amount of time to complete the task during retention. Taken together, these results suggest that more suppression does not necessarily predict better performance during retention and vice versa. The discrepancy between behavioural measures and mu responses serve to question the candidacy of mu suppression as an index of learning.

It is difficult, given these equivocal results, to form a coherent picture of the relationship between mu suppression and learning in the context of this motor task. Research has shown that more implicit motor tasks are more likely to involve the motor system (Maslovat et al., 2010) and consequently yield stronger mu suppression. In implicit motor tasks, it is more difficult for observers to perceive changes in performance and hence strategic understanding is not an option. In such tasks, mu suppression would be more reflective of the observers' learning. Based on the participants' reports following the retention session, it appears that it was relatively easy for the observers to deduce strategies required to do better in the task, especially in terms of time. Therefore, mu suppression may not be the best predictor of the observers' learning in this particular task. Because this study is the first to examine mu suppression changes as a function of practice, more research is needed to clarify the relationship between these two constructs by employing tasks with various degrees of implicitness. Moreover, examining the parietal electrodes would shed more light on the nature of the relationship between learning and mu suppression, as research has shown that observing actions with the intention to subsequently imitate them is associated with increased activity in the right *intraparietal* sulcus (Frey & Gerry, 2006). The authors found that the accuracy by which the observed actions were performed was influenced by the activation within this region only.

4.4 Limitations

This study has some limitations. One of these limitations is the accuracy-speed trade-off. Due to this problem, any increase in one measure could be attributed to a decrease in the other, and not to the examined construct. However, this trade-off did not explain the obtained results in this study. For example, when comparing the three groups during retention, if accuracy-speed trade-off were evident, one would expect the PP group to be slower than the other groups because they made the least number of errors. However, this group did not make the least number of errors because they were slower in the task, as the three groups spent on average the same amount of time in tracing. Similarly, when comparing the PP group during training with both the OP and NP groups during retention, the three groups did not differ in error, yet the OP was the fastest. Therefore, the accuracy-related advantage of PP over the other conditions during retention and the time-related benefit of OP over PP were not due to the speed-accuracy trade-off. However, fixing one measure of the task to examine the changes in the other would rule out any possible trade-off influences and narrow down the alternative explanations of the observed effects.

Monitoring the observers' motion only via a video camera, without a stringent control for muscle activation has introduced another limitation. Although the activation during PP was different from that during OP, there is still a possibility that the left lateralized effect could be due to muscle activation. To avoid such confounding effects, future studies should use electromyography (EMG) to accurately detect any possible movement.

An alternative explanation of the unaffected magnitude of mu suppression throughout both types of practice in this study could be the number of training trials was insufficient (i.e., 45 trials). This number was used because the participants' performance in the learning curve trials leveled out (i.e., plateaued) around the 45th trial. This number was also used because there was a concern that more trials would cause the participants possible discomfort with the EEG net, which in turn could affect their performance. Nevertheless, plateaus do not indicate the absence of learning, as research has shown that this period may reflect a lack of interest, fatigue, or a transition to higher levels of learning, and that learning continues to occur beyond this stage (Adams, 1987). Consequently, increasing the number of the practice trials would provide a more accurate account of the relationship between mu responses and motor learning. Moreover, the absence of changes in mu suppression magnitude during practice could be because of the small sample size (10 per group). As showed by a recent meta-analysis on the validity of mu suppression as an index of MNS activity (Fox et al., 2016), increasing the sample size may provide a clearer image of the strength of MNS activation and allow for actual changes, if any, to occur.

Finally, although mu rhythm is mainly described as EEG oscillations at the frequency range of 8-13Hz, some authors limited mu rhythm to the frequency band of 8-10Hz (e.g., Pineda, 2005). EEG research has identified two frequency ranges within the alpha range (8-13Hz): the lower alpha (8-10) Hz and the upper alpha (10-13) Hz. The lower alpha emanates from the somatosensory cortex and is modulated by motor activity, showing a more anterior and asymmetrical hemispheric effect. The upper band, in contrast, consists of posterior bilateral waves, which cluster mainly around the parieto-occipital cortices, and is primarily modulated by visual stimulation (Cochin et al., 1998; Pfurtscheller, Neuper, & Krausz, 2000; Perry & Bentin, 2009). Given that, the observed suppression in this study could be a result of visual stimulation or motor activation or both. Examining each component separately would shed more light on both the hemispheric activation and the source of stimulation.

4.5 Conclusions

Overall, this study demonstrates that OP induces neurophysiological changes as indexed by mu suppression at central sites, which provides evidence for motor-based processes underling the information transfer during observational practice. However, the lateralized suppression during the observational practice suggests that these processes might not be entirely motor-based, and that cognitive strategies may be at play. Moreover, the lateralized activation during OP and the bilateral activation during PP at the central sites suggest that OP does not trigger all brain areas activated during PP. Therefore, OP cannot replace PP, but it could be used as a substitute when PP is not possible. This is an important finding of this study that has significant implications for rehabilitation, particularly in the early stages of recovery. Moreover, this study confirms the vital role of previous motor experience in modulating mu responses during observation, suggesting that employing movements that are within the observer's motor repertoire are more likely to result in the optimal activation. However, albeit to a lesser extent, observers could benefit from watching movements that they have previous visual experience with.

Furthermore, it appears that the relationship between mu suppression and learning is dependent on the practice type. This, along with the finding that different hemispheric effect is associated with each type of practice, suggests that although these two modes of learning might share some similarities, the underlying mechanisms by which each of them operates might be different. To better understand the relationship between mu responses and motor learning during the OP, future research should address all factors that could influence this relationship. Specifically, future studies should consider the effect of handedness, observation perspective, the amount of visual familiarity, the model's expertise, and task implicitness. These factors would further our understanding of the processes underlying this mode of learning, and hence help optimize its utilization in rehabilitation settings.

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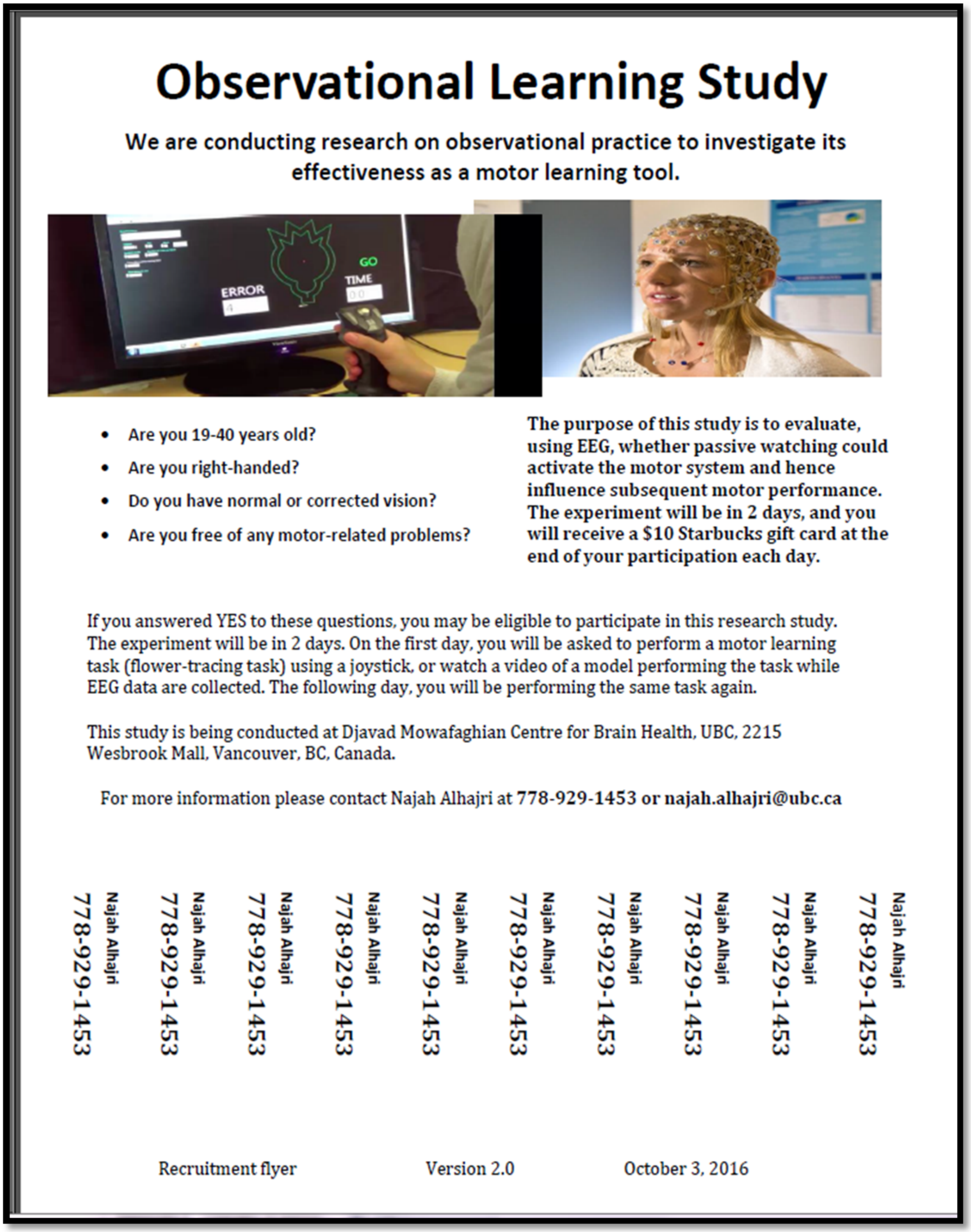
Appendices

Appendix A **Recruitment flyer**



Observational Learning Study

We are conducting research on observational practice to investigate its effectiveness as a motor learning tool.

- Are you 19-40 years old?
- Are you right-handed?
- Do you have normal or corrected vision?
- Are you free of any motor-related problems?

The purpose of this study is to evaluate, using EEG, whether passive watching could activate the motor system and hence influence subsequent motor performance. The experiment will be in 2 days, and you will receive a $10 Starbucks gift card at the end of your participation each day.

If you answered YES to these questions, you may be eligible to participate in this research study. The experiment will be in 2 days. On the first day, you will be asked to perform a motor learning task (flower-tracing task) using a joystick, or watch a video of a model performing the task while EEG data are collected. The following day, you will be performing the same task again.

This study is being conducted at Djavad Mowafaghian Centre for Brain Health, UBC, 2215 Wesbrook Mall, Vancouver, BC, Canada.

