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Differential Effects of Transcranial Direct Current Stimulation of the Motor Cortex and Prefrontal Cortex in Learning a Whole-Body Movement Task

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Statement

This thesis involves two studies. The first experiment which stimulated the primary motor cortex was done during the final year of my undergraduate degree. This thesis is therefore a follow-up from the original experiment. As such, I included both the original and new experiment, in the thesis, to provide a fuller story which carries more weight to the point of research.

Acknowledgments

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Abstract

Research has investigated the use of non-invasive brain interventions, such as transcranial direct current stimulation (tDCS), to enhance motor learning and rehabilitation. Much research has shown that tDCS improves motor learning and that bilateral tDCS is more beneficial than unilateral tDCS in improving motor learning. However, past research has primarily utilised simple motor tasks in measuring motor skill learning. These are not ecologically reliable as whole-body movement is required for everyday activities. This study involved two experiments. Each experiment involved participants learning 12 Ballroom and Latin dance moves whilst undergoing tDCS. All participants underwent three sessions of tDCS, (unilateral, bilateral and sham), over three consecutive days. Participants in the first experiment (n=30) had stimulation to the primary motor cortex (PMC) and those in the second experiment (n=31) had stimulation to the dorsolateral prefrontal cortex (DLPFC). In each experiment, a baseline was taken before the training sessions and two outcome measures were taken; a day after the last training session and two weeks later. In each testing session participants' dance ability was measured. Our results showed that bilateral tDCS impaired performance in both experiments. Unilateral stimulation impaired performance in the first experiment, and did not significantly improve performance any better than the sham stimulation in the second experiment. These results suggest that task complexity plays a crucial role when tDCS procedures are used to modulate motor performance and highlights possible limitations of tDCS in practice.

1 Introduction

Enhancing cognitive processes has become the focus of many researchers, particularly due to the expanding field of modern neuroscience and technology. Such research has been done in those who suffer from neurological injuries and diseases, for rehabilitative purposes, but also in healthy individuals. Improving cognitive processes relies upon neurocognitive circuits being repeatedly activated (Santarnecchi et al. 2015). Transcranial electrical brain stimulation (tES) has been suggested to be a potential candidate to achieve this goal, especially due to its cost effective and easy to use nature (Reis & Fritsch, 2011). tES is a non-invasive stimulation technique that involves passing a weak electrical current typically through one targeted brain region (Reed & Kadosh, 2018). However, due to a desire to have stronger effects, as well as understanding neural mechanisms of different cognitive tasks, bilateral stimulation has been recently proposed. This method usually involves electrodes being placed over both hemispheres of one brain area. This review will look at the effects of bilateral tES on cognitive processes.

The most popular tES method is transcranial direct current stimulation (tDCS). tDCS involves sending a weak constant current through the brain area of choice (Fregni et al. 2005). The current can modulate cortical excitability differently depending on the stimulation protocol such as; montage, duration and amplitude (Schulz, Gerloff & Hummel, 2013). Generally, it is assumed that an anodal electrode will increase excitability whereas a cathodal one will decrease excitability (Bindman, Lippold & Redfearn, 1964). tDCS effects can also last after stimulation ceases, and can potentially last up to 90 minutes (Nitsche & Paulus, 2001). tDCS has been found to positively impact; decision making (Edgcumbe, Thoma, Rivolta, Nitsche & Fu, 2019), working memory (Jones, Johnson & Berryhill, 2020), learning (Gibson et al. 2020) and motor learning (Jackson et al. 2019). It has also been advantageous to those with neurological injuries (Allman et al. 2016) and the elderly (Moghadam, Ardekani & Shamsi, 2020).

Bilateral tES has been suggested to be more beneficial and produce more powerful effects than unilateral tES (Vines, Cerruti & Schlaug, 2008). Bilateral tES can be done in multiple ways; an incongruent montage where the electrodes are of different polarities and a congruent montage where the electrodes are the same polarity. Incongruent montages produce stronger effects by altering the interhemispheric communication. This has proven very beneficial in individuals who have suffered from neurological injuries and thus have an under-performing hemisphere (Di Lazzaro et al. 2014). By applying an anodal electrode to the affected hemisphere and a cathodal electrode to the healthy hemisphere, the affected hemisphere can be released from suppression and excitability can be increased (Vines et al. 2008). This effect can also be relayed in healthy participants where you apply the anodal to the hemisphere which is primarily involved in improving performance, and the cathode to the other hemisphere. This will reduce the interhemispheric inhibition and theoretically improve performance (Kasahara, Tanaka, Hanakawa & Senoo, 2013). This montage is logical in cases where lateralisation between the hemispheres plays an important role in a cognitive task, however when activity is bilateral across both hemispheres a congruent montage may be more beneficial.

This review intends to look at the effects of bilateral tES on cognition. Highlighted domains include; memory, decision making, control and learning. In particular we looked at modulatory effects of different protocols of stimulation in different cognitive domains to understand possible underlining mechanisms of bilateral tES. This review intends to highlight the importance of depth of research into bilateral tES on cognition and serves a premise to research focused on using bilateral tES to modulate learning whole-body movements.

1.1 Effect of Incongruent Bilateral tDCS on Cognition

1.1.1 Memory

Working memory describes the process of maintaining and manipulating information within a very short time scale (Baddeley, 2010). The effects of bilateral tDCS on working memory are however varied, with a tendency of tDCS benefiting low performing individuals more so than healthy individuals. Improvements to visual working memory in healthy young adults have been found after both temporal and posterior parietal cortex (PPC) stimulation (Chi, Fregni & Snyder, 2010; Heinen et al. 2016). Chi et al. (2010), found that only participants who received left-cathodal, right-anodal stimulation showed improvement. Whereas, Heinen et al. (2016) found improvement irrespective of electrode placement to the PPC, suggesting that stimulation over the PPC is more crucial than type of stimulation used. Additionally, it was more beneficial than unilateral tDCS. However, research has also found less positive results. Specifically, Sandrini, Fertoni, Cohen and Miniussi (2012) show the reverse of Heinen et al. (2016), as they allude that stimulation over the PPC impairs performance on a working memory task. A negative effect has also been seen after tDCS to the DLPFC (Mashal et al. 2019). There is also no consistent stimulation paradigm which is responsible for these negative effects. With intensity ranging from 1mA to 2mA and size of electrode ranging from 16cm^2 to 35cm^2. Specifically, left-anodal, right-cathodal stimulation of the dorsolateral prefrontal cortex (DLPFC) seems to impair working memory in healthy young adults (Keshvari, Pouretemad & Ekhtiari, 2013; Mashal & Metzuyanim-Gorelick, 2019). Subsequently, Sandrini et al. (2012) suggested that bilateral PPC tDCS "abolished improvement" (p.399), as improvement was seen in a sham condition with no active stimulation. Interestingly, these three studies evaluated memory offline. Whereas in both Chi et al. (2010) and Heinen et al. (2016) studies, tDCS was concurrent with the working memory task. Furthermore, despite null effects being found, Nikolin, Martin, Loo and Boonstra (2018) did not find impairing effects of tDCS, and their paradigm involved simultaneous stimulation and task. Nitsche and Paulus (2001) have suggested that effects can differ when stimulation is offline compared to online. Therefore, it can be suggested that applying tDCS during a rest period could be damaging to working memory performance.

On the other hand, when we are looking at working memory performance in individuals who are part of a low performing population, the results are more consistent and positive. Working memory and visual working memory improvements have been seen in individuals with autism (Van Steenburgh, Varvaris, Schretlen, Vannorsdall & Gordon, 2017) depression (Moreno et al. 2015; Salehinejad, Rostami & Ghanavati, 2015) and the elderly (Nissim et al. 2019). Similar to studies with healthy individuals the stimulation paradigm is varied in electrode size, stimulation length and stimulation intensity. There is consistency in that tDCS to the DLPFC produces positive effects to working memory. Null effects were seen in healthy older adults after tDCS to the prefrontal cortex (PFC) (Arciniega, Gözenman, Jones, Stephens & Berryhill, 2018). However unilateral tDCS to the PPC did produce observable effects in low performing older adults. Thus showing, that baseline ability matters when tDCS is used to modulate cognition.

Effects of tDCS on long-term memory in healthy individuals are more consistent than the effects on working memory. Long-term memory is typically measured using an encoding-recognition task, where participants learn a set of words or symbols and then have to remember if they have been previously seen. Improved long-term memory has been found after tDCS to the PPC (England, Fyock, Gillis & Hampstead, 2015), temporal cortex (Penolazzi et al. 2010) and PFC (Pergolizzi & Chua, 2017). Pergolizzi and Chua (2015; 2016; 2017) have debated about the roles of the PPC and frontal regions during a recognition task. Specifically, whether the PPC reduces or increases false recognition. As such, authors have suggested that results differ due to task context but also whether participants are low or high performing individuals.

It can therefore be suggested that individual differences and specifically baseline cognitive ability are heavy dictators in the way in which tDCS will affect memory performance.

1.1.2 Language

The effect of baseline cognitive ability also affects the ability of tDCS to improve language performance. Unilateral tDCS and transcranial magnetic stimulation studies have suggested that the right hemisphere is negatively involved in language processing (Naeser et al. 2012) whilst the left hemisphere is positively involved (Marangolo et al. 2013). Therefore, an incongruent bilateral montage is theoretically beneficial, through altering the interhemispheric balance between the hemispheres. This montage has found success through anodal-left, cathodal-right modulation of the primary motor cortex (PMC) and interior frontal gyrus (IFG) (Martin et al. 2017; Lifshitz-Ben-Basat & Mashal, 2018). Furthermore, there has been consistent success in improving language functions in low performing populations (Fiori et al. 2017; Lifshitz-Ben-Basat & Mashal, 2018; Marangola et al. 2016; Martin et al. 2017; Meinzer et al. 2014). Results in healthy young adults are however mixed. Martin et al. (2017) found that after tDCS to the PMC, semantic word retrieval performance was improved. But Malyutina et al. (2018) found that tDCS to the IFG did not improve performance on a word and sentencing processing task. However, Malyutina et al. (2018) did use stronger stimulation for a shorter amount of time (1.5mA and 20minutes versus. 1mA and 30minutes). Hoy et al (2013) further suggested that a longer stimulation time with a lesser intensity may be preferable in producing positive effects. Hoy et al (2013) found that with higher intensity stimulation the results were not greater than at a lower intensity. It is suggested that using a higher intensity elicits synaptic scaling. This homeostatic mechanism results in the prevention of changes in neuronal excitability, which are crucial in improving within a cognitive domain (Rodger et al. 2012). Overall, whilst it is apparent that tDCS does improve language performance, this is contingent upon conditions. Mainly baseline cognitive level and stimulation parameters.

1.1.3 Decision Making

Decision making is a complex task which involves evaluating ones wants and intensions whilst utilising past and current information to make choices in a goal-directed manner (Soyata et al. 2019). The DLPFC has been suggested as a key brain region involved in decision making, and as such the majority of research has focused on stimulating this region. In particular right-anodal, left cathodal tDCS of the DLPFC has been shown to; reduce risky decision making (Fecteau et al. 2007a, 2007b), augment fairer decisions (Luo, Ye, Zheng, Chen & Huang, 2017) and increase cognitive reflection (Edgcumbe et al. 2019). Improved decision making has also been seen in individuals with a gambling disorder (Soyata et al. 2019) and those with obsessive compulsive disorder (Yekta, Rostami & Fayyaz, 2015). However, these positive effects are not consistent. Russo, Twyman, Cooper, Fitzgerald and Wallace (2017) replicated Fecteau et al. (2017a) with more participants and found that right-anodal, left cathodal tDCS increased risky decision making. Authors suggest that individual differences such as hormonal and metabolic fluctuations are independent to each study and therefore, whilst replication of methodology can stay consistent, individual differences are unpredictable. Krause and Kadosh (2014) suggest that the perception that tES works through polarity specific neural modulation is over-simplistic and that any individual difference causes unpredictability. Therefore, confounding factors like age, hormone levels, medication use and cortical morphology should be heavily considered. Subsequently, Boggio et al. (2010) found that after tDCS of the DLPFC, risky decision making was increased in a group of healthy older adults. West, Tiernan, Kieffaber, Bailey & Anderson (2014), found that there are differences in physiology between healthy old and young adults in a risk game. Primarily there were differences in regions associated with feedback processing. Authors suggest that these differences result in changes to the way older adults process the valence and motivational importance in risky decisions. Consequently, there is a lack of research looking at the effects of bilateral tDCS on decision making in healthy older adults, and so definite conclusions cannot be drawn. Researchers should also be mindful in how they examine decision making as it is suggested there is differentiation between ambiguous and risky decision making. The Balloon Analogue Risk Task (BART) is a popular test to examine risk taking, but is more ambiguous in nature compared to gambling tasks, like the Iowa Gambling Task which utilise risky decision making more. Consequently, it is further suggested that this differentiation is also at a physiological level (Krain, Wilson, Arbuckle, Castellanos & Milham, 2006). The DLPFC is more responsible in ambiguous tasks (Hyder et al. 1997), whereas the orbitofrontal cortex (OFC) and parietal cortex are responsible for risky decision making (Bechara. 2001). As such decision making has been successfully modulated with tDCS to the OFC and Wernicke's area (Oullet et al. 2015; Weltman & Lavidor, 2013).

Decision making can also be seen at the perceptual level. Whereby information is gathered from sensory systems to influence our behaviour (Heekeren, Marrett & Ungerleider, 2008). Stimulation of the PMC has been indicated as an area involved in perceptual decision making, however results are not conclusive. Javadi, Beyko, Walsh and Kanai (2015) found that bilateral tDCS to the PMC resulted in biased perceptual decision making, depending on polarity of stimulation. However, Turkakin et al. (2018) were unable to replicate these findings, however their methodology was not the same, with a different task being used as well as a different stimulation surface area. This highlights the difficulty of replicating results using tDCS. Overall, there is a positive trend of, especially the DLPFC, enhancing decision making in both healthy and low-performing individuals. However, type of task and individual differences should be approached cautiously.