For more information please contact Najah Alhajri at **778-929-1453 or najah.alhajri@ubc.ca**

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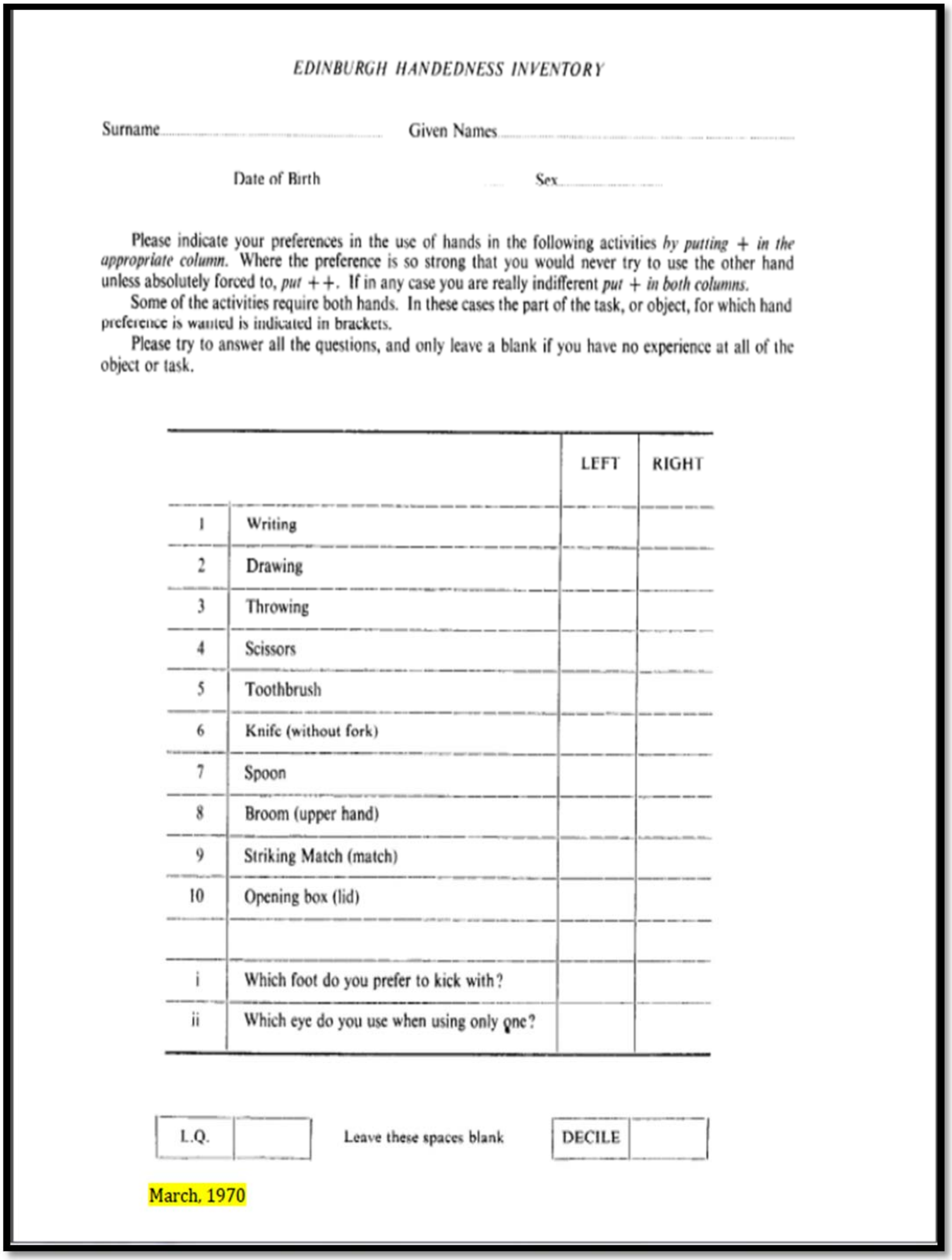
Recruitment flyer Version 2.0 October 3, 2016

Appendix B **Edinburgh Handedness inventory**



EDINBURGH HANDEDNESS INVENTORY

Surname.. Given Names..

Date of Birth Sex..............................

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column.* Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put ++.* If in any case you are really indifferent *put + in both columns.*

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

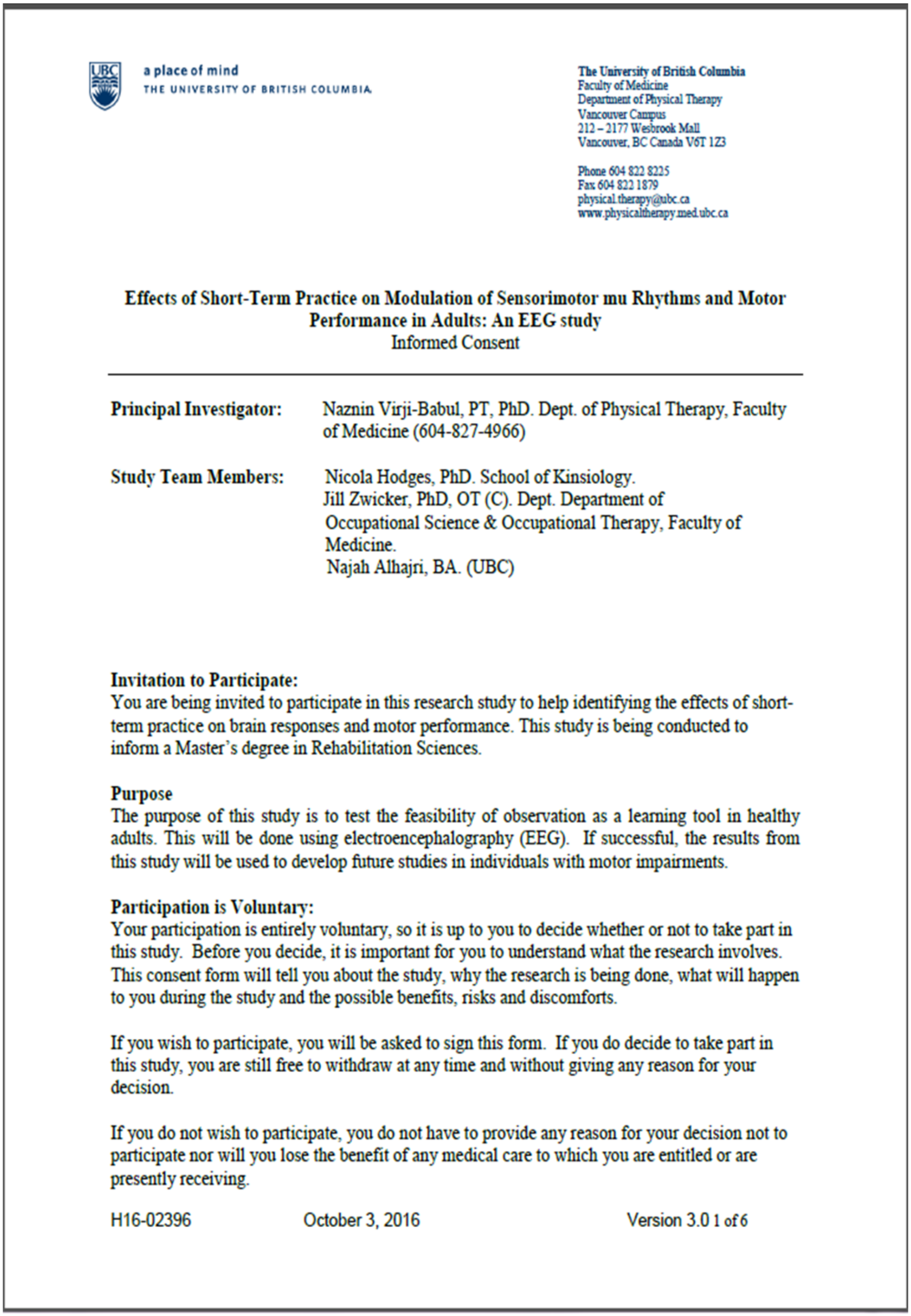
Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	DECILE	

March, 1970

Appendix C **Consent from**



a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

The University of British Columbia
Faculty of Medicine
Department of Physical Therapy
Vancouver Campus
212 – 2177 Wesbrook Mall
Vancouver, BC Canada V6T 1Z3

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Effects of Short-Term Practice on Modulation of Sensorimotor mu Rhythms and Motor Performance in Adults: An EEG study

Informed Consent

Principal Investigator: Naznin Virji-Babul, PT, PhD. Dept. of Physical Therapy, Faculty of Medicine (604-827-4966)

Study Team Members:
Nicola Hodges, PhD. School of Kinsiology.
Jill Zwicker, PhD, OT (C). Dept. Department of Occupational Science & Occupational Therapy, Faculty of Medicine.
Najah Alhajri, BA. (UBC)

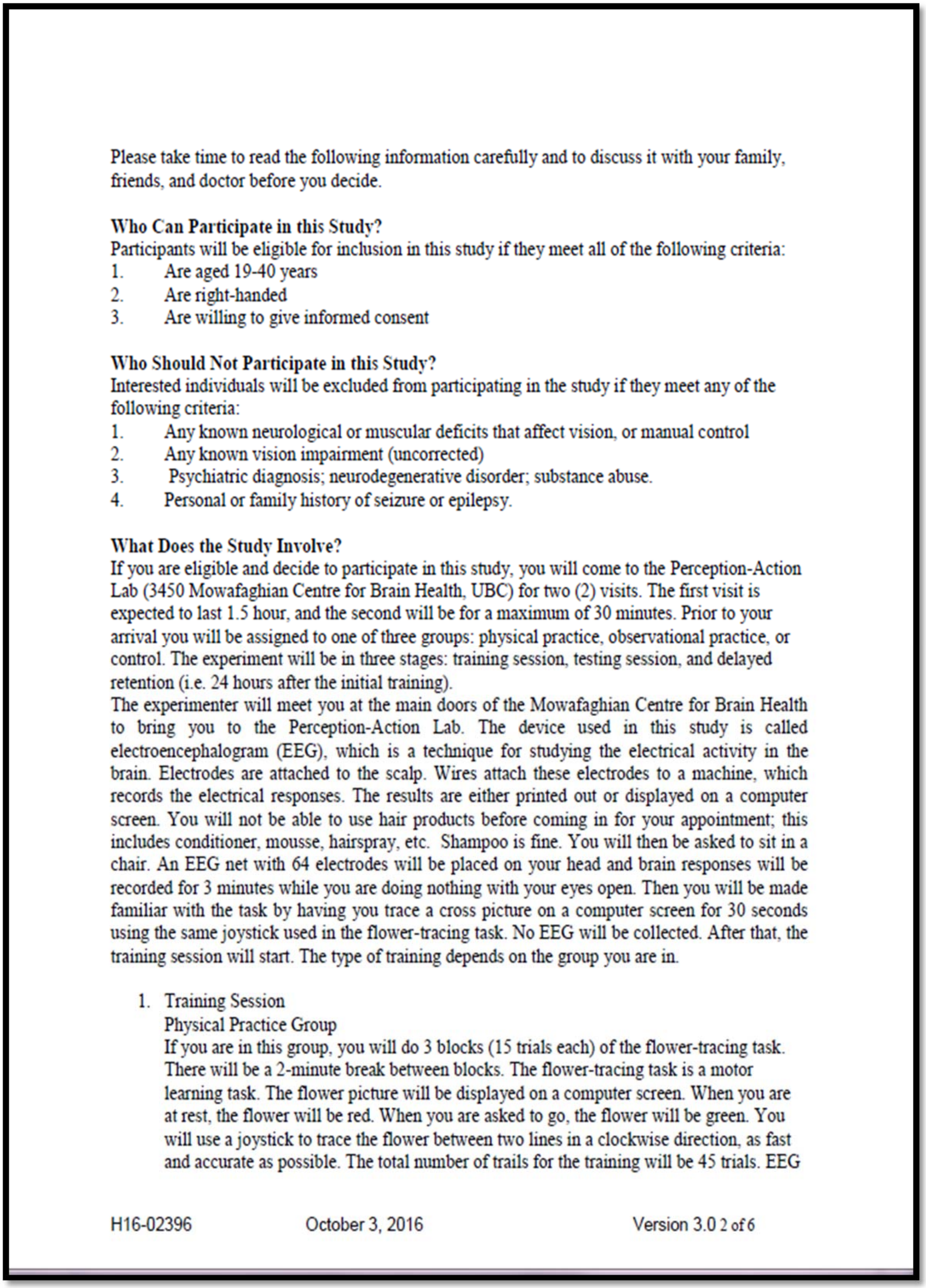
Invitation to Participate:
You are being invited to participate in this research study to help identifying the effects of short-term practice on brain responses and motor performance. This study is being conducted to inform a Master's degree in Rehabilitation Sciences.