1.1.4 Control

Inhibitory processes are enacted when individual's control, obey or stop actions. The inferior frontal cortex (IFC) has been implemented in modulating this function. However, research looking at the effect of bilateral tDCS over the IFC is mixed. Cunillera, Brignani, Cucurell, Fuentemilla and Miniussi (2016) found that anodal-right, cathodal-left IFC stimulation improved performance on a response inhibition task, however Dambacher et al. (2015) were not able to confirm these results. Importantly, the type of response inhibition being evaluated needs to be considered. Response inhibition can be broken down into proactive inhibition and reactive inhibition. Proactive inhibition is when behaviour is controlled over time by creating a response tendency, whereas reactive inhibition is when we inhibit an already initiated response (Castro-Meneses, Johnson & Sowman, 2015). Subsequently, Cunillera et al. (2016) found positive effects on proactive inhibition but found null effects similar to Dambacher et al. (2015) on a reactive inhibition task. However, Leite et al. (2018) found no effects of anodal-right, cathodal-left IFC on a proactive control task. By comparing these two studies, it is noticeable Leite et al. (2018) used significantly larger electrodes (35cm^2 versus. 9cm^2). Therefore, Cunillera et al. (2016) would have had more focal stimulation of the IFC compared to Leite et al. (2018). Consequently, increased focality also leads to increased interindividual variability (Mikkonen, Laakso, Tanaka & Hirata, 2020). Brevet-Aeby, Brunelin, Iceta, Padovan and Poulet (2016) further suggest that methodology is important in research looking at impulsivity, and that differences in such can explain the inconsistency. The decision to stimulate anodal-right, cathodal-left is due to the idea that the right-IFC is suggested to be a key influencer in inhibitory behaviour (Cunillera, Fuentemilla, Brignani, Cucurell & Miniussi, 2014; Stramaccia et al. 2015). The role of the left-IFC has thus been downplayed and it is suggested that applying cathodal stimulation to this region will heighten the role of the right-IFC (Leite et al. 2018). However, Leite et al. (2018) further suggested that the left-IFC may play a key role in inhibitory processes, and thus any positive effects are nullified with cathodal tDCS of the left-IFC (Swick, Ashley & Turken, 2008). tDCS over the IFC also had reverse effects on a self-control task. After stimulation self-control was reduced which in-turn increased chocolate consumption (To et al. 2018).

Self-control has also been modulated with tDCS over the DLPFC. Vanderhasselt et al. (2020), found that tDCS to the DLPFC (anodal-right, cathodal-left) improved cognitive control, reduced the influence a reward has on action tendencies and reduced the amount of beer tasting. Similarly, Martinotti et al. (2018) found that in an individual with gambling disorder, tDCS to the DLPFC reduced gambling craving. These studies are very similar to To et al. (2018) who looked at reducing chocolate consumption, via self-control, in self-confessed chocolate addicts. Vanderhasselt et al. (2020) has suggested that modulation of the DLPFC, for improved self-control, is especially beneficial in individuals who crave. Therefore, perhaps the DLPFC is more appropriate at improving self-control than the IFC. The DLPFC is suggested to be a key area involved in self-control because of its links to decision making. Fregni et al. (2008) suggest that disrupting the decision-making process involved in craving is the key to improved self-control. They found that anodal-right, cathodal-left tDCS to the DLPFC reduced food craving. Similarly, this montage has also shown to decrease risk taking (Fecteau et al. 2007a, 2007b). DLPFC modulation has also improved behavioural inhibition in children with ADHD and task-switching (Leite, Carvalho, Fregni, Boggio & Gonçalves, 2013; Munz et al. 2015).

1.1.5 Learning

The PMC is the primary area of stimulation involved in motor learning. Altering the interhemispheric balance between the hemispheres is widely known as beneficial for improving motor learning in specific limbs (Vines et al. 2008). This is by a process of reducing the excitability in one hemisphere (via cathodal stimulation) which promotes the excitability in the other hemisphere (via anodal stimulation). Tasks used to measure motor learning are varied from tracing tasks (Prichard, Weiller, Fritch & Reis, 2014) to finger sequence tapping tasks (Karok & Witney, 2013). Improved learning has been found in healthy adults (Karok & Whitney, 2013; Naros et al. 2016; Waters-Meteiner, Husain, Wiestler & Diedrichsen, 2014) and stroke patients (Lefebvre et al. 2013). Electrode paradigms are also diverse with intensity ranging from 1mA to 2mA, electrode size varying between 16cm^2 to 35cm^2 and stimulation length between 10 minutes and 30 minutes. Learning has also been successfully modulated by tDCS to the DLPFC (Ljubisavljevic et al. 2019; Looi et al. 2016). Fleming, Rothwell, Sztriha, Teo and Newham (2017) however found that bilateral tDCS to the PMC did not improve motor learning in stroke patients. Authors suggest that their task, where individuals had to move the cursor to an illuminated symbol in sequences of 12 which was to be repeated 25 times and then anticipate targets, was not sensitive enough. Consequently, as motor learning can be observed in many ways, it has been found that there are no significant effects of tDCS across the types of motor learning tasks (Hashemirad et al. 2016).

1.1.6 Other Cognitive Domains

A few studies have looked at the effect of bilateral tDCS on attention. Improved visual attention was found after left-cathodal, right anodal tDCS to the DLPFC (Vierheilig, Mühlberger, Polak & Herrman, 2016) and performance on an auditory attention task improved after left-anodal, right cathodal tDCS over the superior temporal gyrus (Lewald 2016). Roe et al. (2016) highlight the importance of task consideration in evaluating attention. Authors found that when attentional load was high bilateral tDCS to the PPC impaired performance. Kasahara et al. (2013), called attention to the importance of lateralization and individual differences. They found that anodal-left, cathodal-right tDCS over the PPC only improved numerical performance in individuals with left hemisphere lateralization. tDCS to the DLPFC has also improved; planning processes (Heinze et al. 2014), cognitive inhibition (Metzuyanim-Gorlick & Mashal, 2016), convergent and divergent thinking (Zmigrod, Colzato & Hommel, 2015) and affective processing (Brunoni et al 2014).

1.2 Effect of Congruent Bilateral tDCS on Cognition

A congruent bilateral montage, which involves applying electrodes of the same polarity over both hemispheres, is a less frequently used method, but is still understood to produce stronger effects. Effects of using this congruent montage are relatively mixed. Klein et al. (2013) found that tDCS to the PPC, using electrodes of the same polarity, affected performance on a numerical task. However, (Hauser, Rotzer, Grabner, Mérillat & Jäncke, 2013) did not repeat these effects. Hauser et al. (2013) have suggested that increasing the activity in both hemispheres is too simple, and that an incongruent montage may be more successful. This idea is emphasised by their finding that anodal tDCS to only the left-PPC resulted in improved numerical cognition. Additionally, these studies differ in that Klein et al. (2013) tested performance using an ‘online’ paradigm, compared to Hauser et al. (2013) who used an ‘offline’ paradigm. Furthermore, Martin, Liu, Alonzo, Green & Loo (2014) found that ‘online’ tDCS was associated with superior skill acquisition compared to ‘offline’ tDCS.

When modulating attention, improvements were found on spatial attention, after anodal-bilateral tDCS to the temporal cortex, where individuals increased the amount of correct localizations in a ‘cocktail party’ task (Lewald, 2019). However, efforts to improve sustained attention were not effective after anodal-bilateral tDCS to the DLPFC (Jacoby & Lavidor, 2018). Authors suggest that this is due to a significant learning effect.

Effects of congruent-bilateral tDCS also fall to the same issues that face incongruent montages, in that baseline ability dictates the effect on certain cognitive domains. Behavioural inhibition was improved in children with ADHD after anodal-bilateral tDCS to the DLPFC (Munz et al. 2015). Cognitive functioning has also improved in individuals with dementia (Ferucci et al. 2018) and individuals who have suffered from a stroke (Park, Koh, Choi & Ko, 2013). Performance on working memory tasks improved after anodal-bilateral tDCS to the temporal cortex and DLPFC in individuals with Alzheimer's and healthy older adults (Boggio et al. 2012; Park, Seo, Kim & Ko, 2014). However, Möller, Nemmi, Karlsson and Klingberg (2017) found that tDCS to the DLPFC resulted in impaired performance on a working memory task in healthy young adults. Authors highlight the importance of considering the placement of the reference electrode, as they found that changing it from the occipital lobe to the supraorbital area resulted in improved performance (still impaired).

1.3 Effect of Bilateral tACS/tRNS on Cognition

Other methods of tES include transcranial random noise stimulation (tRNS) and transcranial alternating current stimulation (tACS). tRNS involves applying a random electrical oscillation spectrum over the cortex between 0.1 and 640Hz (Qi, Mitsche & Zschorlich, 2019). Although the mechanisms behind tRNS are not fully understood, it is suggested that the excitability is increased via stochastic resonance whereby the weak signal detection in the nervous system is enhanced by the frequent opening on NaC channels (Peña, Sampedro, Ibarretxe-Bilbao, Zubiaurre-Elorza & Ojeda, 2019). While tACS involves applying an alternating current which changes between the anode and the cathode (Herrmann, Rach, Neuling & Strüber, 2013). tACS interacts with established cortical activity by synchronising or desynchronising ongoing oscillations (Jaušovec & Jaušovec, 2014).

Consistent findings have shown that tRNS applied to the DLPFC improves numerical cognition (Looi et al. 2017; Popescu et al. 2016; Snowball et al. 2013). These studies included multiple days of training and stimulation. This has been suggested to induce more significant results, compared to having only one stimulation session (Moliadze, Fritzsche & Antal, 2014). Subsequently, Sheffield, Raz, Sella & Kadosh (2020) suggest tRNS can produce more powerful effects than tDCS.

Similar to the effects of tDCS on memory, the effects of tACS are influenced by individual differences. Tseng, Lu & Juan (2018) found that the effects on visual working memory differed between low and high performers. In-phase tACS to the PPC only improved visual working memory in low performing individuals, whilst effects were non-existent for high performers. Subsequently, anti-phase tACS significantly impaired performance in high performers. tACS is also vulnerable to replication difficulty. Meiron and Lavidor (2014) found that tACS to the DLPFC improved working memory. However, Jones, Arciniega, Berryhill (2019) were unable to find any effect of tACS on working memory. Jones et al. (2019) do mention that they used a harder task (3-back task versus. 2-back), larger electrodes (25cm^2 versus. 16cm^2) and a difference in electrode placement (F3 & F4 versus F3/AF3 & F4/AF4). Therefore, consideration should be taken when arriving at a methodology. Consistent positive effects have been found on long-term memory (Ambrus et al. 2015; Jones et al. 2018).

tRNS to the auditory cortex has also enhanced the right ear advantage (Prete, D’Anselmo, Tommasi & Brancucci, 2018) and improved phoneme categorization in adults with developmental dyslexia, whilst tACS improved phoneme categorization in children and adolescents with developmental dyslexia (Rufener, Krauel, Meyer, Heinze & Zaehle, 2019).

1.4 Importance of population group

A clear pattern emerging from the research is that individual differences and in particular baseline cognitive levels are a key influencer in how tDCS effects certain cognitive domains. Respectively, attention should be focused on the physiological differences, as this is what will influence the effects of tCDS. Interestingly, the difference between healthy young and old adults is more ambiguous than one may initially conceive. Changes due to healthy ageing can alter brain physiology by both maintaining, increasing and decreasing activity in distinct brain regions. Grady et al. (1998) found that healthy older adults performed worse on a memory task and also had differences in their brain physiology. Older adults had less activation in the right ventrolateral PFC, greater activity in the left DLPFC and similar activity on the left anterior PFC, compared to healthy younger adults. When there is similarity in activation, but difference in performance level it is suggested to be due to less effective neural processes in older adults (Spreng Wojtowicz & Grady, 2010). Colcombe, Kramer, Erickson and Scalf (2005) found that older adults had less grey and white matter density in the PFC, and that lower white matter levels resulted in poorer performance. Subsequently, Grady (2008) suggest there is increased activation in the PFC and this is largely compensatory for the lack of activation in other areas, including medial temporal areas and the hippocampus. Similarly, Baciu et al. (2016) found that in healthy older adults there is atypical activation involved in lexical tasks, which they suggest are due to compensatory mechanisms. Zarahn, Rakitin, Abela, Flynn & Stern (2007) also found that during a recognition task, older adults had reduced neuropil in the cortex and hippocampus as well as an increase of dead tissue in the white matter and basal ganglia.

Interhemispheric interactions are key to successful cognitive processes being performed. Subsequently, it is suggested that this process is mediated by the corpus callosum (Fling, Peltier, Bo, Welsh and Seidler, 2011). As such, research has found age related declines in the corpus callosum (Fling et al. 2011; O'Sullivan et al. 2001). Specifically, the genu corpus callosum, which also declines due to age, is related to less robust interhemispheric inhibition (Fling et al. 2011). Consequently, the efficiency of interhemispheric communication is reduced. This reduction reduces lateralisation between the hemispheres allowing crosstalk between the hemispheres. Talelli, Waddingham, Ewas, Rothwell and Ward (2008) also found that there was less lateralisation present in older adults and a reduction in interhemispheric inhibition. Therefore, due to these physiological differences tDCS is going to react differently between healthy old and young adults.

Another reason for the lack of positive significant results within healthy participants, is that they are reaching a ceiling. Fiori et al. (2017) have stated that in their language task 53% of healthy young adults reached the maximum score compared to only 13% in the elderly. Subsequently, Moreno et al. (2015) found that whilst healthy participants' performance improved in a non-emotional task their performance was not significantly changed in an emotional task. Authors suggest this is due to healthy participants having a strong capability to process emotional content. Participants from a low performing population are going to benefit from tDCS more so than healthy individuals, as they have more room to grow. Subsequently, improvements in low performing individuals may be easier to observe.