Purpose
The purpose of this study is to test the feasibility of observation as a learning tool in healthy adults. This will be done using electroencephalography (EEG). If successful, the results from this study will be used to develop future studies in individuals with motor impairments.

Participation is Voluntary:
Your participation is entirely voluntary, so it is up to you to decide whether or not to take part in this study. Before you decide, it is important for you to understand what the research involves. This consent form will tell you about the study, why the research is being done, what will happen to you during the study and the possible benefits, risks and discomforts.

If you wish to participate, you will be asked to sign this form. If you do decide to take part in this study, you are still free to withdraw at any time and without giving any reason for your decision.

If you do not wish to participate, you do not have to provide any reason for your decision not to participate nor will you lose the benefit of any medical care to which you are entitled or are presently receiving.



Please take time to read the following information carefully and to discuss it with your family, friends, and doctor before you decide.

Who Can Participate in this Study?

Participants will be eligible for inclusion in this study if they meet all of the following criteria:

1. Are aged 19-40 years
2. Are right-handed
3. Are willing to give informed consent

Who Should Not Participate in this Study?

Interested individuals will be excluded from participating in the study if they meet any of the following criteria:

1. Any known neurological or muscular deficits that affect vision, or manual control
2. Any known vision impairment (uncorrected)
3. Psychiatric diagnosis; neurodegenerative disorder; substance abuse.
4. Personal or family history of seizure or epilepsy.

What Does the Study Involve?

If you are eligible and decide to participate in this study, you will come to the Perception-Action Lab (3450 Mowafaghian Centre for Brain Health, UBC) for two (2) visits. The first visit is expected to last 1.5 hour, and the second will be for a maximum of 30 minutes. Prior to your arrival you will be assigned to one of three groups: physical practice, observational practice, or control. The experiment will be in three stages: training session, testing session, and delayed retention (i.e. 24 hours after the initial training).

The experimenter will meet you at the main doors of the Mowafaghian Centre for Brain Health to bring you to the Perception-Action Lab. The device used in this study is called electroencephalogram (EEG), which is a technique for studying the electrical activity in the brain. Electrodes are attached to the scalp. Wires attach these electrodes to a machine, which records the electrical responses. The results are either printed out or displayed on a computer screen. You will not be able to use hair products before coming in for your appointment; this includes conditioner, mousse, hairspray, etc. Shampoo is fine. You will then be asked to sit in a chair. An EEG net with 64 electrodes will be placed on your head and brain responses will be recorded for 3 minutes while you are doing nothing with your eyes open. Then you will be made familiar with the task by having you trace a cross picture on a computer screen for 30 seconds using the same joystick used in the flower-tracing task. No EEG will be collected. After that, the training session will start. The type of training depends on the group you are in.

1. Training Session

   Physical Practice Group

   If you are in this group, you will do 3 blocks (15 trials each) of the flower-tracing task. There will be a 2-minute break between blocks. The flower-tracing task is a motor learning task. The flower picture will be displayed on a computer screen. When you are at rest, the flower will be red. When you are asked to go, the flower will be green. You will use a joystick to trace the flower between two lines in a clockwise direction, as fast and accurate as possible. The total number of trails for the training will be 45 trials. EEG signals will be recorded.

Observational Practice (OP) Group

If you are in this group, you will watch a video of a model doing the flower-tracing task. The session will be divided into three blocks; each block will have 15 trials with a 2-minute break between blocks. The total number of trails for the observational training will be 45 trials. You should not move during the session. The session will be videotaped to monitor any movement. EEG signals will be recorded.

Control group

If you are in the control group, you will not have any training. After the familiarization you will enter the testing session immediately.

2. Testing Session

   During the testing session, you will watch a video of a model doing the last five trials of the flower-tracing task. EEG data will be collected and the session will be videotaped.

3. Delayed retention

   In the delayed retention (i.e. 24 hours after initial training), you will be doing 3 blocks of the flower-tracing task (15 trials each) with a 2-minute break between blocks. The total number of trails for the training will be 45 trials. No EEG data will be recorded.

   Once the two days of testing is complete, your participation is complete.

What Are Possible Harms and Side-Effects of Participation?

The risks are not greater than the risks in everyday life. These procedures will be conducted according to published safety standards. Dr. Virji-Babul or her associates have discussed this research with you and have described them as follows:

<u>Electroencephalography (EEG)</u>: Collection of EEG involves the placement of surface electrodes on your skin. This allows for the detection of electrical brain signals. You will feel little or no discomfort during EEG recording. The EEG only measures electrical brain activity and will not transmit any sensations. Although EEG electrodes cause no permanent skin damage, they may leave red marks when removed, which fade in minutes.

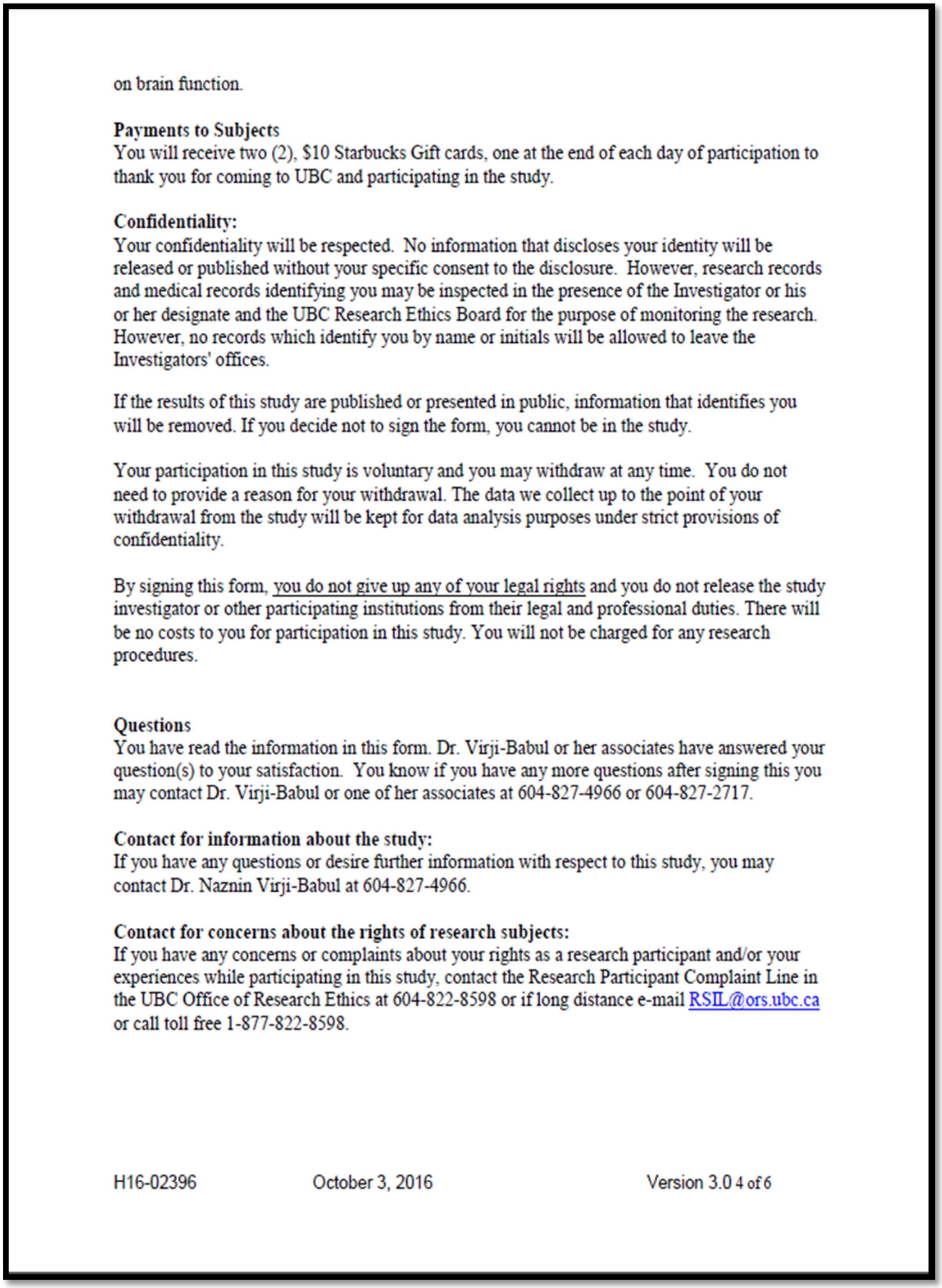
<u>The task</u>

You will be asked to perform 3 blocks (15 trials each) of flower-tracing task using a joystick, or observing video clips of a model performing the task. This may cause some physical discomfort. However, if at any point during the sessions you feel the need to stop, the session will be stopped immediately.

There may be other risks that have not yet been identified, and unexpected side effects that have not been previously observed may occur.

What are the Benefits to You of Participating in the Study?

There is no direct benefit to you for participating in this study. It is hoped that information gained in this research study may be useful in understanding the impact of observational training



on brain function.

Payments to Subjects
You will receive two (2), $10 Starbucks Gift cards, one at the end of each day of participation to thank you for coming to UBC and participating in the study.

Confidentiality:
Your confidentiality will be respected. No information that discloses your identity will be released or published without your specific consent to the disclosure. However, research records and medical records identifying you may be inspected in the presence of the Investigator or his or her designate and the UBC Research Ethics Board for the purpose of monitoring the research. However, no records which identify you by name or initials will be allowed to leave the Investigators' offices.

If the results of this study are published or presented in public, information that identifies you will be removed. If you decide not to sign the form, you cannot be in the study.

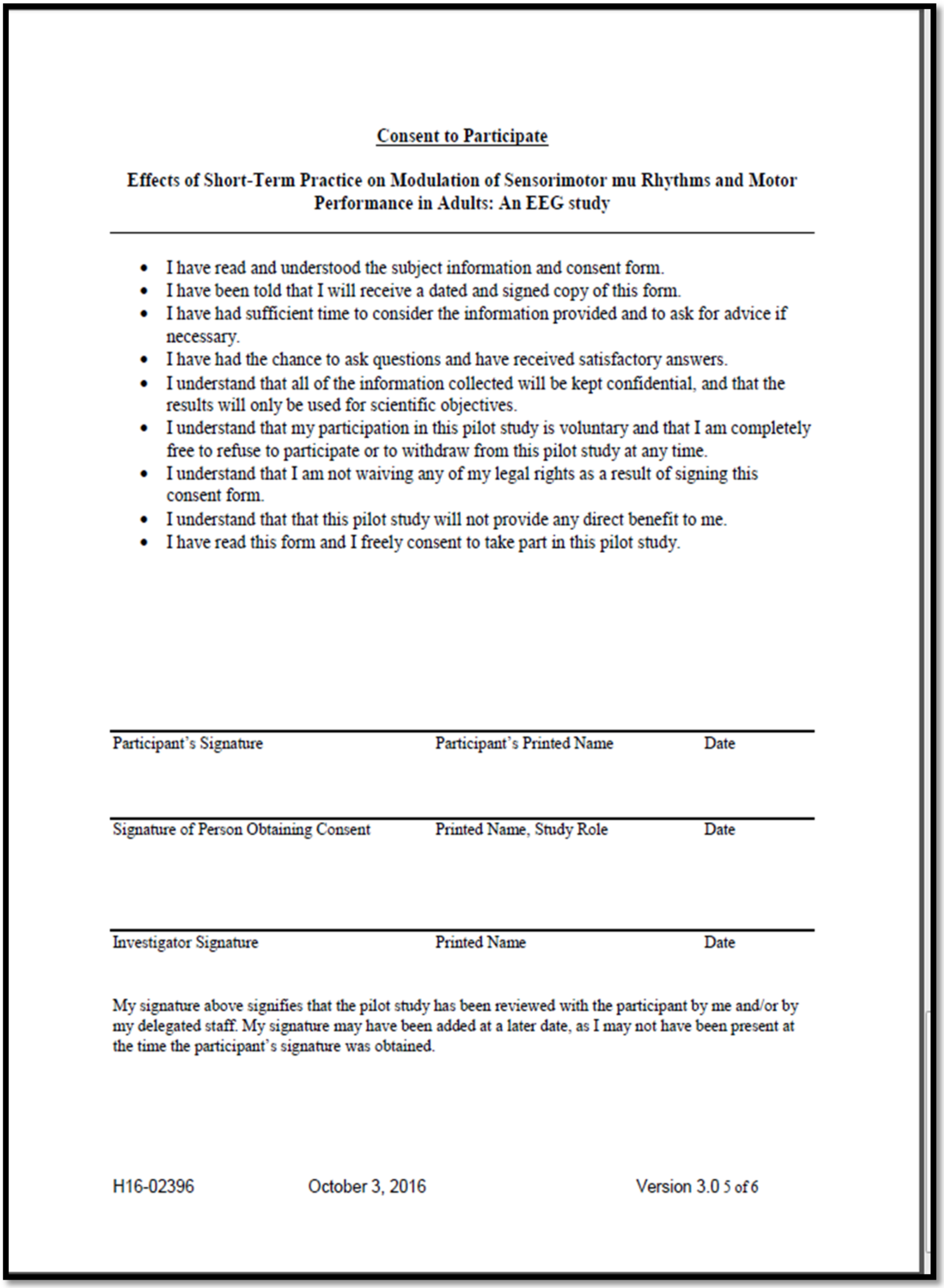
Your participation in this study is voluntary and you may withdraw at any time. You do not need to provide a reason for your withdrawal. The data we collect up to the point of your withdrawal from the study will be kept for data analysis purposes under strict provisions of confidentiality.

By signing this form, you do not give up any of your legal rights and you do not release the study investigator or other participating institutions from their legal and professional duties. There will be no costs to you for participation in this study. You will not be charged for any research procedures.

Questions
You have read the information in this form. Dr. Virji-Babul or her associates have answered your question(s) to your satisfaction. You know if you have any more questions after signing this you may contact Dr. Virji-Babul or one of her associates at 604-827-4966 or 604-827-2717.

Contact for information about the study:
If you have any questions or desire further information with respect to this study, you may contact Dr. Naznin Virji-Babul at 604-827-4966.

Contact for concerns about the rights of research subjects:
If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.



Consent to Participate

Effects of Short-Term Practice on Modulation of Sensorimotor mu Rhythms and Motor Performance in Adults: An EEG study

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- I have read and understood the subject information and consent form.
- I have been told that I will receive a dated and signed copy of this form.
- I have had sufficient time to consider the information provided and to ask for advice if necessary.
- I have had the chance to ask questions and have received satisfactory answers.
- I understand that all of the information collected will be kept confidential, and that the results will only be used for scientific objectives.
- I understand that my participation in this pilot study is voluntary and that I am completely free to refuse to participate or to withdraw from this pilot study at any time.
- I understand that I am not waiving any of my legal rights as a result of signing this consent form.
- I understand that that this pilot study will not provide any direct benefit to me.
- I have read this form and I freely consent to take part in this pilot study.

Participant's Signature	Participant's Printed Name	Date
Signature of Person Obtaining Consent	Printed Name, Study Role	Date
Investigator Signature	Printed Name	Date

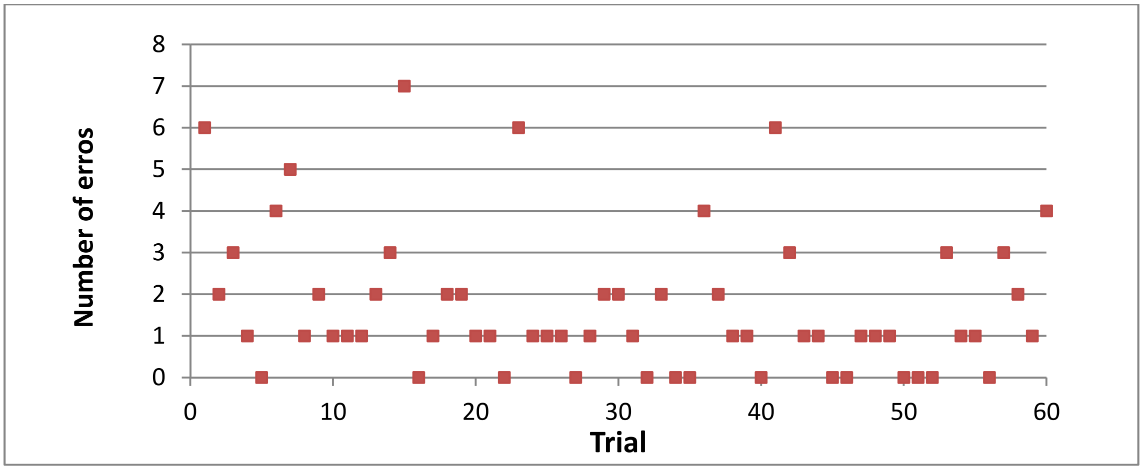
My signature above signifies that the pilot study has been reviewed with the participant by me and/or by my delegated staff. My signature may have been added at a later date, as I may not have been present at the time the participant's signature was obtained.

H16-02396 October 3, 2016 Version 3.0 5 of 6

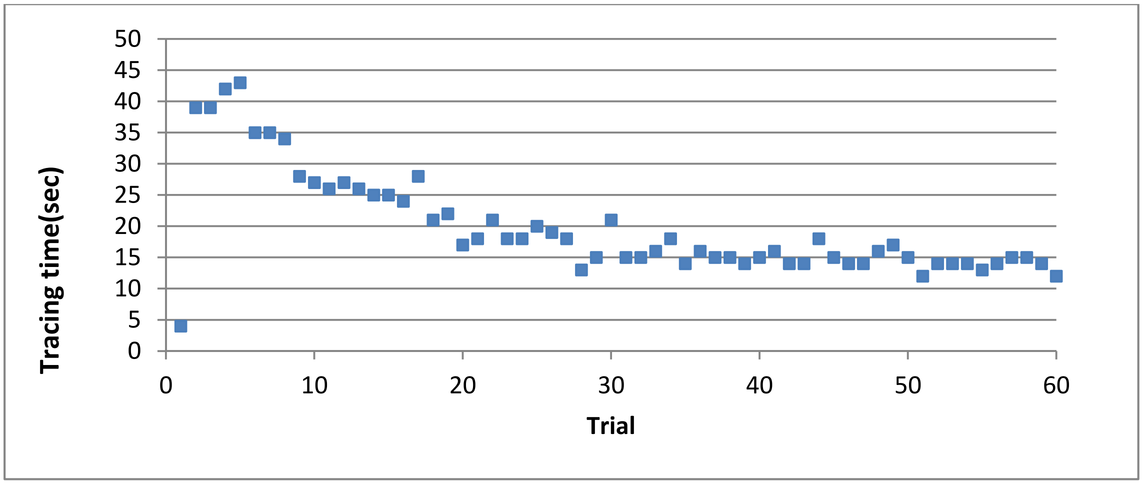
Appendix D **The learning curve of the flower-tracing task**

Performance leveled out around the 45th trial.

1. Number of errors



2. Total tracing time



Appendix E **Means and standard deviations for the tracing time and number of errors**

Means and Standard deviations of the number of errors for PP, OP, and NP groups during retention (first 10 trials).

	PP (*N* =10)		OP (*N* =10)		NP (*N* = 10)	
Trial	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	5.80	4.96	10.20	4.18	10.30	4.16
2	4.30	5.29	10.00	2.98	10.30	2.83
3	2.20	2.25	6.30	3.56	7.80	2.78
4	2.80	2.70	7.40	3.60	8.30	5.96
5	3.40	3.34	6.70	2.54	6.20	2.70
6	2.20	1.69	4.70	3.59	5.40	1.35
7	3.10	3.73	5.70	4.14	7.00	2.31
8	2.30	1.70	6.10	2.33	6.60	2.88
9	2.90	2.38	4.30	2.06	5.20	3.55
10	3.10	3.28	5.00	4.11	4.70	3.68

Means and Standard deviations of the tracing time for PP, OP, and NP groups during retention (first 10 trials).

	PP (*N* =10)		OP (*N* = 10)		NP (*N* = 10)	
Trial	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	23.80	6.18	24.80	7.24	28.80	6.01
2	24.70	6.70	22.10	5.36	26.40	8.77
3	24.50	7.15	21.80	5.71	25.60	7.72
4	23.00	6.93	21.20	5.43	25.30	3.71
5	22.80	5.96	21.00	4.62	22.80	4.56
6	24.70	8.23	22.20	6.25	23.80	4.87
7	24.00	7.26	20.60	6.43	24.00	6.57
8	23.60	7.24	20.30	5.58	23.90	6.30
9	21.80	7.83	20.50	5.21	23.80	6.21
10	23.20	6.96	21.20	4.92	23.40	6.29

Means and Standard deviations of the number of errors for PP group during training, and OP and NP groups during retention.