Overall, research is mixed regarding the effects of bilateral tES on cognition. Despite the mixed results, there is a considerable amount of research suggesting that tES is more beneficial to individuals with a lower baseline cognitive ability. Furthermore, this review highlights that studies utilising tES are vulnerable to replication issues.

Considering research using a congruent montage is limited, we decided to run a study evaluating the effect of congruent tDCS over both the PMC and DLPFC on whole-body movement. Whole-body movement encompasses a range of cognitive domains, such as memory, learning and perception.

Whole-body movement and skill acquisition are important aspects, facilitating our integration within society (Ronsse, Miall & Swinnen, 2009). Subsequently, individuals who have reduced mobility due to neurological injuries and diseases are suggested to have increased dependency, increased depression and lower life satisfaction (Broe et al. 1999). Furthermore, it is suggested that 37.6% of individuals with serious mental health symptoms are also comorbid with a long-term physical condition (Mental health statistics: physical health conditions, 2020). Shen et al. (2017) additionally, found that depression levels were highest in individuals with a physical disability compared to other types of disability. Therefore, it is paramount to be able to regain mobility following injuries. Physical therapy to regain motor abilities is recommended to individuals with such physical ailments (Pascual-Leone, Amedi, Fregni & Merabet, 2005). However, research has suggested that the sole effects of physical therapy are insufficient to correct the errors of neurological injury (Sriraman, Oishi & Madhaven, 2014). Therefore, research has been directed towards other intervention methods such as non-invasive tES (Sriraman et al. 2014). Subsequently, research has suggested that whilst physical therapy alone is beneficial, when it is combined with tES positive effects are greater (Bolognini et al, 2011; Cho & Cha, 2015).

tES has been shown to be beneficial in improving simple motor movement, such as; serial reaction time tasks (Giustiniani et al. 2019), upper limb rehabilitation in stroke patients (Arnao et al. 2019) and finger tapping in individuals with neurological disabilities (Bolognini et al. 2011). However, research looking at the effect of tES on whole-body movement is minimal. Therefore, this study aims to look at different protocols of tDCS and its ability to impact upon whole-body movement.

Research on the effects of tDCS on minor movements is plentiful (Apšvalka, Ramsey & Cross, 2018; Hashemirad, Zoghi, Fitzgerald & Jaberzadeh, 2016; Moura et al. 2017; Rocha et al. 2016; Srirman et al. 2014). Minor movements occur in the writs, hands, fingers, feet and toes, and typically only involve movements with one goal. Positive effects of tDCS have been found in studies looking at; motor adaptation (Weightman, Brittain, Punt, Niall & Jenkinson, 2020), throwing tasks (Jackson et al. 2019), serial reaction time finger tapping tasks (Ehsani, Bakhtiary, Jaberzadeh, Talimkhani & Hajihsani, 2016; Talimkhani et al. 2019) and balance tasks (Kaminski et al. 2016; Zandvliet, Meskers, Kwakkel & van Wegen 2018). Additionally, similar positive effects have been found in patients suffering from neurological injuries and illnesses, such as in stroke (Rocha et al. 2016; Allman et al. 2016) and Parkinson's disease (Kami, Sadler, Nantel and Carlsen, 2018).

All studies above used a unilateral stimulation configuration. In these studies, only one hemisphere was actively stimulated. Stimulation of both hemispheres is known as bilateral stimulation and research suggests this also positively impacts motor learning (Bologni et al. 2011; Waters-Metenier et al. 2014). Furthermore, coupled with physical therapy bilateral stimulation has proven to be beneficial in treating individuals with motor disabilities such as those with stroke (Lindenberg, Renga, Zhu, Nair & Schlaug, 2010; Bologni et al. 2011). Moreover, it has been suggested that the effects of bilateral stimulation are stronger and last longer than unilateral stimulation (Sehm, Kipping, Schäfer, Villringer and Ragert, 2013; Vines et al. 2008). The long-lasting effects of bilateral tDCS make this a more appropriate technique in the treatment for individuals with motor disabilities. A possible explanation of this superior effect, Waters, Wiestler and Diedrichsen (2017) have suggested that higher efficacy for bilateral stimulation is due to electrical currents running transversely, subsequently increasing the plasticity in both primary motor cortices (Waters et al. 2017; Lindenberg, Sieg, Meinzer, Nachtigall & Flöel, 2016).

While past research has suggested beneficial effects of tDCS in paradigms for simple-body movements, the application of tDCS and whole-body motor movement learning has been neglected greatly (Kaminski et al. 2013; Kaminski et al. 2016; Steiner et al. 2016). By identifying the relationship between the two, results can be used to provide a more conclusive evaluation of the effects of tDCS on motor learning. Additionally, the results could also be implemented into treatment programmes to help the motor recovery of individuals who have suffered from illnesses and diseases. Therefore, in this study we investigated the effects of different protocols of tDCS on simple dance moves, which is a form of whole-body movement.

2 Experiment 1 – primary motor cortex stimulation

Previous research has shown that the PMC is active during a motor task (Dushanova & Donoghue, 2010; Honda, Wise, Weeks, Deiber & Hallett, 1998; Kakei, Hoffman & Strick, 1999; Muellbacher, Ziemann, Boroojerdi, Cohen & Hallett, 2001). The PMC is important in movement and more specifically motor learning because it facilitates; motor adaptation (Ehsani et al. 2016), skilled voluntary movements (Kida & Mitsushima, 2018) and fast online performance improvement (Karok, Fletcher & Whitney, 2017). Consequently, tDCS of the PMC also enhances movement (McCambridge, Bradnam, Stinear & Byblow, 2011), motor learning (Ciechanski & Kirton, 2016; Yamaguchi et al. 2020), motor sequence learning (Hashemirad et al. 2016; Stagg et al. 2011) and motor learning of novel skills (Dumel et al. 2018).

We hypothesised that active anodal-tDCS over the right-PMC will be more beneficial than sham stimulation at improving an individual’s ability to learn dance moves. Furthermore, we hypothesised that bilateral anodal tDCS over both motor cortices will be more advantageous than unilateral stimulation over the right-PMC at improving an individual’s ability to learn dance moves.

2.1 Method

2.1.1 Participants

The sample included 30 participants (29 females, age mean[SD] = 18.97[1.26] years old). None of the participants had experience with Latin or Ballroom dancing, as indicated in a pre-study questionnaire. All participants gave written informed consent. The study was approved by the local ethics committee in the School of Psychology at the University of Kent.

2.1.2 Materials

Dance videos and scoring

Twelve dance videos were recorded. For the details of the dance moves please see Appendix A. Each move was performed by a male and a female dancer, so to match the participants' gender. Criteria for the scoring stimuli was created by an experienced Latin and Ballroom dancer. Participants were evaluated on posture, size of movement, timing, arms, legs and overall performance ability. Criteria for arms, legs and overall performance was different depending on the move performed. Please see Appendix A for the details. Scoring was done by the two experimenters (one experienced Ballroom and Latin dancer and one with limited experience), there was a significant positive relationship between both experimenters ($r(46) = .865$, $p< 0.001$), indicating that there is a strong inter-rater reliability between the marking scores of each experimenter.

Transcranial Direct Current Stimulation (tDCS)

One or two tDCS (NeuroConn, Germany) stimulators were used with current amplitude of 1.5mA and 10 seconds ramp up and down. 1.5mA was used as previous research has suggested that 2mA does not improve learning (Hoy et al. 2013; Parkin, Bhandri, Glen & Walsh, 2019) and 1.5mA was more effective in a motor learning task than

1mA (Cuypers et al. 2013). Stimulation was applied to either the right PMC (Unilateral stimulation) or both primary motor cortices (Bilateral stimulation). According to the international EEG 10-20 system, the active anodal electrode was placed on either C4 (Unilateral stimulation), or C3 and C4 (Bilateral stimulation) (Jasper, 1958). Depending on the stimulation protocol one or two cathode electrodes were placed on the upper arms, contralateral to the side of corresponding anode electrode, Figure 1. Electrodes were 5×5cm^{2}, and were soaked in salt-water solution. For unilateral and bilateral stimulation protocols, stimulation was applied for five minutes before motor learning commenced, and then continued throughout the training paradigm which lasted 15 minutes, for a total time of 20 minutes. For sham stimulation, the placement of the electrodes was the same as unilateral stimulation, however stimulation was only applied for 10 seconds before being turned off.

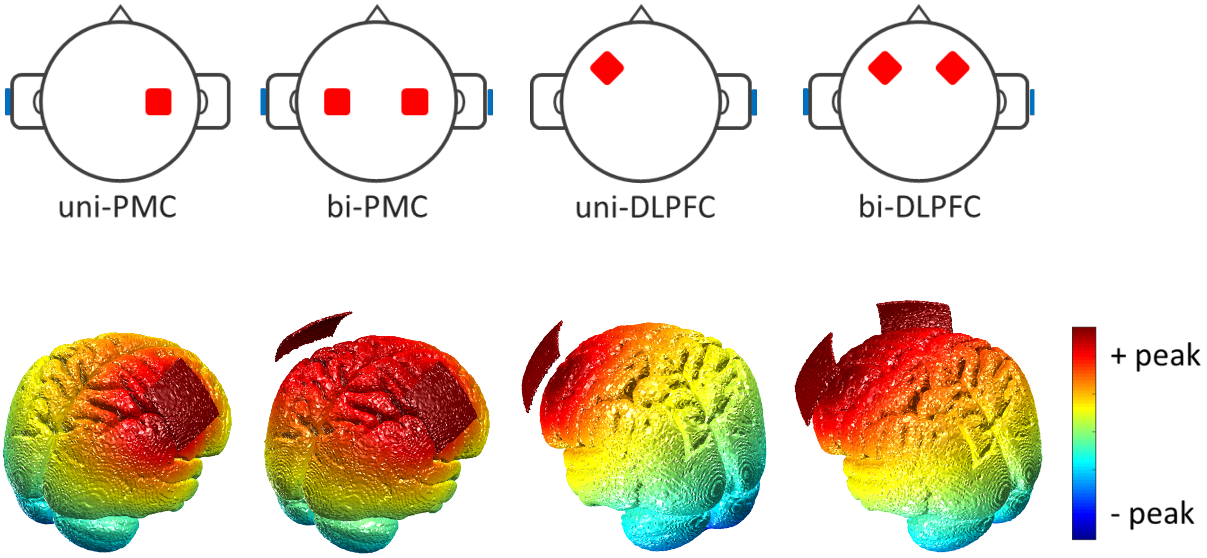


Figure 1. Placement of the electrodes (top panel) and simulation of the brain stimulation (bottom panel) (Huang et al, 2019) for Experiment 1 (stimulation of the primary motor cortex; PMC) and Experiment 2 (stimulation of the dorsolateral prefrontal cortex; DLPFC) using unilateral (uni-) and

bilateral (bi-) electrode montage. Anode electrodes were placed on the target area and cathode electrodes were placed on the contralateral shoulder.

2.2 Design

A within-subjects design was used; participants were involved in all three conditions of the experiment. The independent variable had three levels (Bilateral/Unilateral/Sham). The dependent variable was percentage change in participants' dancing ability from the baseline, scored based on the criteria. This was measured over three different days; baseline test, outcome measure one and outcome measure two.

2.3 Procedure

The study involved six sessions over seven separate days; a baseline measure, three consecutive tDCS training sessions, an outcome measure one and an outcome measure two, see Figure 2.

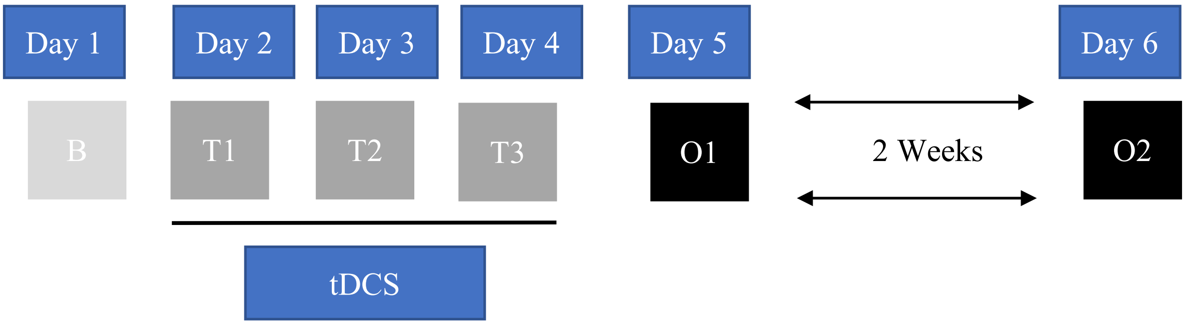


Figure 2. Summary of the procedure of the study. Participants took part in one baseline measure (B), followed by three training sessions (T1, T2 & T3) in which they received dance training in combination with different protocols of brain stimulation. Following the intervention, two outcome measures were conducted to investigate effects of training immediately following training (Post-intervention, O1) and lasting effects of training (Follow-up, O2).

The baseline measure involved the participant undertaking the dance test, where they were tested on all 12 moves. There were four ballroom moves, including Walz Box Step Forward, and Eight Latin moves, including Cha Cha New York and Samba Basic (Appendix A). Participants would first watch the dance move performed twice and then they would perform the move to the best of their ability (without watching the video), this is when they would be marked on their dance ability. Once they have performed the move the test would proceed to the next move.

In each training session, the participant underwent a different type of brain stimulation; the stimulation type was randomised and the participant was blind to the type of stimulation being received. Whilst stimulation was running the participant practiced four of the original 12 moves. T1, T2 and T3 all involved a different set of 4 dance moves. The participant observed the move twice, danced along with the video four times, danced alone three times, danced along with the video twice more and then danced alone for a final time. After this sequence is completed the next move will be shown. The outcome measure one and outcome measure two involved the same procedure as the baseline measure.

2.4 **Analysis**

To account for inter-subject variability, participants' percentage change on sessions O1 and O2 was calculated based on their performance in the baseline session. A 3×2 repeated measure analysis of variance (rANOVA) was run with stimulation condition (Bilateral/Unilateral/ Sham) and session (Post-intervention/Follow-up) as within subject factors and performance percentage change as dependent variable.