	PP (*N* =10)		OP (*N* =10)		NP (*N* =10)	
Trial	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	8.60	4.88	10.20	4.18	10.30	4.16
2	7.60	5.87	10.00	2.98	10.30	2.83
3	6.70	4.30	6.30	3.56	7.80	2.78
4	5.30	4.47	7.40	3.60	8.30	5.96
5	4.40	2.91	6.70	2.54	6.20	2.70
6	3.20	2.49	4.70	3.59	5.40	1.35
7	5.20	5.63	5.70	4.14	7.00	2.31
8	4.00	2.98	6.10	2.33	6.60	2.88
9	3.20	3.58	4.30	2.06	5.20	3.55
10	3.00	3.56	5.00	4.11	4.70	3.68

Means and Standard deviations of the tracing time for PP group during training, and OP and NP groups during retention (first 10 trials).

	PP (*N* =10)		OP (*N* = 10)		NP (*N* = 10)	
Trial	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	31.60	5.02	24.80	7.24	28.80	6.01
2	29.30	5.14	22.10	5.36	26.40	8.77
3	26.80	5.49	21.80	5.71	25.60	7.72
4	26.90	4.40	21.20	5.43	25.30	3.71
5	27.30	4.95	21.00	4.62	22.80	4.56
6	27.60	4.14	22.20	6.25	23.80	4.87
7	27.50	3.63	20.60	6.43	24.00	6.57
8	27.70	3.53	20.30	5.58	23.90	6.30
9	27.20	5.05	20.50	5.21	23.80	6.21
10	26.70	5.38	21.20	4.92	23.40	6.29

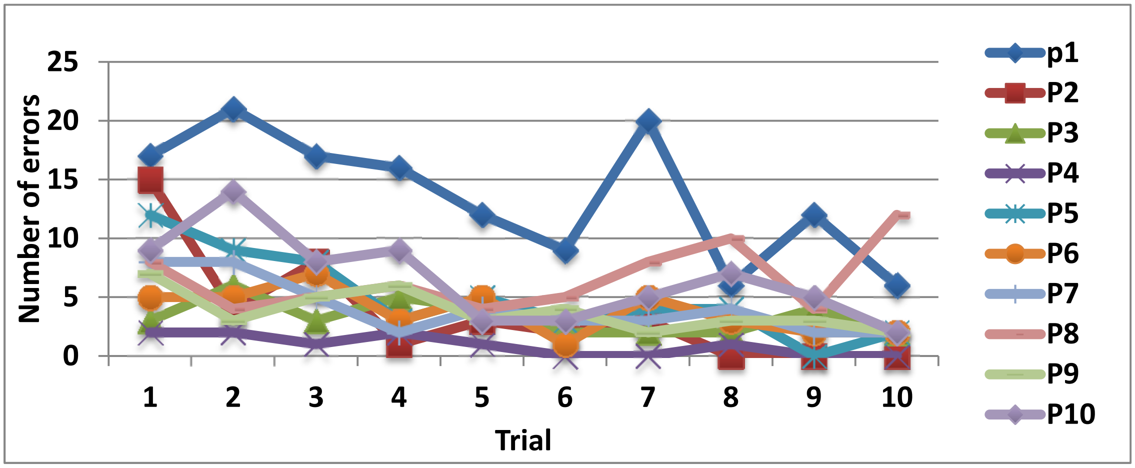
Mixed ANOVA results on comparing MSI across electrodes and blocks for PP and OP groups

Factors	*df*	*F*	η^2	*p*
Electrode	2	1.05	0.055	0.362
Block	2	1.14	0.059	0.333
Group	1	2.78	0.134	0.113
Block*Group	2	0.79	0.042	0.463
Electrode*Group	2	1.36	0.070	0.269
Block*Electrode	4	0.45	0.024	0.775
Electrode*Group*Block	4	0.01	0.001	<0.99

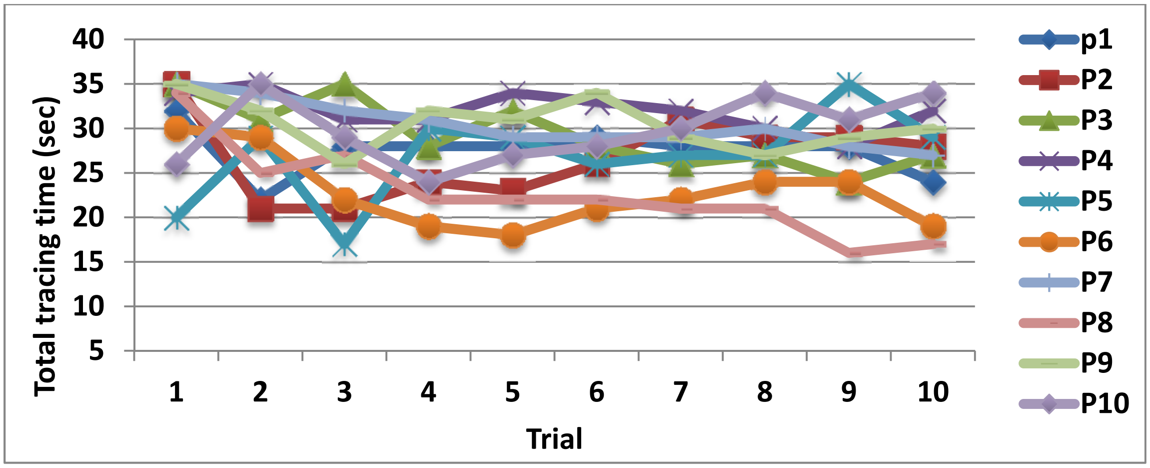
Appendix F **Changes in performance across the first 10 trials of training and retention for each participant of PP, OP, and NP groups**

F.1 Training session (PP group)

1. Error



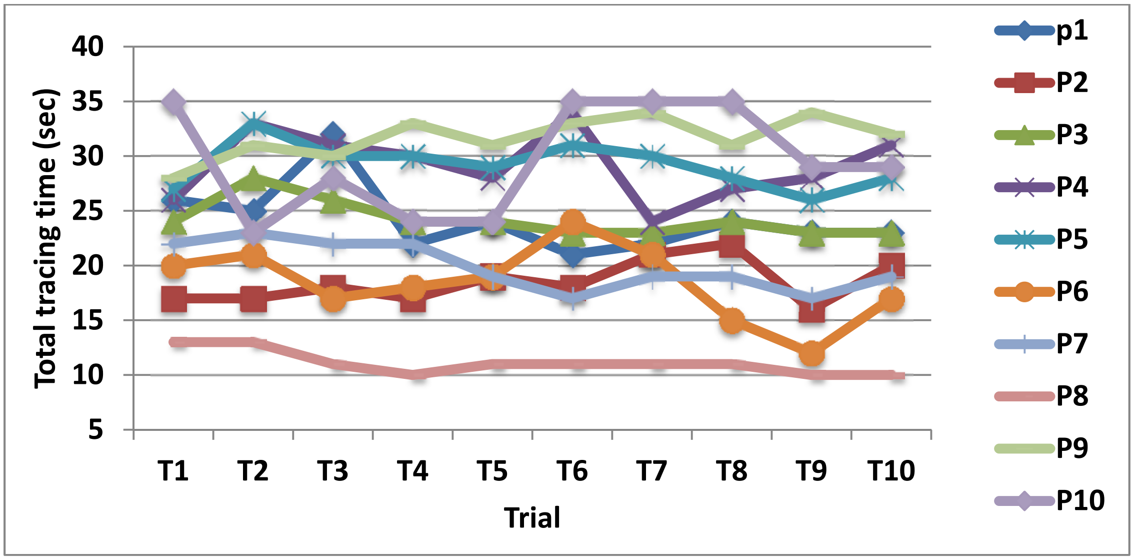
2. **Time**



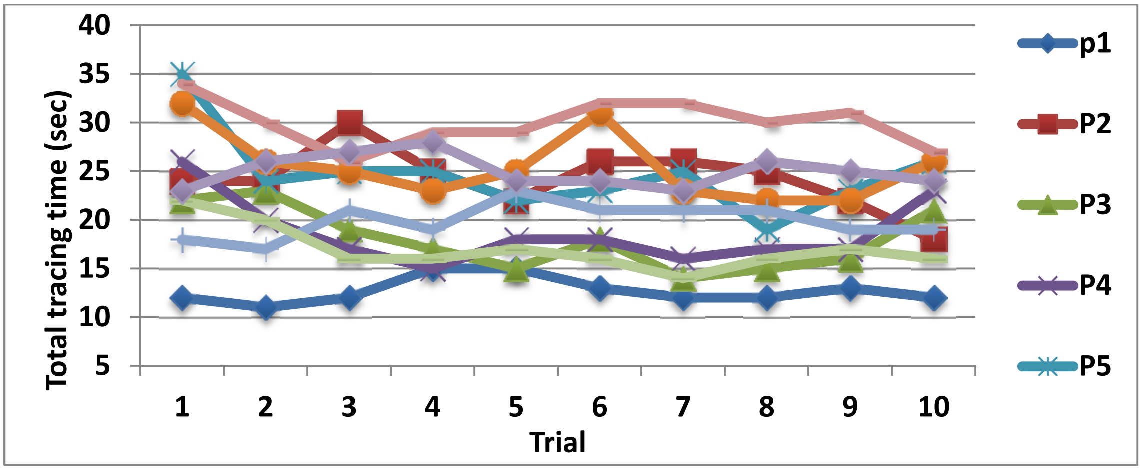
F.2 Retention session

1. Time

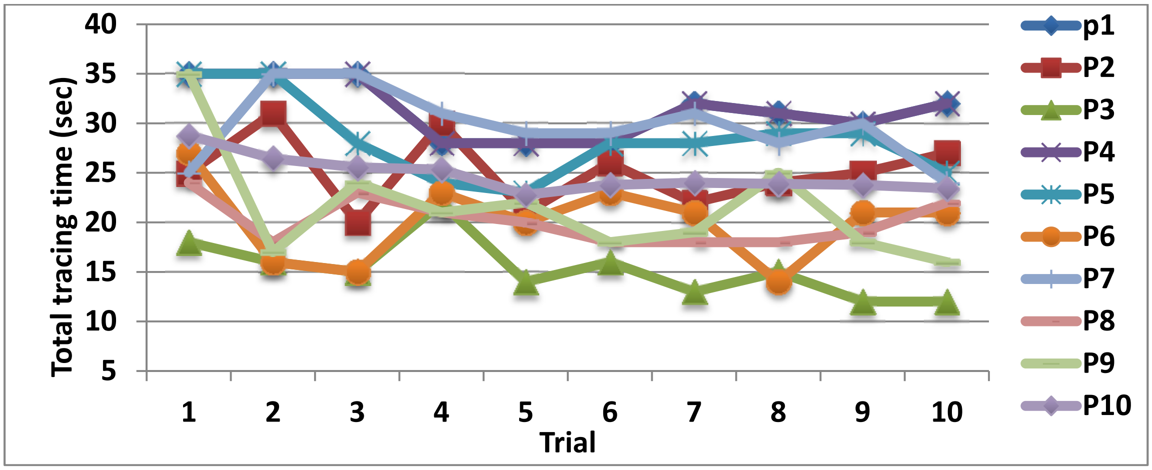
PP group



OP Group

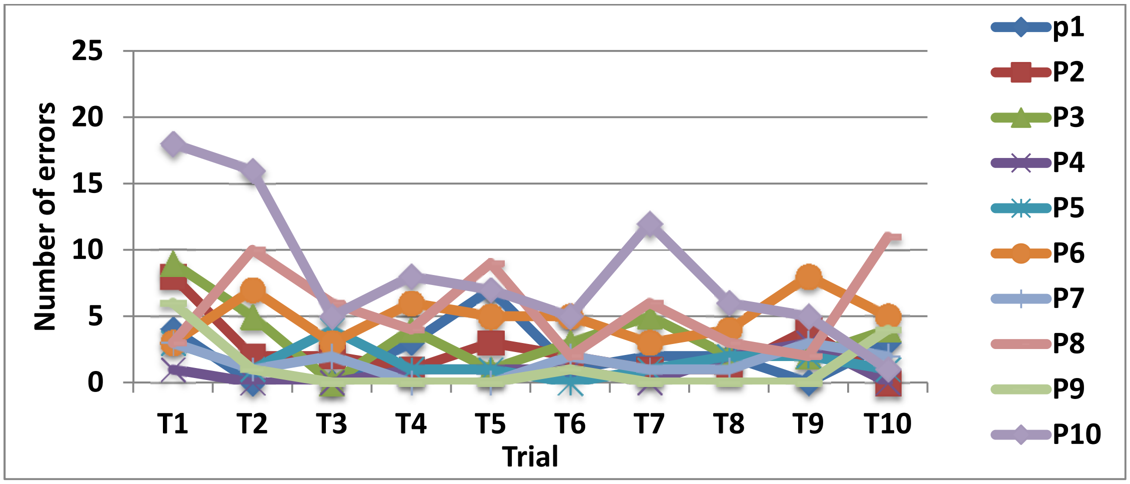


NP Group

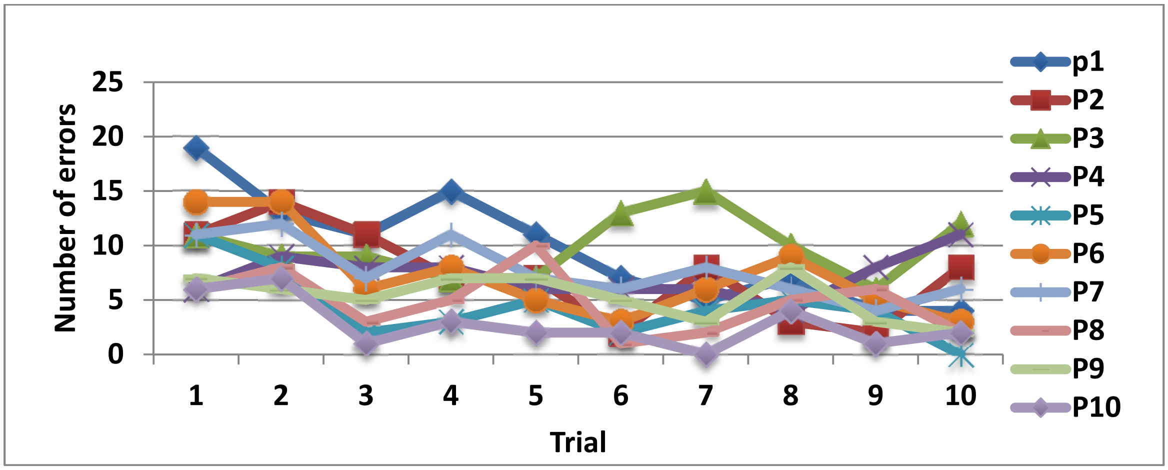


2. Error

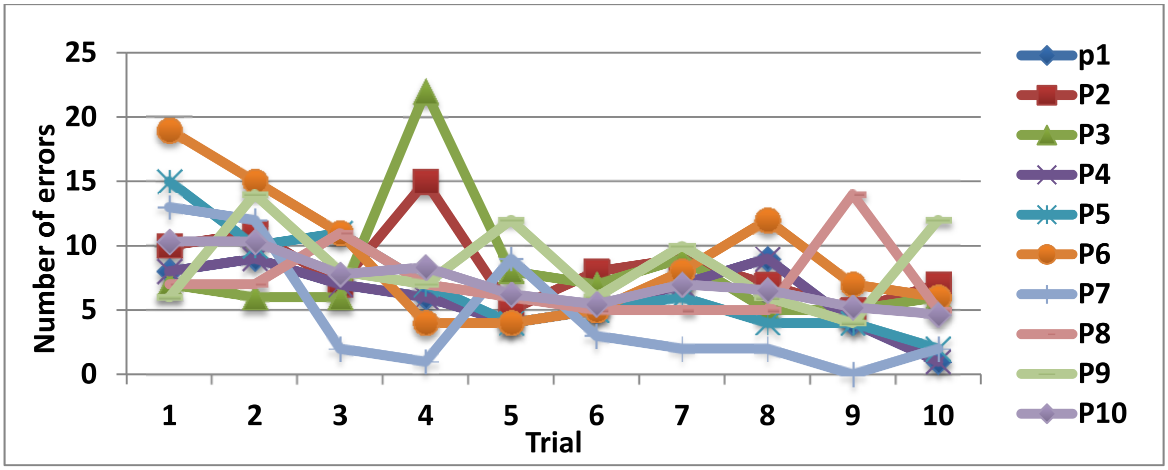
PP group



OP group



NP group

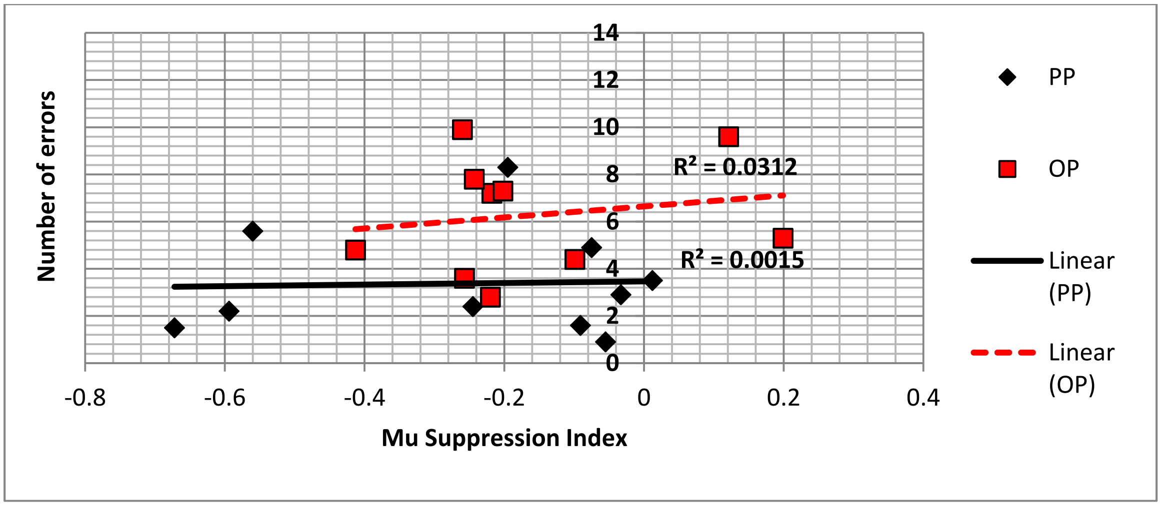


Appendix G **Graphic representation of the relationships between mu suppression at central electrodes and performance during training and testing sessions**

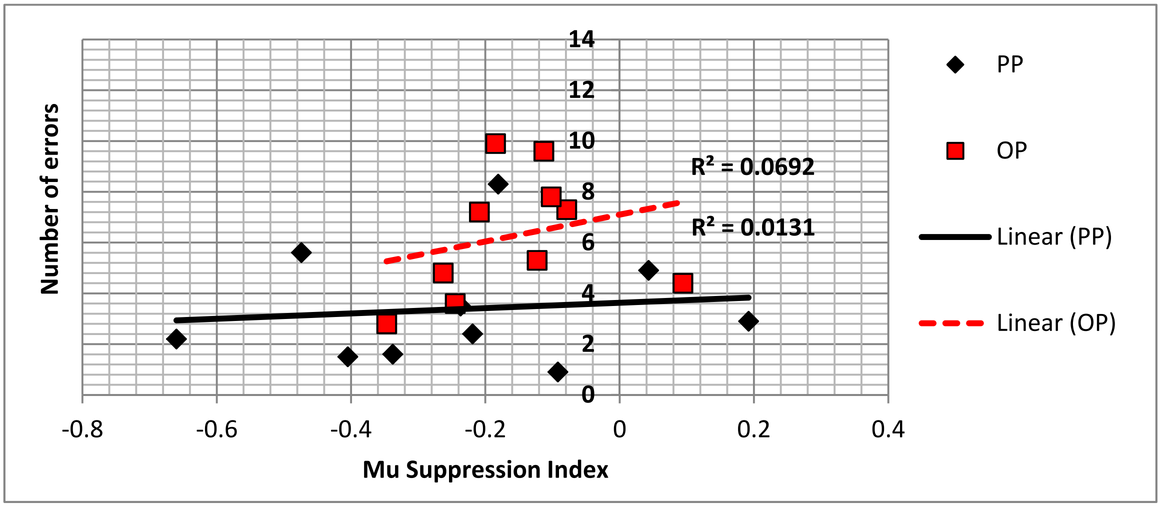
G.1 The relationship between mu suppression during training session and performance during retention PP and OP groups: Time & error

1. Error

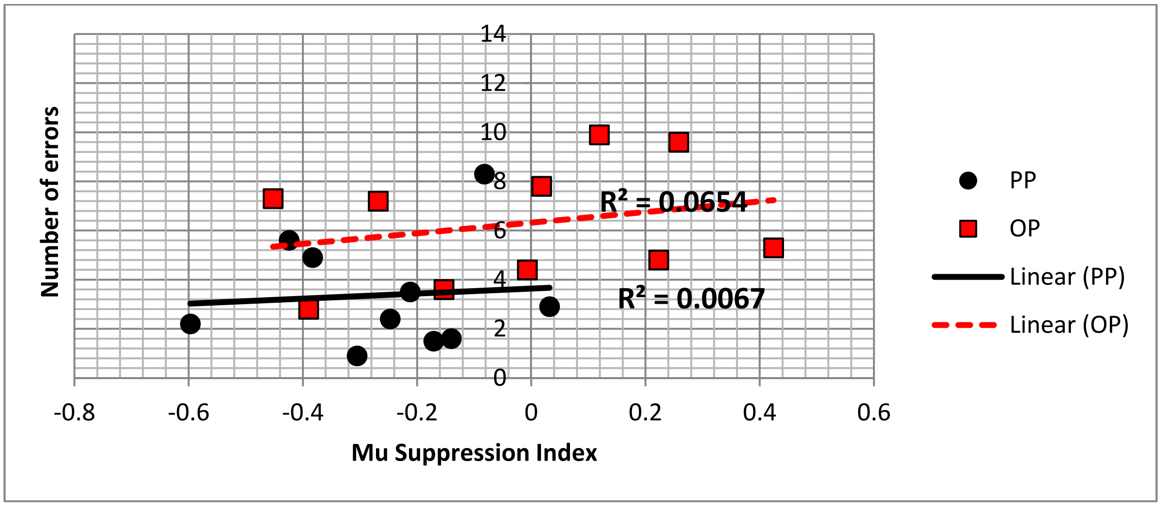
   a. At C3 (Central left hemisphere)



   b. At CZ (Central medial)