2.5 Results

The rANOVA showed a significant main effect of stimulation condition ($F(2,58) = 5.417$, $p = 0.007$, $\eta_p^2 = 0.157$) and session ($F(1,29) = 37.491$, $p < 0.001$, $\eta_p^2 = 0.564$), but a non-significant interaction effect ($F(2,58) = 0.230$, $p = 0.795$, $\eta_p^2 = 0.008$). Post-hoc paired-sample t-tests showed significant difference between Sham and Unilateral (Sham mean[SD] = 42.73[0.18]%, Unilateral 37.52[0.15]%, t(29) = 2.213, p = 0.038, d = 0.404), and Sham and Bilateral (Bilateral 35.14[0.14]%, t(29) = 3.033, p = 0.006, d = 0.554), but no significant difference between Unilateral and Bilateral (t(29) = 0.921, p = 0.257, d = 0.168). See Figure 3 for a summary of the performance of the participants.

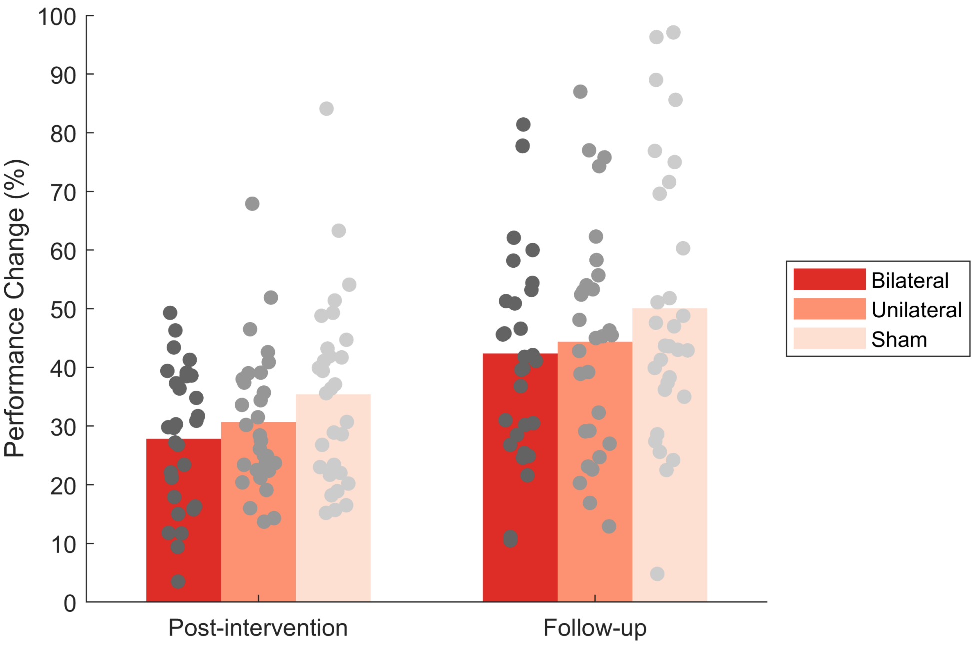


Figure 3. Performance percentage change from the baseline for the participants in different conditions and sessions in Experiment 1 with stimulation of the primary motor cortex. Sham stimulation showed significantly higher performance as compared to Unilateral ($p = 0.038$) and Bilateral ($p = 0.006$) stimulation conditions across the two testing sessions.

2.6 Summary

We investigated the effect of unilateral anodal stimulation over the right-PMC and bilateral anodal stimulation over both motor cortices on the learning of Ballroom and Latin dance moves. It was expected that active stimulation would be more effective than sham stimulation at improving dance performance and that specifically bilateral stimulation would be more beneficial than unilateral stimulation. However, contrary to our hypotheses, our analysis suggested that both unilateral and bilateral stimulation impaired performance, considering that the performance in the stimulation conditions improved significantly less than the sham condition. Despite post-hoc indicating no significant difference between unilateral and bilateral, unilateral caused slightly lower impairment compared to bilateral.

3 Experiment 2 – dorsolateral prefrontal cortex stimulation

Another brain region which has been suggested to be involved in motor learning, and more specifically whole-body movement is the DLPFC. The DLPFC is associated with working-memory (Techayusukcharoen, Iida and Aoki, 2019), long-term memory (Blumenfeld & Ranganath, 2006), attention (Kondo, Osaka & Osaka, 2004), planning (Kaller et al. 2011) and reasoning (Nelson et al. 2016). Subsequently, such aspects have also been heightened through the use of tDCS (Boggio et al. 2006; Fregni et al. 2005; Harty et al. 2014; Javadi & Walsh, 2012; Javadi, Cheng & Walsh, 2012). The DLPFC is important as it links visual cues with information within working memory to produce the required movement (Fuster, 2001). Additionally, Fujiyama (2016) suggests that the DLPFC is active in both preparation of movement but also control of movement. Specifically, the DLPFC is prominent when the task is both novel and the learning paradigm involves observation and imitation learning (Mineo et al. 2018). These aspects are important in the process of learning dance, therefore, suggesting that the DLPFC may be an efficacious brain region for improving an individual's ability in motor learning (Pascual-Leone, Wassermann, Grafman and Hallett, 1996). Additionally, it has been shown that tDCS over the DLPFC can modulate task switching and multitasking (Leite, Carvalho, Regni and Goncalves, 2011; Frank, Harty, Kluge & Kadosh, 2018; Hsu, Zanto, Anguera, Lin & Gazzaley, 2015, Nelson et al. 2016), which are important for whole-body movement as individuals will need to think about both spatial awareness and coordination concordantly.

We hypothesised that active anodal tDCS over the left-DLPFC will be more beneficial than sham stimulation at improving an individual's ability to learn dance moves. Furthermore, we hypothesised that bilateral anodal-tDCS will be more advantageous than unilateral stimulation at improving an individual's ability to learn dance moves.

3.1 Method

3.1.1 Participants

The sample included 31 participants (all females, age Mean[SD] = 19.32[1.33] years old). None of the participants had experience with Latin or Ballroom dancing, as indicated in a pre-study questionnaire.

3.1.2 Materials

The same materials were used for both experiments.

Transcranial Direct Current Stimulation (tDCS)

One or two tDCS (NeuroConn, Germany) stimulators were used, depending on the protocol), with current amplitude of 1.5mA and 10 seconds ramp up and down. Stimulation was applied to either the left-DLPFC (Unilateral stimulation) or both the left- and right-DLPFC (Bilateral stimulation). According to the international EEG 10-20 system, the active anodal electrode was placed on either the F3 (Unilateral stimulation), or F3 and F4 (Bilateral stimulation) (Jasper, 1958). The cathode electrode was applied on the upper arm, contralateral to the side of the anode electrode. When the protocol required bilateral stimulation both upper arms were used, Figure 1. Electrodes were 5×5cm^2, and were soaked in a salt-water solution. For sham stimulation, electrode placement was that of the unilateral condition, however stimulation was only applied for 10 seconds before being turned off.

3.1.3 **Procedure**

The procedure used for the first experiment was repeated for the second experiment.

3.2 **Results**

An rANOVA was run with stimulation condition (Bilateral/Unilateral/Sham) and session (Post-intervention/Follow-up) as within subject factors on performance percentage change from baseline. Results showed a significant main effect of condition ($F(2,46)= 7.517$, $p = 0.001$, $\eta_p^2 = 0.246$) and a significant main effect session ($F(1,23)= 65.586$, $p < 0.001$, $\eta_p^2 = 0.740$), but a non-significant interaction effect ($F(2,46)= 0.542$, $p = 0.585$, $\eta_p^2 =0.023$).

Post-hoc paired-sample t-tests showed a non-significant difference between Sham and Unilateral (Sham mean[SD] = 42.40[0.18]%, Unilateral 44.20[0.18]%, t(29) = 0.740, p = 0.298, d = 0.135), but a significant difference between Sham and Bilateral (Bilateral 34.20[0.14]%, t(29) = 2.562, p = 0.019, d = 0.468), and Unilateral and Bilateral (t(29) = 3.421, p = 0.003, d = 0.625). See Figure 4 for a summary of the performance of the participants.

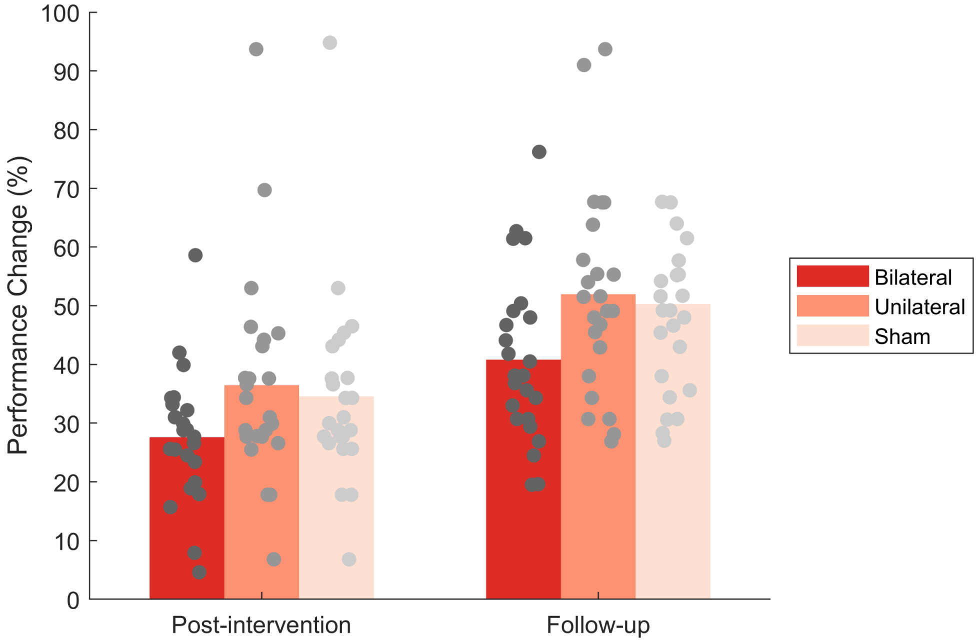


Figure 4. Performance percentage change from the baseline for the participants in different conditions and sessions in Experiment 2 with stimulation of the dorsolateral prefrontal cortex. Bilateral stimulation showed significantly lower performance compared to Sham ($p = 0.019$) and Unilateral ($p = 0.003$) stimulation conditions across the two testing sessions.

3.3 Summary

In the second experiment, we investigated the effects of unilateral anodal-tDCS over the left-DLPFC and bilateral anodal-tDCS over both DLPFC, on the learning of Ballroom and Latin dance moves. Similar to the first experiment, we expected that active stimulation would be more effective than sham stimulation in improving dance performance and that bilateral would be more effective than unilateral. Contrary to our hypotheses, it was found that unilateral tDCS did not significantly improve performance compared to the Sham condition. Furthermore, bilateral stimulation impaired performance as compared to the other conditions.

4 Discussion

In this study, we investigated the effect of tDCS on motor behaviour that requires whole-body movement. Stimulation was delivered either unilaterally or bilaterally over either the PMC or DLPFC. Our results showed that bilateral stimulation impaired performance as compared to the sham stimulation, regardless of area of stimulation. Unilateral stimulation showed impairing effects only if applied to the right-PMC. Unilateral stimulation of the left-DLPFC did not differ significantly from the sham stimulation.

There is an abundance of research, which has successfully found a positive effect of tDCS on motor movement and learning (Kang, Summers & Cauraugh, 2016; Nitsche et al. 2003; Reis & Fritsch, 2011). These studies, however, demonstrated learning effects through simple motor tasks, which have very limited ecological validity (Ronsse et al. 2009). Every day activities are dependent on complex whole-body motor movement, multi-tasking and an awareness of direction in space and speed (Bläsing, Calvo-Merino, Cross & Jola, 2012). Our results showed impairing effects of bilateral tDCS over PMC and DLPFC, and also impairing effect of unilateral tDCS over PMC. Therefore, special considerations need to be made in order to harness beneficial effects of tDCS. A few mechanisms could explain the impairing effects observed in this study.

Effects of tDCS on motor performance is contingent on the complexity of the task. Previous research has found that PMC stimulation does not improve performance on bimanual or complex tasks (Fleming et al. 2017; Furuya, Klaus, Nitsche, Paulus & Altenmüller, 2014; Mesquita, Lage, Franchini, Romano-Silva & Alberquerque, 2019; Pixa, Berger, Steinberg & Doppelayr, 2019), which are cognitively more demanding (Szameitat, Lesien, von Cramon, Sterr & Schubert, 2006). Complex motor tasks engage brain networks beyond networks engaged in simple motor tasks. Therefore, stimulation protocols used for simple motor movements might not be suitable for complex whole-body movements (Pixa & Pollok, 2018). For complex whole-body movements, individuals not only need to coordinate their body parts, but they also need to attend to and organise multiple pieces of information (Brown, Martinez & Parsons, 2005). Additionally, research has suggested that the modulation of one region is not appropriate for complex whole-body movement (Fischer et al. 2017; Pixa & Pollok, 2018; Vancleef, Meesen, Swinnen & Fujiyama, 2016). Therefore, while stimulation of the motor cortex might help with motor movement, and stimulation of the DLPFC might help with information processing, isolated stimulation of these brain areas might not be able to drive complex brain networks required in complex whole-body movements such as dance.

Contrary to the majority of past research, our results showed that bilateral tDCS in both experiments led to impaired performance. One possible explanation is that the effects of tDCS might reverse depending on the task. Bortoletto, Pellicciari, Rodella and Miniussi (2014) found that when anodal-tDCS of the right-PMC was paired with a fast motor learning protocol compared to a slow motor learning protocol, learning and performance was reduced. Authors suggested that the learning of a fast motor task increases cortical excitability alone and that in addition to the excitatory effects of tDCS lead to reversal of the facilitatory effects. According to the neuronal-noise framework the effects of tDCS are dependent on the strength of the signal in relation to the amount of noise present (Miniussi, Harris & Ruzzoli, 2013). Signal relates to neural activity operational to the task and the noise conveys random neural activity.

tDCS effects are state-dependant (Hsu, Juan & Tseng, 2016). Subsequently, Pixa and Pollok (2018) suggest that during complex movement there is increased activity in prefrontal, parietal and temporal areas. Hence because neurones are highly active due to motor practice the noise levels will increase, subsequently decreasing the signal-to-noise ratio and impairing performance. Additionally, Miniussi et al. (2013) found that the reversibility effects of tDCS are also seen when tasks, which require skill but are not established, are combined with tDCS.

As motor-tasks become more established neuronal noise levels decrease, leaving the signal to clearly materialise and allow anodal-tDCS to enable performance improvement. For participants within our study, Ballroom and Latin dance was a novel task. So, it can be expected that neuronal noise levels were high. Therefore, any tDCS applied would have impaired learning and performance of dance. Therefore, it could be suggested that by practicing more and allowing the task to become more habitual the signal will be able to materialise more clearly allowing tDCS to improve behaviour.

Another possible explanation for the impairing effects of bilateral tDCS in our study is that we stimulated both literalities with the same polarity (anodal), while the majority of past research applying bilateral tDCS used an incongruent montage; for example, anodal-tDCS of the right-PMC and cathodal-tDCS of the left-PMC. This incongruent montage has proved beneficial in improving; dual task performance (Ljubisavljevic et al. 2019), motor learning (Karok & Witney, 2013), fatigue in fast motor tasks (Arias et al. 2016) and rehabilitation for stroke patients (Goodwill, Tea, Morgan, Daly & Kidgell, 2016; Lefebvre et al. 2013). It has, however, shown that incongruent bilateral tDCS favours one laterality over the other. Javadi et al. (2015) showed that anodal- and cathodal-tDCS of the right- and left-PMC, respectively, leads to increased and decreased response on the left- and right-hand side of the body, respectively. Inversely, the opposite polarity of stimulation led to the opposite effect. Similarly, research using incongruent montages, use this montage to solely modulate a specific limb (Arias et al. 2016; Karok et al. 2017; Mordillo-Mateos et al. 2012; Naros et al. 2016; Vines et al. 2008). The success of this tDCS protocol is suggested to be due to the reduction of interhemispheric inhibition. This idea of decreasing the excitability of one hemisphere to promote the excitability of the other hemisphere is logical when we are improving unimanual skills, where cortical excitability is localised to one area (Gomes-Osman & Field-Fote, 2013). But with whole-body and complex movements balanced bilateral activation and effective communication between the hemispheres is required (Chettouf, Rueda-Delgado, de Vries, Ritter & Daffertshofer, 2020; Waller, Forrester, Villagra & Whitall, 2008). Therefore, we opted not to use incongruent stimulation and instead apply anodal-tDCS bilaterally.

Previous research has found success with anodal bilateral stimulation. Angius et al. (2018) showed that with anodal bilateral tDCS, participants had increased endurance in a cycling task. Hadoush, Al-Jarrah, Khalil, Al-Sharman and Al-Ghazawi (2018) suggested that bilateral anodal-tDCS to the DLPFC and PMC, concordantly, improved balance and functional ability and in turn reduced fear of falling. And Gomes-Osman and Field-Fote (2013), found that after bilateral anodal-tDCS, participants performed better on a bimanual typing task. However, the nature of these tasks is simple requiring minimal cognitive input to perform the tasks successfully. Therefore, the comparability to this study is reduced. Subsequently, Mequita et al. (2019), also showed a deleterious effect of anodal bilateral tDCS, within a taekwondo task. This task is similar to the dance task, involved in this study, in that it required high complexity involving multi-joint actions and awareness of self in space. Consequently, this reaffirms the importance of considering task complexity when modulating motor behaviour with tDCS.

A possible limitation of this study is that we did not measure the adverse effects of the stimulation on participants. Participants were blinded to type of stimulation they were receiving, however this was not tested. It is known that tDCS can cause mild irritation. Subsequently with bilateral tDCS there would have been more irritation than with unilateral stimulation. Therefore, the increased irritation, with bilateral tDCS, may have made it harder for participants to focus on learning the dance moves. Accordingly, it would be useful for future research to evaluate the effect of tDCS irritation has on learning motor tasks.

Additionally, stimulation would not have been focal (see figure 1). The size of the electrodes ($25cm^2$) would result in other areas of the brain being stimulated, regions which may not be crucial in the enhancement of motor learning, or may be inhibitory to motor learning.

Bastani and Jaberzadeh (2013) found that 12cm^2 electrodes increased corticospinal activity the most compared to 25cm^2 and 35cm^2 electrodes. Thus, using smaller electrodes will increase the efficacy of stimulating the primary region of choice.

When using tDCS for clinical purposes, a unilateral or incongruent montage is most often used (Kim, Lee, Kim, Cho & Paik, 2019; Lefebvre et al. 2013). Primarily in clinical studies which use tDCS, the purpose is to improve performance only on the affected side of the brain (Bolognini et al. 2011; Raithatha et al. 2016; Yozbatiran et al. 2016). Both unilateral and incongruent bilateral tDCS can offer explanations to how this process happens. Contrarily, as research using a congruent bilateral montage is much rarer there are many unknowns about the mechanistic effects. The same can additionally be said for complex motor movement, where the neural underpinnings are still uncertain. Therefore, to apply congruent tDCS to a clinical population without knowing how it will affect the neural mechanisms is unwise as a further detriment to their movement could be made.

The initial literature suggested that performance effects are heavily influenced by an individual's baseline performance. Whilst this study made sure that all participants did not have Ballroom and Latin dance experience, there would still have been differences in baseline score due to individual's differing in speed of learning, coordination and rhythm. Subsequently, it would be able to see if participants who had lower initial baseline scores benefited from the tES protocol more than individuals with higher baseline scores.

To summarise, when we are looking at modulating brain regions in association with motor learning, complexity of the task needs to be considered. Furthermore, research needs to look more closely about the neural mechanisms that underpin complex whole-body movement and how such mechanisms can be modulated. While there is a great body of literature on the improving effects of tDCS on simple motor learning tasks, tDCS in combination with complex whole-body movements should be considered cautiously.

5 References

Allman, C., Amadi, U., Winkler, A. M., Wilkins, L., Filippini, N., Kischka, U., ... & Johansen-Berg, H. (2016). Ipsilesional anodal tDCS enhances the functional benefits of rehabilitation in patients after stroke. *Science translational medicine*, *8*(330), 330re1-330re1.

Ambrus, G. G., Pisoni, A., Primaßin, A., Turi, Z., Paulus, W., & Antal, A. (2015). Bi-frontal transcranial alternating current stimulation in the ripple range reduced overnight forgetting. *Frontiers in cellular neuroscience*, *9*, 374.

Angius, L., Mauger, A. R., Hopker, J., Pascual-Leone, A., Santarnecchi, E., & Marcora, S. M. (2018). Bilateral extracephalic transcranial direct current stimulation improves endurance performance in healthy individuals. *Brain stimulation*, *11*(1), 108-117.

Apšvalka, D., Ramsey, R., & Cross, E. S. (2018). Anodal tDCS over primary motor cortex provides no advantage to learning motor sequences via observation. *Neural plasticity*, *2018*.

Arciniega, H., Gözenman, F., Jones, K. T., Stephens, J. A., & Berryhill, M. E. (2018). Frontoparietal tDCS benefits visual working memory in older adults with low working memory capacity. *Frontiers in aging neuroscience*, *10*, 57.

Arias, P., Corral-Bergantiños, Y., Robles-García, V., Madrid, A., Oliviero, A., & Cudeiro, J. (2016). Bilateral tDCS on primary motor cortex: effects on fast arm reaching tasks. *PLoS One*, *11*(8), e0160063.

Arnao, V., Riolo, M., Carduccio, F., Tuttolomondo, A., D’Amelio, M., Brighina, F., ... & Aridon, P. (2019). Effects of transcranial random noise stimulation combined with Graded Repetitive Arm Supplementary Program (GRASP) on motor rehabilitation of the upper limb in sub-acute ischemic stroke patients: a randomized pilot study. *Journal of Neural Transmission*, *126*(12), 1701-1706.

Baciu, M., Boudiaf, N., Cousin, E., Perrone-Bertolotti, M., Pichat, C., Fournet, N., ... & Krainik, A. (2016). Functional MRI evidence for the decline of word retrieval and generation during normal aging. *Age*, *38*(1), 3.

Baddeley, A., Logie, R., Bressi, S., Sala, S. D., & Spinnler, H. (1986). Dementia and working memory. *The Quarterly Journal of Experimental Psychology Section A*, *38*(4), 603-618.

Bastani, A., & Jaberzadeh, S. (2013). a-tDCS differential modulation of corticospinal excitability: the effects of electrode size. *Brain stimulation*, *6*(6), 932-937.

Bechara, A. (2001, July). Neurobiology of decision-making: risk and reward. In *Seminars in clinical neuropsychiatry* (Vol. 6, No. 3, p. 205).

Bindman, L. J., Lippold, O. C. J., & Redfearn, J. W. T. (1964). The action of brief polarizing currents on the cerebral cortex of the rat (1) during current flow and (2) in the production of long-lasting after-effects. *The Journal of physiology*, *172*(3), 369.

Bläsing, B., Calvo-Merino, B., Cross, E. S., Jola, C., Honisch, J., & Stevens, C. J. (2012). Neurocognitive control in dance perception and performance. *Acta psychologica*, *139*(2), 300-308.

Blumenfeld, R. S., & Ranganath, C. (2006). Dorsolateral prefrontal cortex promotes long-term memory formation through its role in working memory organization. *Journal of Neuroscience*, *26*(3), 916-925.

Boggio, P. S., Campanhã, C., Valasek, C. A., Fecteau, S., Pascual-Leone, A., & Fregni, F. (2010). Modulation of decision-making in a gambling task in older adults with transcranial direct current stimulation. *European Journal of Neuroscience*, *31*(3), 593-597.

Boggio, P. S., Ferrucci, R., Mameli, F., Martins, D., Martins, O., Vergari, M., ... & Priori, A. (2012). Prolonged visual memory enhancement after direct current stimulation in Alzheimer's disease. *Brain stimulation*, *5*(3), 223-230.

Boggio, P. S., Ferrucci, R., Rigonatti, S. P., Covre, P., Nitsche, M., Pascual-Leone, A., & Fregni, F. (2006). Effects of transcranial direct current stimulation on working memory in patients with Parkinson's disease. *Journal of the neurological sciences*, *249*(1), 31-38.

Bolognini, N., Vallar, G., Casati, C., Latif, L. A., El-Nazer, R., Williams, J., ... & Fregni, F. (2011). Neurophysiological and behavioral effects of tDCS combined with constraint-induced movement therapy in poststroke patients. *Neurorehabilitation and neural repair*, *25*(9), 819-829.

Bortoletto, M., Pellicciari, M. C., Rodella, C., & Miniussi, C. (2015). The interaction with task-induced activity is more important than polarization: a tDCS study. *Brain stimulation*, *8*(2), 269-276.

Brevet-Aeby, C., Brunelin, J., Iceta, S., Padovan, C., & Poulet, E. (2016). Prefrontal cortex and impulsivity: Interest of noninvasive brain stimulation. *Neuroscience & Biobehavioral Reviews*, *71*, 112-134.

Broe, G. A., Jorm, A. F., Creasey, H., Grayson, D., Edelbrook, D., Waite, L. M., ... & Casey, A. (1999). Impact of chronic systemic and neurological disorders on disability, depression and life satisfaction. *International journal of geriatric psychiatry*, *14*(6), 497-499.

Brown, S., Martinez, M. J., & Parsons, L. M. (2006). The neural basis of human dance. *Cerebral cortex*, *16*(8), 1157-1167.

Brunoni, A. R., Zanao, T. A., Vanderhasselt, M. A., Valiengo, L., de Oliveira, J. F., Boggio, P. S., ... & Fregni, F. (2014). Enhancement of affective processing induced by bifrontal transcranial direct current stimulation in patients with major depression. *Neuromodulation: Technology at the Neural Interface*, *17*(2), 138-142.

Castro-Meneses, L. J., Johnson, B. W., & Sowman, P. F. (2015). The effects of impulsivity and proactive inhibition on reactive inhibition and the go process: insights from vocal and manual stop signal tasks. *Frontiers in human neuroscience*, *9*, 529.

Chettouf, S., Rueda-Delgado, L. M., de Vries, R., Ritter, P., & Daffertshofer, A. (2020). Are unimanual movements bilateral?. *Neuroscience & Biobehavioral Reviews*.

Chi, R. P., Fregni, F., & Snyder, A. W. (2010). Visual memory improved by non-invasive brain stimulation. *Brain Research*, *1353*, 168-175.

Cho, H. S., & Cha, H. G. (2015). Effect of mirror therapy with tDCS on functional recovery of the upper extremity of stroke patients. *Journal of physical therapy science*, *27*(4), 1045-1047.

Ciechanski, P., & Kirton, A. (2016). Transcranial direct-current stimulation (tDCS): principles and emerging applications in children. In *Pediatric Brain Stimulation* (pp. 85-115). Academic Press.

Colcombe, S. J., Kramer, A. F., Erickson, K. I., & Scalf, P. (2005). The implications of cortical recruitment and brain morphology for individual differences in inhibitory function in aging humans. *Psychology and aging*, *20*(3), 363.

Cunillera, T., Brignani, D., Cucurell, D., Fuentemilla, L., & Miniussi, C. (2016). The right inferior frontal cortex in response inhibition: A tDCS–ERP co-registration study. *Neuroimage*, *140*, 66-75.

Cunillera, T., Fuentemilla, L., Brignani, D., Cucurell, D., & Miniussi, C. (2014). A simultaneous modulation of reactive and proactive inhibition processes by anodal tDCS on the right inferior frontal cortex. *PloS one*, *9*(11), e113537.