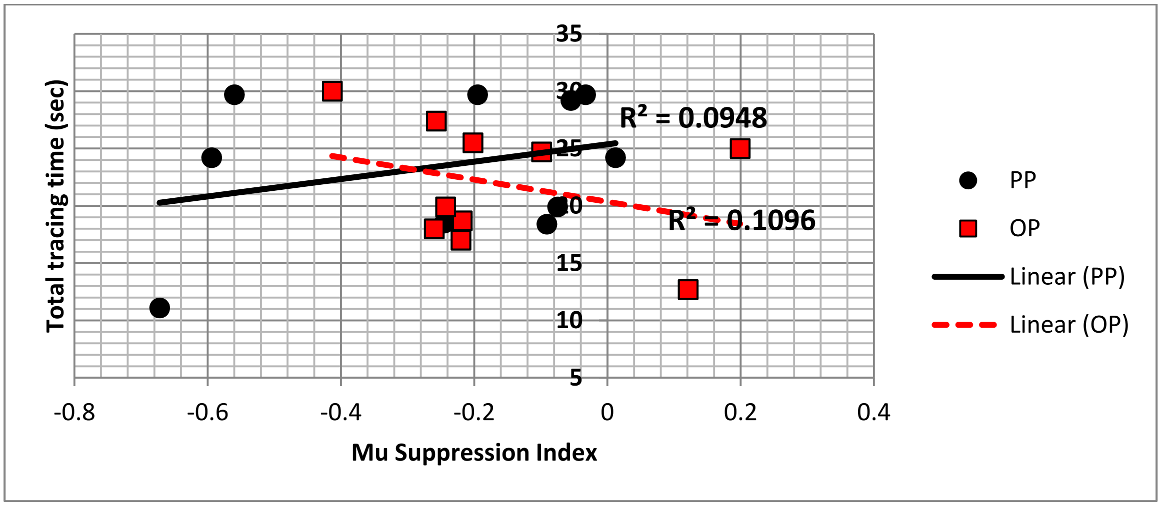


c. At C4 (Central right hemisphere)

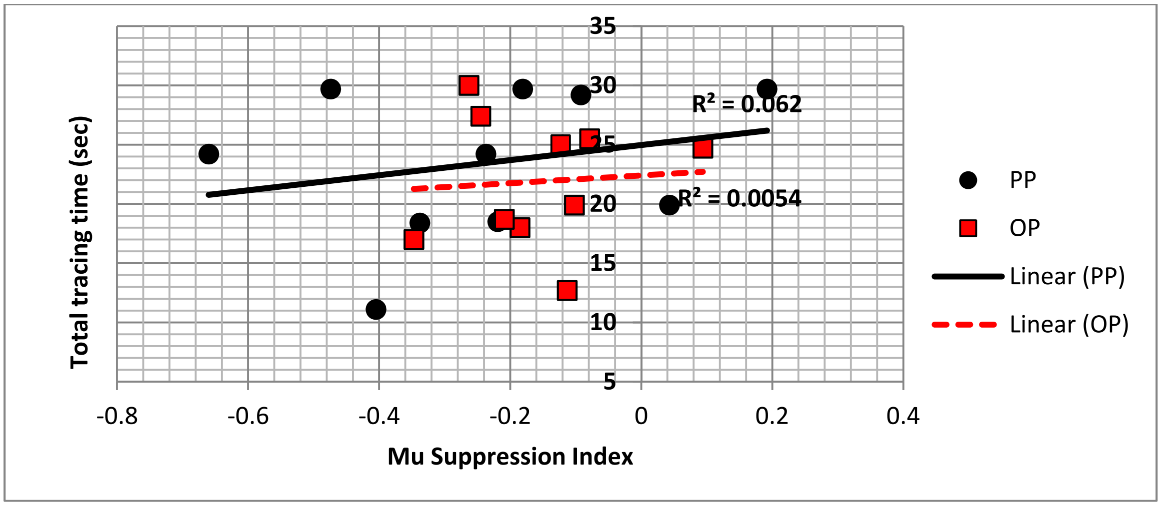


2. Time

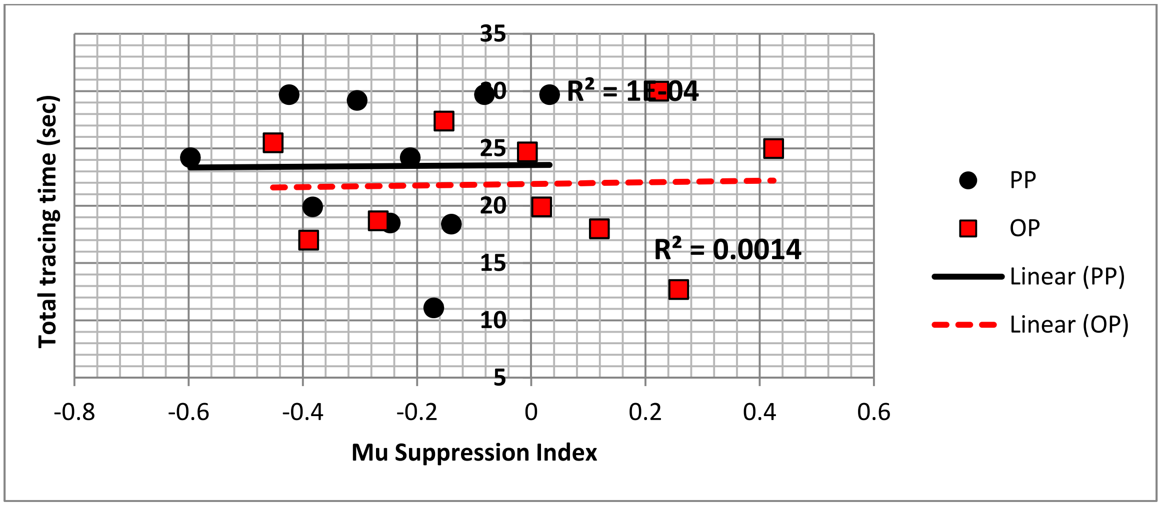
a. At C3 (Central left hemisphere)



b. At CZ (Central medial)



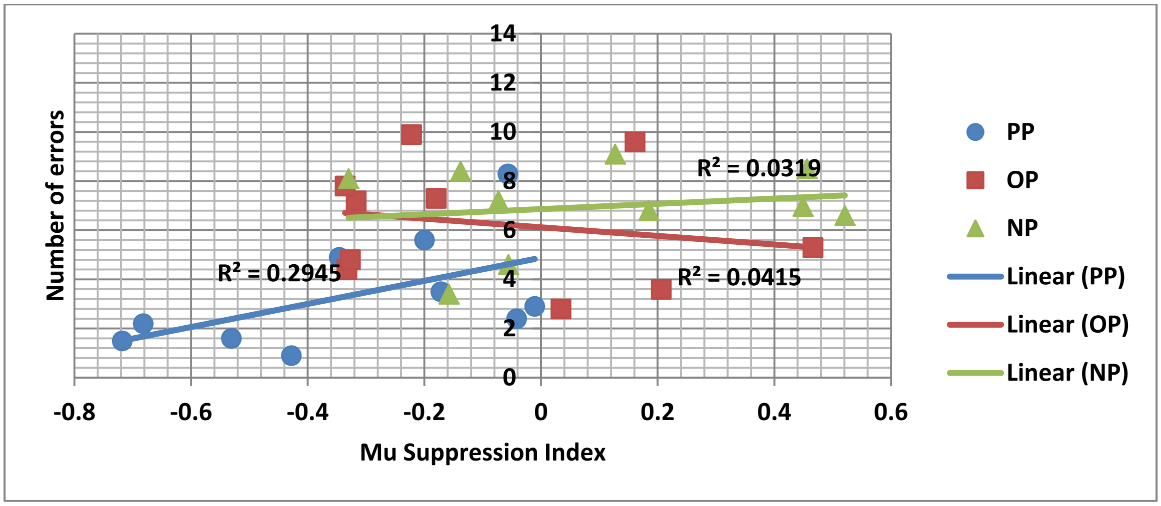
c. At C4 (central right hemisphere)



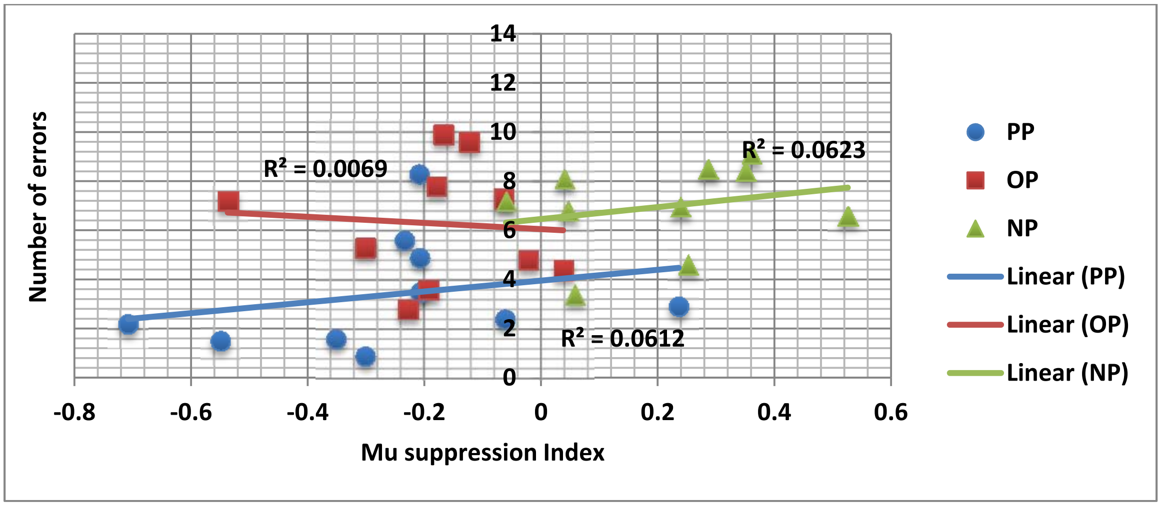
G.2 The relationship between mu suppression during testing session and performance during retention for PP and OP, and NP groups: Time & error