Cuypers, K., Leenus, D. J., van den Berg, F. E., Nitsche, M. A., Thijs, H., Wenderoth, N., & Meesen, R. L. (2013). Is motor learning mediated by tDCS intensity?. *PLoS One*, *8*(6), e67344.

Dambacher, F., Schuhmann, T., Lobbestael, J., Arntz, A., Brugman, S., & Sack, A. T. (2015). No effects of bilateral tDCS over inferior frontal gyrus on response inhibition and aggression. *PloS one*, *10*(7), e0132170.

Di Lazzaro, V., Dileone, M., Capone, F., Pellegrino, G., Ranieri, F., Musumeci, G., ... & Fregni, F. (2014). Immediate and late modulation of interhemipheric imbalance with bilateral transcranial direct current stimulation in acute stroke. *Brain stimulation*, *7*(6), 841-848.

Dumel, G., Bourassa, M. È., Charlebois-Plante, C., Desjardins, M., Doyon, J., Saint-Amour, D., & De Beaumont, L. (2018). Multisession anodal transcranial direct current stimulation induces motor cortex plasticity enhancement and motor learning generalization in an aging population. *Clinical Neurophysiology*, *129*(2), 494-502.

Dushanova, J., & Donoghue, J. (2010). Neurons in primary motor cortex engaged during action observation. *European Journal of Neuroscience*, *31*(2), 386-398.

Edgcumbe, D. R., Thoma, V., Rivolta, D., Nitsche, M. A., & Fu, C. H. (2019). Anodal transcranial direct current stimulation over the right dorsolateral prefrontal cortex enhances reflective judgment and decision-making. *Brain stimulation*, *12*(3), 652-658.

Ehsani, F., Bakhtiary, A. H., Jaberzadeh, S., Talimkhani, A., & Hajihasani, A. (2016). Differential effects of primary motor cortex and cerebellar transcranial direct current stimulation on motor learning in healthy individuals: a randomized double-blind sham-controlled study. *Neuroscience research*, *112*, 10-19.

England, H. B., Fyock, C., Gillis, M. M., & Hampstead, B. M. (2015). Transcranial direct current stimulation modulates spatial memory in cognitively intact adults. *Behavioural brain research*, *283*, 191-195.

Fecteau, S., Knoch, D., Fregni, F., Sultani, N., Boggio, P., & Pascual-Leone, A. (2007). Diminishing risk-taking behavior by modulating activity in the prefrontal cortex: a direct current stimulation study. *Journal of Neuroscience*, *27*(46), 12500-12505.

Fecteau, S., Pascual-Leone, A., Zald, D. H., Liguori, P., Théoret, H., Boggio, P. S., & Fregni, F. (2007). Activation of prefrontal cortex by transcranial direct current stimulation reduces appetite for risk during ambiguous decision making. *Journal of Neuroscience*, *27*(23), 6212-6218.

Ferrucci, R., Mrakic-Sposta, S., Gardini, S., Ruggiero, F., Vergari, M., Mameli, F., ... & Pietroboni, A. M. (2018). Behavioral and neurophysiological effects of transcranial direct current stimulation (tDCS) in fronto-temporal dementia. *Frontiers in behavioral neuroscience*, *12*, 235.

Fiori, V., Nitsche, M., Iasevoli, L., Cucuzza, G., Caltagirone, C., & Marangolo, P. (2017). Differential effects of bihemispheric and unihemispheric transcranial direct current stimulation in young and elderly adults in verbal learning. *Behavioural brain research*, *321*, 170-175.

Fischer, D. B., Fried, P. J., Ruffini, G., Ripolles, O., Salvador, R., Banus, J., ... & Fox, M. D. (2017). Multifocal tDCS targeting the resting state motor network increases cortical excitability beyond traditional tDCS targeting unilateral motor cortex. *Neuroimage*, *157*, 34-44.

Fleming, M. K., Rothwell, J. C., Sztriha, L., Teo, J. T., & Newham, D. J. (2017). The effect of transcranial direct current stimulation on motor sequence learning and upper limb function after stroke. *Clinical Neurophysiology*, *128*(7), 1389-1398.

Fling, B. W., Peltier, S., Bo, J., Welsh, R. C., & Seidler, R. D. (2011). Age differences in interhemispheric interactions: callosal structure, physiological function, and behavior. *Frontiers in neuroscience*, *5*, 38.

Frank, B., Harty, S., Kluge, A., & Cohen Kadosh, R. (2018). Learning while multitasking: short and long-term benefits of brain stimulation. *Ergonomics*, *61*(11), 1454-1463.

Fregni, F., Boggio, P. S., Nitsche, M., Bermpohl, F., Antal, A., Feredoes, E., ... & Pascual-Leone, A. (2005). Anodal transcranial direct current stimulation of prefrontal cortex enhances working memory. *Experimental brain research*, *166*(1), 23-30.

Fregni, F., Orsati, F., Pedrosa, W., Fecteau, S., Tome, F. A., Nitsche, M. A., ... & Boggio, P. S. (2008). Transcranial direct current stimulation of the prefrontal cortex modulates the desire for specific foods. *Appetite*, *51*(1), 34-41.

Fujiyama, H., Van Soom, J., Rens, G., Cuypers, K., Heise, K. F., Levin, O., & Swinnen, S. P. (2016). Performing two different actions simultaneously: The critical role of interhemispheric interactions during the preparation of bimanual movement. *Cortex*, *77*, 141-154.

Furuya, S., Klaus, M., Nitsche, M. A., Paulus, W., & Altenmüller, E. (2014). Ceiling effects prevent further improvement of transcranial stimulation in skilled musicians. *Journal of Neuroscience*, *34*(41), 13834-13839.

Fuster, J. M. (2001). The prefrontal cortex—an update: time is of the essence. *Neuron*, *30*(2), 319-333.

Gibson, B. C., Mullins, T. S., Heinrich, M. D., Witkiewitz, K., Alfred, B. Y., Hansberger, J. T., & Clark, V. P. (2020). Transcranial direct current stimulation facilitates category learning. *Brain Stimulation*, *13*(2), 393-400.

Giustiniani, A., Tarantino, V., Bonaventura, R. E., Smirni, D., Turriziani, P., & Oliveri, M. (2019). Effects of low-gamma tACS on primary motor cortex in implicit motor learning. *Behavioural brain research*, *376*, 112170.

Gomes-Osman, J., & Field-Fote, E. C. (2013). Bihemispheric anodal corticomotor stimulation using transcranial direct current stimulation improves bimanual typing task performance. *Journal of motor behavior*, *45*(4), 361-367.

Goodwill, A. M., Teo, W. P., Morgan, P., Daly, R. M., & Kidgell, D. J. (2016). Bihemispheric-tDCS and upper limb rehabilitation improves retention of motor function in chronic stroke: a pilot study. *Frontiers in human neuroscience*, *10*, 258.

Grady, C. L., McIntosh, A. R., Bookstein, F., Horwitz, B., Rapoport, S. I., & Haxby, J. V. (1998). Age-related changes in regional cerebral blood flow during working memory for faces. *Neuroimage*, *8*(4), 409-425.

Hadoush, H., Al-Jarrah, M., Khalil, H., Al-Sharman, A., & Al-Ghazawi, S. (2018). Bilateral anodal transcranial direct current stimulation effect on balance and fearing of fall in patient with Parkinson’s disease. *NeuroRehabilitation*, *42*(1), 63-68.

Harty, S., Robertson, I. H., Miniussi, C., Sheehy, O. C., Devine, C. A., McCreery, S., & O'Connell, R. G. (2014). Transcranial direct current stimulation over right dorsolateral prefrontal cortex enhances error awareness in older age. *Journal of Neuroscience*, *34*(10), 3646-3652.

Hashemirad, F., Zoghi, M., Fitzgerald, P. B., & Jaberzadeh, S. (2016). The effect of anodal transcranial direct current stimulation on motor sequence learning in healthy individuals: a systematic review and meta-analysis. *Brain and cognition*, *102*, 1-12.

Hauser, T. U., Rotzer, S., Grabner, R. H., Mérillat, S., & Jäncke, L. (2013). Enhancing performance in numerical magnitude processing and mental arithmetic using transcranial Direct Current Stimulation (tDCS). *Frontiers in human neuroscience*, *7*, 244.

Heekeren, H. R., Marrett, S., & Ungerleider, L. G. (2008). The neural systems that mediate human perceptual decision making. *Nature reviews neuroscience*, *9*(6), 467-479.

Heinen, K., Sagliano, L., Candini, M., Husain, M., Cappelletti, M., & Zokaei, N. (2016). Cathodal transcranial direct current stimulation over posterior parietal cortex enhances distinct aspects of visual working memory. *Neuropsychologia*, *87*, 35-42.

Heinze, K., Ruh, N., Nitschke, K., Reis, J., Fritsch, B., Unterrainer, J. M., ... & Kaller, C. P. (2014). Transcranial direct current stimulation over left and right DLPFC: lateralized effects on planning performance and related eye movements. *Biological psychology*, *102*, 130-140.

Herrmann, C. S., Rach, S., Neuling, T., & Strüber, D. (2013). Transcranial alternating current stimulation: a review of the underlying mechanisms and modulation of cognitive processes. *Frontiers in human neuroscience*, *7*, 279.

Honda, M., Wise, S. P., Weeks, R. A., Deiber, M. P., & Hallett, M. (1998). Cortical areas with enhanced activation during object-centred spatial information processing. A PET study. *Brain: a journal of neurology*, *121*(11), 2145-2158.

Hoy, K. E., Emonson, M. R., Arnold, S. L., Thomson, R. H., Daskalakis, Z. J., & Fitzgerald, P. B. (2013). Testing the limits: investigating the effect of tDCS dose on working memory enhancement in healthy controls. *Neuropsychologia*, *51*(9), 1777-1784.

Hsu, T. Y., Juan, C. H., & Tseng, P. (2016). Individual differences and state-dependent responses in transcranial direct current stimulation. *Frontiers in human neuroscience*, *10*, 643.

Hsu, W. Y., Zanto, T. P., Anguera, J. A., Lin, Y. Y., & Gazzaley, A. (2015). Delayed enhancement of multitasking performance: effects of anodal transcranial direct current stimulation on the prefrontal cortex. *Cortex*, *69*, 175-185.

Hyder, F., Phelps, E. A., Wiggins, C. J., Labar, K. S., Blamire, A. M., & Shulman, R. G. (1997). "Willed action": a functional MRI study of the human prefrontal cortex during a sensorimotor task. *Proceedings of the National Academy of Sciences*, *94*(13), 6989-6994.

Jackson, A. K., de Albuquerque, L. L., Pantovic, M., Fischer, K. M., Guadagnoli, M. A., Riley, Z. A., & Poston, B. (2019). Cerebellar transcranial direct current stimulation enhances motor learning in a complex overhand throwing task. *The Cerebellum*, *18*(4), 813-816.

Jacoby, N., & Lavidor, M. (2018). Null tDCS effects in a sustained attention task: the modulating role of learning. *Frontiers in psychology*, *9*, 476.

Jasper, H. (1958). Report of the committee on methods of clinical examination in electroencephalography. *Electroencephalogr Clin Neurophysiol*, *10*, 370-375.

Jaušovec, N., & Jaušovec, K. (2014). Increasing working memory capacity with theta transcranial alternating current stimulation (tACS). *Biological psychology*, *96*, 42-47.

Javadi, A. H., Beyko, A., Walsh, V., & Kanai, R. (2015). Transcranial direct current stimulation of the motor cortex biases action choice in a perceptual decision task. *Journal of cognitive neuroscience*, *27*(11), 2174-2185.

Javadi, A.-H., & Walsh, V. (2012). Transcranial direct current stimulation (tDCS) of the left dorsolateral prefrontal cortex modulates declarative memory. *Brain stimulation*, *5*(3), 231-241.

Javadi, A.-H., Cheng, P., & Walsh, V. (2012). Short duration transcranial direct current stimulation (tDCS) modulates verbal memory. *Brain stimulation*, *5*(4), 468-474.

Jones, A. P., Choe, J., Bryant, N. B., Robinson, C. S., Ketz, N. A., Skorheim, S. W., ... & Heinrich, M. D. (2018). Dose-dependent effects of closed-loop tACS delivered during slow-wave oscillations on memory consolidation. *Frontiers in Neuroscience*, *12*, 867.

Jones, K. T., Arciniega, H., & Berryhill, M. E. (2019). Replacing tDCS with theta tACS provides selective, but not general WM benefits. *Brain research*, *1720*, 146324.

Jones, K. T., Johnson, E. L., & Berryhill, M. E. (2020). Frontoparietal theta-gamma interactions track working memory enhancement with training and tDCS. *Neuroimage*, *211*, 116615.

Kakei, S., Hoffman, D. S., & Strick, P. L. (1999). Muscle and movement representations in the primary motor cortex. *Science*, *285*(5436), 2136-2139.

Kaller, C. P., Heinze, K., Frenkel, A., Läppchen, C. H., Unterrainer, J. M., Weiller, C., ... & Rahm, B. (2013). Differential impact of continuous theta-burst stimulation over left and right DLPFC on planning. *Human brain mapping*, *34*(1), 36-51.

Kami, A. T., Sadler, C., Nantel, J., & Carlsen, A. N. (2018). Transcranial direct current stimulation (TDCS) over supplementary motor area (SMA) improves upper limb movement in individuals with Parkinson's disease. *Journal of Exercise, Movement, and Sport (SCAPPS refereed abstracts repository)*, *50*(1), 36-36.

Kaminski, E., Hoff, M., Sehm, B., Taubert, M., Conde, V., Steele, C. J., ... & Ragert, P. (2013). Effect of transcranial direct current stimulation (tDCS) during complex whole body motor skill learning. *Neuroscience letters*, *552*, 76-80.

Kaminski, E., Steele, C. J., Hoff, M., Gundlach, C., Rjosk, V., Sehm, B., ... & Ragert, P. (2016). Transcranial direct current stimulation (tDCS) over primary motor cortex leg area promotes dynamic balance task performance. *Clinical Neurophysiology*, *127*(6), 2455-2462.

Kang, N., Summers, J. J., & Cauraugh, J. H. (2016). Transcranial direct current stimulation facilitates motor learning post-stroke: a systematic review and meta-analysis. *Journal of Neurology, Neurosurgery & Psychiatry*, *87*(4), 345-355.

Karok, S., & Witney, A. G. (2013). Enhanced motor learning following task-concurrent dual transcranial direct current stimulation. *PloS one*, *8*(12), e85693.

Karok, S., Fletcher, D., & Witney, A. G. (2017). Task-specificity of unilateral anodal and dual-M1 tDCS effects on motor learning. *Neuropsychologia*, *94*, 84-95.

Kasahara, K., Tanaka, S., Hanakawa, T., Senoo, A., & Honda, M. (2013). Lateralization of activity in the parietal cortex predicts the effectiveness of bilateral transcranial direct current stimulation on performance of a mental calculation task. *Neuroscience letters*, *545*, 86-90.

Keshvari, F., Pouretemad, H. R., & Ekhtiari, H. (2013). The polarity-dependent effects of the bilateral brain stimulation on working memory. *Basic and Clinical Neuroscience*, *4*(3), 224.

Kida, H., & Mitsushima, D. (2018). Mechanisms of motor learning mediated by synaptic plasticity in rat primary motor cortex. *Neuroscience Research*, *128*, 14-18.

Kim, W. S., Lee, K., Kim, S., Cho, S., & Paik, N. J. (2019). Transcranial direct current stimulation for the treatment of motor impairment following traumatic brain injury. *Journal of NeuroEngineering and Rehabilitation*, *16*(1), 1-10.

Klein, E., Mann, A., Huber, S., Bloechle, J., Willmes, K., Karim, A. A., ... & Moeller, K. (2013). Bilateral bi-cephalic tDCS with two active electrodes of the same polarity modulates bilateral cognitive processes differentially. *PLoS One*, *8*(8), e71607.

Kondo, H., Osaka, N., & Osaka, M. (2004). Cooperation of the anterior cingulate cortex and dorsolateral prefrontal cortex for attention shifting. *Neuroimage*, *23*(2), 670-679.

Krain, A. L., Wilson, A. M., Arbuckle, R., Castellanos, F. X., & Milham, M. P. (2006). Distinct neural mechanisms of risk and ambiguity: a meta-analysis of decision-making. *Neuroimage*, *32*(1), 477-484.

Lakes, K. D., Marvin, S., Rowley, J., San Nicolas, M., Arastoo, S., Viray, L., ... & Jurnak, F. (2016). Dancer perceptions of the cognitive, social, emotional, and physical benefits of modern styles of partnered dancing. *Complementary therapies in medicine*, *26*, 117-122.

Lefebvre, S., Laloux, P., Peeters, A., Desfontaines, P., Jamart, J., & Vandermeeren, Y. (2013). Dual-tDCS enhances online motor skill learning and long-term retention in chronic stroke patients. *Frontiers in human neuroscience*, *6*, 343.

Leite, J., Carvalho, S., Fregni, F., & Gonçalves, O. F. (2011). Task-specific effects of tDCS-induced cortical excitability changes on cognitive and motor sequence set shifting performance. *PloS one*, *6*(9), e24140.

Leite, J., Carvalho, S., Fregni, F., Boggio, P. S., & Gonçalves, Ó. F. (2013). The effects of cross-hemispheric dorsolateral prefrontal cortex transcranial direct current stimulation (tDCS) on task switching. *Brain stimulation*, *6*(4), 660-667.

Leite, J., Gonçalves, Ó. F., Pereira, P., Khadka, N., Bikson, M., Fregni, F., & Carvalho, S. (2018). The differential effects of unihemispheric and bihemispheric tDCS over the inferior frontal gyrus on proactive control. *Neuroscience research*, *130*, 39-46.

Lewald, J. (2016). Modulation of human auditory spatial scene analysis by transcranial direct current stimulation. *Neuropsychologia*, *84*, 282-293.

Lewald, J. (2019). Bihemispheric anodal transcranial direct-current stimulation over temporal cortex enhances auditory selective spatial attention. *Experimental brain research*, *237*(6), 1539-1549.

Lifshitz-Ben-Basat, A., & Mashal, N. (2018). Improving naming abilities among healthy young-old adults using transcranial direct current stimulation. *Journal of psycholinguistic research*, *47*(1), 113-124.

Lindenberg, R., Renga, V., Zhu, L. L., Nair, D., & Schlaug, G. M. D. P. (2010). Bihemispheric brain stimulation facilitates motor recovery in chronic stroke patients. *Neurology*, *75*(24), 2176-2184.

Lindenberg, R., Sieg, M. M., Meinzer, M., Nachtigall, L., & Flöel, A. (2016). Neural correlates of unihemispheric and bihemispheric motor cortex stimulation in healthy young adults. *Neuroimage*, *140*, 141-149.

Ljubisavljevic, M. R., Joji, O., Filipovic, S., Bjekic, J., Szolics, M., & Nagelkerke, N. (2019). Effects of tDCS of Dorsolateral Prefrontal Cortex on Dual-Task Performance Involving Manual Dexterity and Cognitive Task in Healthy Older Adults. *Frontiers in aging neuroscience*, *11*, 144.

Looi, C. Y., Duta, M., Brem, A. K., Huber, S., Nuerk, H. C., & Kadosh, R. C. (2016). Combining brain stimulation and video game to promote long-term transfer of learning and cognitive enhancement. *Scientific reports*, *6*, 22003.

Looi, C. Y., Lim, J., Sella, F., Lolliot, S., Duta, M., Avramenko, A. A., & Kadosh, R. C. (2017). Transcranial random noise stimulation and cognitive training to improve learning and cognition of the atypically developing brain: a pilot study. *Scientific reports*, *7*(1), 1-10.

Luo, J., Ye, H., Zheng, H., Chen, S., & Huang, D. (2017). Modulating the activity of the dorsolateral prefrontal cortex by tDCS alters distributive decisions behind the veil of ignorance via risk preference. *Behavioural Brain Research*, *328*, 70-80.

Malyutina, S., Zelenkova, V., Buivolova, O., Oosterhuis, E. J., Zmanovsky, N., & Feurra, M. (2018). Modulating the interhemispheric balance in healthy participants with transcranial direct current stimulation: No significant effects on word or sentence processing. *Brain and language*, *186*, 60-66.

Marangolo, P. (2013). tDCS over the left inferior frontal cortex improves speech production in aphasia. *Frontiers in Human Neuroscience*, *7*, 539.

Marangolo, P., Fiori, V., Sabatini, U., De Pasquale, G., Razzano, C., Caltagirone, C., & Gili, T. (2016). Bilateral transcranial direct current stimulation language treatment enhances functional connectivity in the left hemisphere: preliminary data from aphasia. *Journal of Cognitive Neuroscience*, *28*(5), 724-738.

Martin, A. K., Meinzer, M., Lindenberg, R., Sieg, M. M., Nachtigall, L., & Flöel, A. (2017). Effects of transcranial direct current stimulation on neural networks in young and older adults. *Journal of cognitive neuroscience*, *29*(11), 1817-1828.

Martin, D. M., Liu, R., Alonzo, A., Green, M., & Loo, C. K. (2014). Use of transcranial direct current stimulation (tDCS) to enhance cognitive training: effect of timing of stimulation. *Experimental brain research*, *232*(10), 3345-3351.

Martinotti, G., Chillemi, E., Lupi, M., Risio, L. D., Pettorruso, M., & Giannantonio, M. D. (2018). Gambling disorder and bilateral transcranial direct current stimulation: A case report. *Journal of behavioral addictions*, *7*(3), 834-837.

Mashal, N., & Metzuyanim-Gorelick, S. (2019). New information on the effects of transcranial direct current stimulation on n-back task performance. *Experimental brain research*, *237*(5), 1315-1324.

McCambridge, A. B., Bradnam, L. V., Stinear, C. M., & Byblow, W. D. (2011). Cathodal transcranial direct current stimulation of the primary motor cortex improves selective muscle activation in the ipsilateral arm. *Journal of Neurophysiology*, *105*(6), 2937-2942.

Meinzer, M., Lindenberg, R., Sieg, M. M., Nachtigall, L., Ulm, L., & Flöel, A. (2014). Transcranial direct current stimulation of the primary motor cortex improves word-retrieval in older adults. *Frontiers in aging neuroscience*, *6*, 253.

Meiron, O., & Lavidor, M. (2014). Prefrontal oscillatory stimulation modulates access to cognitive control references in retrospective metacognitive commentary. *Clinical Neurophysiology*, *125*(1), 77-82.

Meng, X., Li, G., Jia, Y., Liu, Y., Shang, B., Liu, P., ... & Chen, L. (2020). Effects of dance intervention on global cognition, executive function and memory of older adults: a meta-analysis and systematic review. *Aging clinical and experimental research*, *32*(1), 7-19.

Mental Health Foundation. 2020. *Mental Health Statistics: Physical Health Conditions*. [online] Available at: <https://www.mentalhealth.org.uk/statistics/mental-health-statistics-physical-health-conditions> [Accessed 8 August 2020].

Mesquita, P. H. C., Lage, G. M., Franchini, E., Romano-Silva, M. A., & Albuquerque, M. R. (2019). Bi-hemispheric anodal transcranial direct current stimulation worsens taekwondo-related performance. *Human movement science*, *66*, 578-586.

Metzuyanim-Gorlick, S., & Mashal, N. (2016). The effects of transcranial direct current stimulation over the dorsolateral prefrontal cortex on cognitive inhibition. *Experimental brain research*, *234*(6), 1537-1544.

Mikkonen, M., Laakso, I., Tanaka, S., & Hirata, A. (2020). Cost of focality in TDCS: Interindividual variability in electric fields. *Brain stimulation*, *13*(1), 117-124.

Mineo, L., Fetterman, A., Concerto, C., Warren, M., Infortuna, C., Freedberg, D., ... & Battaglia, F. (2018). Motor facilitation during observation of implied motion: Evidence for a role of the left dorsolateral prefrontal cortex. *International Journal of Psychophysiology*, *128*, 47-51.

Miniussi, C., Harris, J. A., & Ruzzoli, M. (2013). Modelling non-invasive brain stimulation in cognitive neuroscience. *Neuroscience & Biobehavioral Reviews*, *37*(8), 1702-1712.

Moghadam, M. F., Ardekani, M. K., & Shamsi, A. (2020). The effects of transcranial Direct Current Stimulation on working memory in the elderly with normal cognitive impairments. *Archives of Psychiatry and Psychotherapy*, *1*, 56-62.

Möller, A., Nemmi, F., Karlsson, K., & Klingberg, T. (2017). Transcranial electric stimulation can impair gains during working memory training and affects the resting state connectivity. *Frontiers in Human Neuroscience*, *11*, 364.

Moliadze, V., Fritzsche, G., & Antal, A. (2014). Comparing the efficacy of excitatory transcranial stimulation methods measuring motor evoked potentials. *Neural plasticity*, *2014*.

Mordillo-Mateos, L., Turpin-Fenoll, L., Millán-Pascual, J., Núñez-Pérez, N., Panyavin, I., Gómez-Argüelles, J. M., ... & Oliviero, A. (2012). Effects of simultaneous bilateral tDCS of the human motor cortex. *Brain stimulation*, *5*(3), 214-222.

Moreno, M. L., Vanderhasselt, M. A., Carvalho, A. F., Moffa, A. H., Lotufo, P. A., Benseñor, I. M., & Brunoni, A. R. (2015). Effects of acute transcranial direct current stimulation in hot and cold working memory tasks in healthy and depressed subjects. *Neuroscience Letters*, *591*, 126-131.

Moura, R. C. F., Santos, C., Collange Grecco, L., Albertini, G., Cimolin, V., Galli, M., & Oliveira, C. (2017). Effects of a single session of transcranial direct current stimulation on upper limb movements in children with cerebral palsy: A randomized, sham-controlled study. *Developmental neurorehabilitation*, *20*(6), 368-375.

Muellbacher, W., Ziemann, U., Boroojerdi, B., Cohen, L., & Hallett, M. (2001). Role of the human motor cortex in rapid motor learning. *Experimental brain research*, *136*(4), 431-438.

Munz, M. T., Prehn-Kristensen, A., Thielking, F., Mölle, M., Göder, R., & Baving, L. (2015). Slow oscillating transcranial direct current stimulation during non-rapid eye movement sleep improves behavioral inhibition in attention-deficit/hyperactivity disorder. *Frontiers in cellular neuroscience*, *9*, 307.

Naeser, M. A., Martin, P. I., Ho, M., Treglia, E., Kaplan, E., Baker, E. H., & Pascual-Leone, A. (2012). Transcranial Magnetic Stimulation and Aphasia Research. *The Handbook of the Neuropsychology of Language*, *1*, 679-699.

Naros, G., Geyer, M., Koch, S., Mayr, L., Ellinger, T., Grimm, F., & Gharabaghi, A. (2016). Enhanced motor learning with bilateral transcranial direct current stimulation: impact of polarity or current flow direction?. *Clinical Neurophysiology*, *127*(4), 2119-2126.

Nelson, J., McKinley, R. A., Phillips, C., McIntire, L., Goodyear, C., Kreiner, A., & Monforton, L. (2016). The effects of transcranial direct current stimulation (tDCS) on multitasking throughput capacity. *Frontiers in Human Neuroscience*, *10*, 589.

Nikolin, S., Martin, D., Loo, C. K., & Boonstra, T. W. (2018). Effects of TDCS dosage on working memory in healthy participants. *Brain stimulation*, *11*(3), 518-527.