1. Error

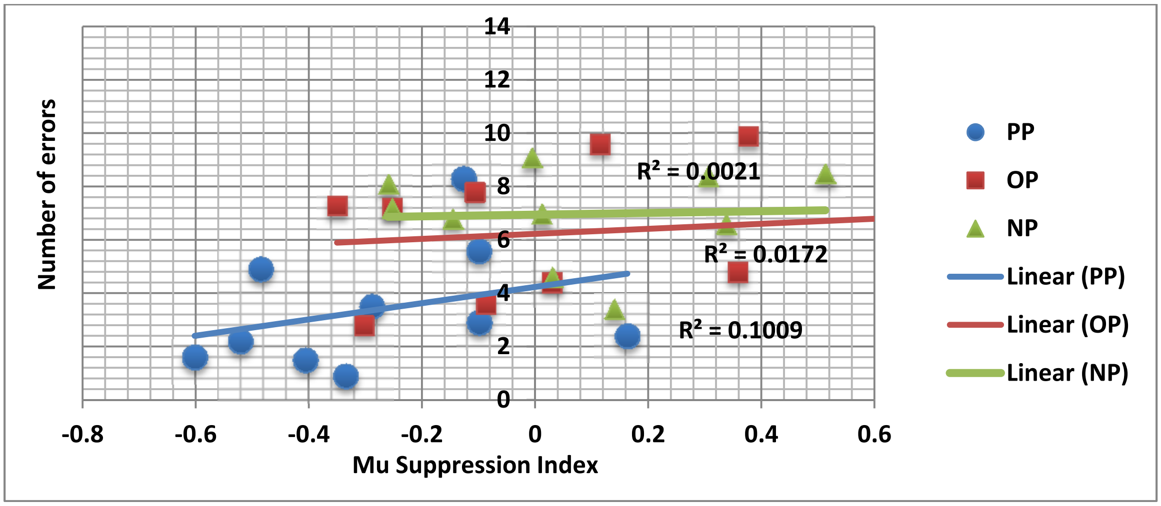
d. At C3 (Central left hemisphere)



b. At CZ (Central medial)

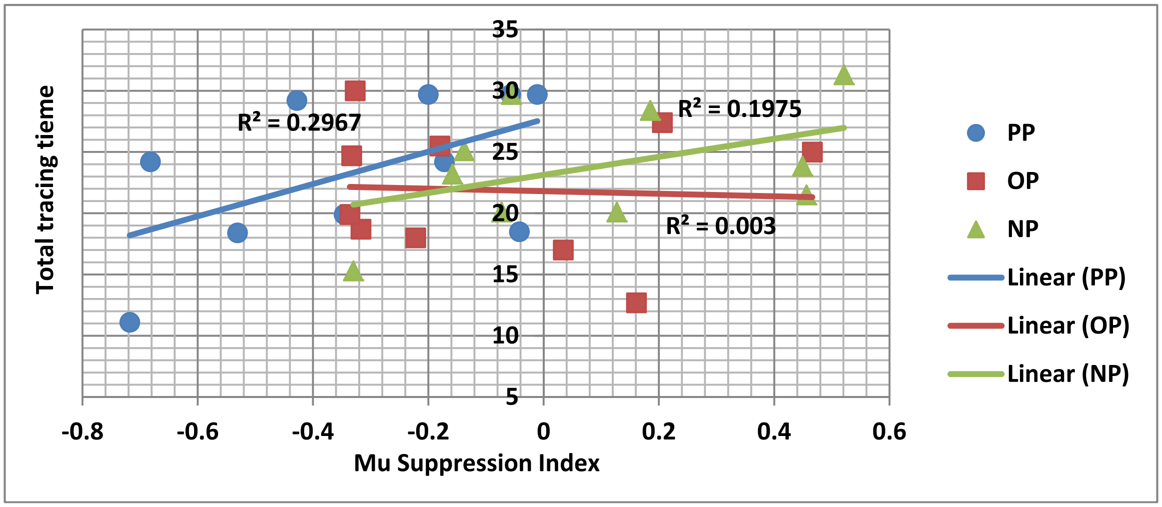


C. At C4 (Central right hemisphere)

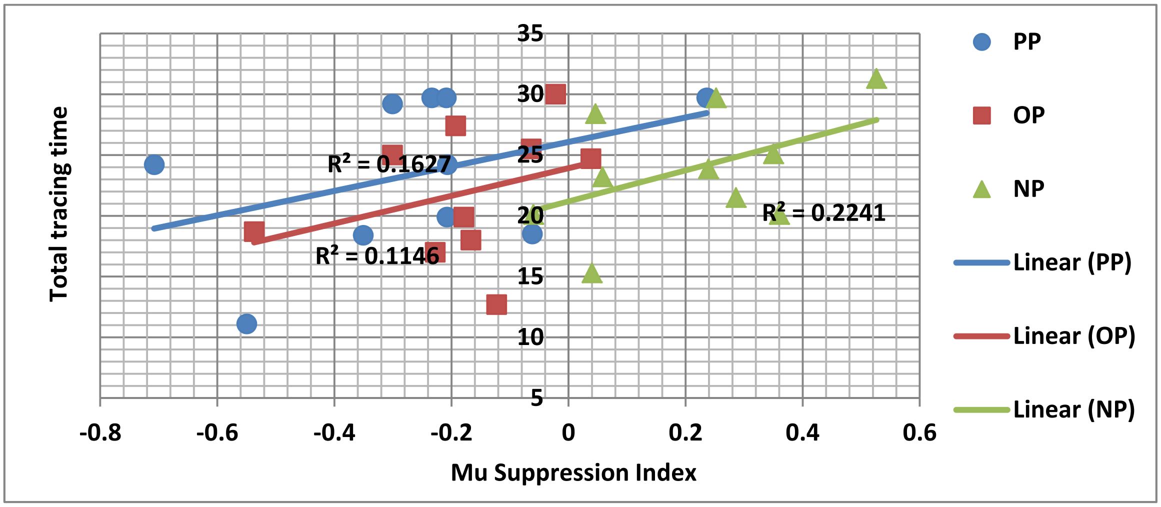


2. Time

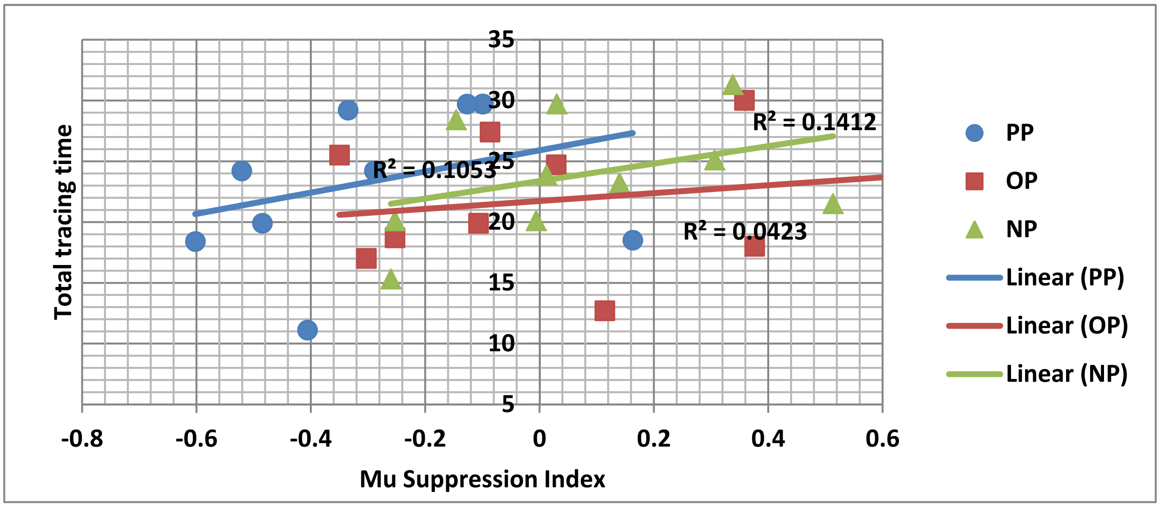
a. At C3 (Central left hemisphere)



b. At CZ (Central medial)



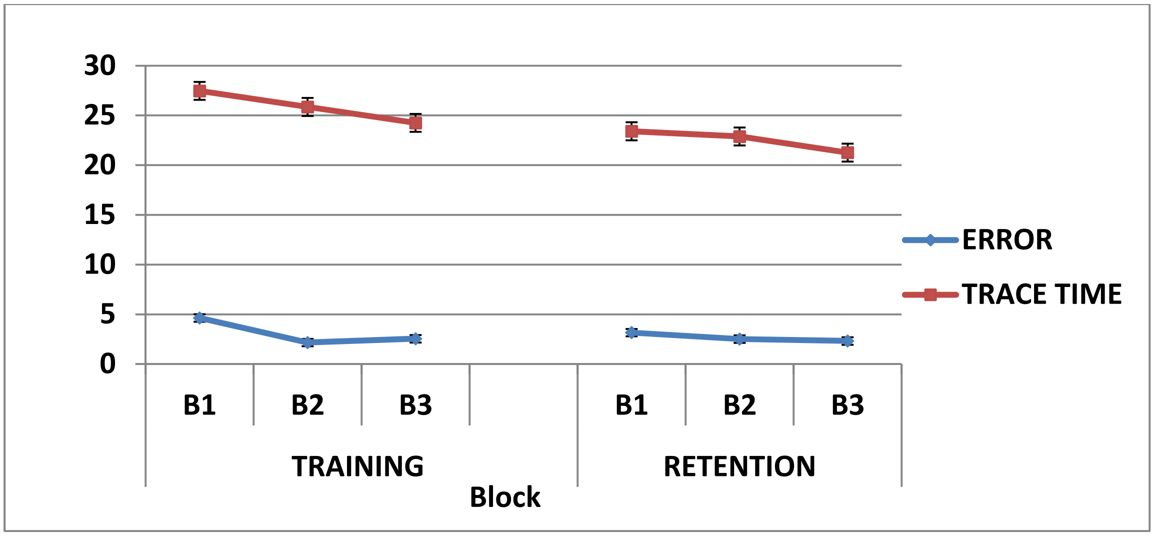
c. At C4 (Central right hemisphere)



Appendix H **Performance of the PP group during training and retention**

Two separate 3 [block; B1, B2, B3] × 3 [electrode: C3, CZ, C4] × 2 [stage; training, retention] repeated measures ANOVA was performed to compare: (1) the average number of errors; and (2) the average tracing time for the PP group during training and retention. All the assumptions of RMANOVA were met. The sphericity assumption, however, was violated; therefore, the Greenhouse test was used. In regard to the error analysis, the results revealed a significant main effect for the block, [*F* (1.10, 9.87) = 19.05, *p* = .001], indicating that the PP group spent significantly less time during B3 compared to B1. However, both the main effect for the stage, [*F* (1, 9) = .44, *p* = .524, *ns*], and the interaction between the block and the stage, [*F* (1.23, 11.04) = 4.58, *p* = .05, *ns*] were non-significant. The non-significant main effect for the stage suggested that there was no significant difference in the average number of errors between the training and retention stages.

The sphericity assumption for the time analysis was not violated. This analysis yielded a significant main effect for the block, [*F* (1, 9) = 11.22, *p* = .009], indicating that the PP group spent significantly less time during B3 compared to B1. Moreover, there was a significant main effect for the stage, [*F* (2, 18) = 17.44, *p* < .001], indicating that this group spent significantly less time during the retention session compared to the training session. The interaction between the block and the stage, however, was not significant, [*F* (2, 18) = .65, *p* = .532, *ns*].


30
25
20
15
10
5
0
ERROR
TRACE TIME
B1
B2
B3
B1
B2
B3
TRAINING
RETENTION
Block