Nissim, N. R., O'Shea, A., Indahlastari, A., Telles, R., Richards, L., Porges, E., ... & Woods, A. J. (2019). Effects of in-scanner bilateral frontal tDCS on functional connectivity of the working memory network in older adults. *Frontiers in aging neuroscience*, *11*, 51.

Nitsche, M. A., & Paulus, W. (2001). Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. *Neurology*, *57*(10), 1899-1901.

Nitsche, M. A., Schauenburg, A., Lang, N., Liebetanz, D., Exner, C., Paulus, W., & Tergau, F. (2003). Facilitation of implicit motor learning by weak transcranial direct current stimulation of the primary motor cortex in the human. *Journal of cognitive neuroscience*, *15*(4), 619-626.

O'Sullivan, M. R. C. P., Jones, D. K., Summers, P. E., Morris, R. G., Williams, S. C. R., & Markus, H. S. (2001). Evidence for cortical "disconnection" as a mechanism of age-related cognitive decline. *Neurology*, *57*(4), 632-638.

Ouellet, J., McGirr, A., Van den Eynde, F., Jollant, F., Lepage, M., & Berlim, M. T. (2015). Enhancing decision-making and cognitive impulse control with transcranial direct current stimulation (tDCS) applied over the orbitofrontal cortex (OFC): a randomized and sham-controlled exploratory study. *Journal of psychiatric research*, *69*, 27-34.

Park, S. H., Seo, J. H., Kim, Y. H., & Ko, M. H. (2014). Long-term effects of transcranial direct current stimulation combined with computer-assisted cognitive training in healthy older adults. *Neuroreport*, *25*(2), 122-126.

Pascual-Leone, A., Amedi, A., Fregni, F., & Merabet, L. B. (2005). The plastic human brain cortex. *Annu. Rev. Neurosci.*, *28*, 377-401.

Pascual-Leone, A., Wassermann, E. M., Grafman, J., & Hallett, M. (1996). The role of the dorsolateral prefrontal cortex in implicit procedural learning. *Experimental brain research*, *107*(3), 479-485.

Peña, J., Sampedro, A., Ibarretxe-Bilbao, N., Zubiaurre-Elorza, L., & Ojeda, N. (2019). Improvement in creativity after transcranial random noise stimulation (tRNS) over the left dorsolateral prefrontal cortex. *Scientific reports*, *9*(1), 1-9.

Penolazzi, B., Di Domenico, A., Marzoli, D., Mammarella, N., Fairfield, B., Franciotti, R., ... & Tommasi, L. (2010). Effects of transcranial direct current stimulation on episodic memory related to emotional visual stimuli. *PloS one*, *5*(5), e10623.

Pergolizzi, D., & Chua, E. F. (2015). Transcranial direct current stimulation (tDCS) of the parietal cortex leads to increased false recognition. *Neuropsychologia*, *66*, 88-98.

Pergolizzi, D., & Chua, E. F. (2016). Transcranial direct current stimulation over the parietal cortex alters bias in item and source memory tasks. *Brain and cognition*, *108*, 56-65.

Pergolizzi, D., & Chua, E. F. (2017). Increased contextual cue utilization with tDCS over the prefrontal cortex during a recognition task. *Brain research*, *1655*, 1-9.

Pixa, N. H., & Pollok, B. (2018). Effects of tDCS on bimanual motor skills: a brief review. *Frontiers in behavioral neuroscience*, *12*, 63.

Pixa, N. H., Berger, A., Steinberg, F., & Doppelmayr, M. (2019). Parietal, but not motor cortex, HD-atDCS deteriorates learning transfer of a complex bimanual coordination task. *Journal of Cognitive Enhancement*, *3*(1), 111-123.

Popescu, T., Krause, B., Terhune, D. B., Twose, O., Page, T., Humphreys, G., & Kadosh, R. C. (2016). Transcranial random noise stimulation mitigates increased difficulty in an arithmetic learning task. *Neuropsychologia*, *81*, 255-264.

Prete, G., D'Anselmo, A., Tommasi, L., & Brancucci, A. (2018). Modulation of the dichotic right ear advantage during bilateral but not unilateral transcranial random noise stimulation. *Brain and cognition*, *123*, 81-88.

Prichard, G., Weiller, C., Fritsch, B., & Reis, J. (2014). Effects of different electrical brain stimulation protocols on subcomponents of motor skill learning. *Brain stimulation*, *7*(4), 532-540.

Qi, F., Nitsche, M. A., & Zschorlich, V. R. (2019). Interaction Between Transcranial Random Noise Stimulation and Observation-Execution Matching Activity Promotes Motor Cortex Excitability. *Frontiers in neuroscience*, *13*, 69.

Raithatha, R., Carrico, C., Powell, E. S., Westgate, P. M., Chelette II, K. C., Lee, K., ... & Sawaki, L. (2016). Non-invasive brain stimulation and robot-assisted gait training after incomplete spinal cord injury: A randomized pilot study. *NeuroRehabilitation*, *38*(1), 15-25.

Reed, T., & Kadosh, R. C. (2018). Transcranial electrical stimulation (tES) mechanisms and its effects on cortical excitability and connectivity. *Journal of inherited metabolic disease*, *41*(6), 1123-1130.

Reis, J., & Fritsch, B. (2011). Modulation of motor performance and motor learning by transcranial direct current stimulation. *Current opinion in neurology*, *24*(6), 590-596.

Rocha, S., Silva, E., Foerster, Á., Wiesiolek, C., Chagas, A. P., Machado, G., ... & Monte-Silva, K. (2016). The impact of transcranial direct current stimulation (tDCS) combined with modified constraint-induced movement therapy (mCIMT) on upper limb function in chronic stroke: a double-blind randomized controlled trial. *Disability and rehabilitation*, *38*(7), 653-660.

Rodger, J., Mo, C., Wilks, T., Dunlop, S. A., & Sherrard, R. M. (2012). Transcranial pulsed magnetic field stimulation facilitates reorganization of abnormal neural circuits and corrects behavioral deficits without disrupting normal connectivity. *The FASEB Journal*, *26*(4), 1593-1606.

Roe, J. M., Nesheim, M., Mathiesen, N. C., Moberget, T., Alnæs, D., & Sneve, M. H. (2016). The effects of tDCS upon sustained visual attention are dependent on cognitive load. *Neuropsychologia*, *80*, 1-8.

Ronsse, R., Miall, R. C., & Swinnen, S. P. (2009). Multisensory integration in dynamical behaviors: maximum likelihood estimation across bimanual skill learning. *Journal of Neuroscience*, *29*(26), 8419-8428.

Rufener, K. S., Krauel, K., Meyer, M., Heinze, H. J., & Zaehle, T. (2019). Transcranial electrical stimulation improves phoneme processing in developmental dyslexia. *Brain stimulation*, *12*(4), 930-937.

Russo, R., Twyman, P., Cooper, N. R., Fitzgerald, P. B., & Wallace, D. (2017). When you can, scale up: Large-scale study shows no effect of tDCS in an ambiguous risk-taking task. *Neuropsychologia*, *104*, 133-143.

Salehinejad, M. A., Rostami, R., & Ghanavati, E. (2015). Transcranial direct current stimulation of dorsolateral prefrontal cortex of major depression: improving visual working memory, reducing depressive symptoms. *NeuroRegulation*, *2*(1), 37-37.

Sandrini, M., Fertonani, A., Cohen, L. G., & Miniussi, C. (2012). Double dissociation of working memory load effects induced by bilateral parietal modulation. *Neuropsychologia*, *50*(3), 396-402.

Santarnecchi, E., Brem, A. K., Levenbaum, E., Thompson, T., Kadosh, R. C., & Pascual-Leone, A. (2015). Enhancing cognition using transcranial electrical stimulation. *Current Opinion in Behavioral Sciences*, *4*, 171-178.

Schulz, R., Gerloff, C., & Hummel, F. C. (2013). Non-invasive brain stimulation in neurological diseases. *Neuropharmacology*, *64*, 579-587.

Sehm, B., Kipping, J. A., Schäfer, A., Villringer, A., & Ragert, P. (2013). A comparison between uni-and bilateral tDCS effects on functional connectivity of the human motor cortex. *Frontiers in human neuroscience*, *7*, 183.

Sheffield, J. G., Raz, G., Sella, F., & Kadosh, R. C. (2020). How can noise alter neurophysiology in order to improve human behaviour? A combined transcranial random noise stimulation and electroencephalography study. *bioRxiv*.

Shen, S. C., Huang, K. H., Kung, P. T., Chiu, L. T., & Tsai, W. C. (2017). Incidence, risk, and associated factors of depression in adults with physical and sensory disabilities: A nationwide population-based study. *PloS one*, *12*(3), e0175141.

Snowball, A., Tachtsidis, I., Popescu, T., Thompson, J., Delazer, M., Zamarian, L., ... & Kadosh, R. C. (2013). Long-term enhancement of brain function and cognition using cognitive training and brain stimulation. *Current Biology*, *23*(11), 987-992.

Soyata, A. Z., Aksu, S., Woods, A. J., İşçen, P., Saçar, K. T., & Karamürsel, S. (2019). Effect of transcranial direct current stimulation on decision making and cognitive flexibility in gambling disorder. *European archives of psychiatry and clinical neuroscience*, *269*(3), 275-284.

Spreng, R. N., Wojtowicz, M., & Grady, C. L. (2010). Reliable differences in brain activity between young and old adults: a quantitative meta-analysis across multiple cognitive domains. *Neuroscience & Biobehavioral Reviews*, *34*(8), 1178-1194.

Sriraman, A., Oishi, T., & Madhavan, S. (2014). Timing-dependent priming effects of tDCS on ankle motor skill learning. *Brain research*, *1581*, 23-29.

Stagg, C. J., Jayaram, G., Pastor, D., Kincses, Z. T., Matthews, P. M., & Johansen-Berg, H. (2011). Polarity and timing-dependent effects of transcranial direct current stimulation in explicit motor learning. *Neuropsychologia*, *49*(5), 800-804.

Steiner, K. M., Enders, A., Thier, W., Batsikadze, G., Ludolph, N., Ilg, W., & Timmann, D. (2016). Cerebellar tDCS does not improve learning in a complex whole body dynamic balance task in young healthy subjects. *PloS one*, *11*(9), e0163598.

Stramaccia, D. F., Penolazzi, B., Sartori, G., Braga, M., Mondini, S., & Galfano, G. (2015). Assessing the effects of tDCS over a delayed response inhibition task by targeting the right inferior frontal gyrus and right dorsolateral prefrontal cortex. *Experimental brain research*, *233*(8), 2283-2290.

Swick, D., Ashley, V., & Turken, U. (2008). Left inferior frontal gyrus is critical for response inhibition. *BMC neuroscience*, *9*(1), 1-11.

Szameitat, A. J., Lepsien, J., Von Cramon, D. Y., Sterr, A., & Schubert, T. (2006). Task-order coordination in dual-task performance and the lateral prefrontal cortex: an event-related fMRI study. *Psychological research*, *70*(6), 541-552.

Talelli, P., Waddingham, W., Ewas, A., Rothwell, J. C., & Ward, N. S. (2008). The effect of age on task-related modulation of interhemispheric balance. *Experimental Brain Research*, *186*(1), 59-66.

Talimkhani, A., Abdollahi, I., Mohseni-Bandpei, M. A., Ehsani, F., Khalili, S., & Jaberzadeh, S. (2019). Differential effects of unihemispheric concurrent dual-site and conventional tDCS on motor learning: A randomized, sham-controlled study. *Basic and clinical neuroscience*, *10*(1), 59.

Techayusukcharoen, R., Iida, S., & Aoki, C. (2019). Observing brain function via functional near-infrared spectroscopy during cognitive program training (dual task) in young people. *Journal of physical therapy science*, *31*(7), 550-555.

To, C., Falcone, M., Loughead, J., Logue-Chamberlain, E., Hamilton, R., Kable, J., ... & Ashare, R. L. (2018). Got chocolate? bilateral prefrontal cortex stimulation augments chocolate consumption. *Appetite*, *131*, 28-35.

Tseng, P., Iu, K. C., & Juan, C. H. (2018). The critical role of phase difference in theta oscillation between bilateral parietal cortices for visuospatial working memory. *Scientific reports*, *8*(1), 1-9.

Turkakin, E., Akbıyık, S., Akyol, B., Gürdere, C., Çakmak, Y. Ö., & Balcı, F. (2018). Differential bilateral primary motor cortex tDCS fails to modulate choice bias and readiness in perceptual decision making. *Frontiers in neuroscience*, *12*, 410.

Van Steenburgh, J. J., Varvaris, M., Schretlen, D. J., Vannorsdall, T. D., & Gordon, B. (2017). Balanced bifrontal transcranial direct current stimulation enhances working memory in adults with high-functioning autism: a sham-controlled crossover study. *Molecular autism*, *8*(1), 1-15.

Vancleef, K., Meesen, R., Swinnen, S. P., & Fujiyama, H. (2016). tDCS over left M1 or DLPFC does not improve learning of a bimanual coordination task. *Scientific reports*, *6*, 35739.

Vanderhasselt, M. A., Allaert, J., De Raedt, R., Baeken, C., Krebs, R. M., & Herremans, S. (2020). Bifrontal tDCS applied to the dorsolateral prefrontal cortex in heavy drinkers: Influence on reward-triggered approach bias and alcohol consumption. *Brain and Cognition*, *138*, 105512

Vierheilig, N., Mühlberger, A., Polak, T., & Herrmann, M. J. (2016). Transcranial direct current stimulation of the prefrontal cortex increases attention to visual target stimuli. *Journal of Neural Transmission*, *123*(10), 1195-1203.

Vines, B. W., Cerruti, C., & Schlaug, G. (2008). Dual-hemisphere tDCS facilitates greater improvements for healthy subjects' non-dominant hand compared to uni-hemisphere stimulation. *BMC neuroscience*, *9*(1), 103.

Waller, S. M., Forrester, L., Villagra, F., & Whitall, J. (2008). Intracortical inhibition and facilitation with unilateral dominant, unilateral nondominant and bilateral movement tasks in left-and right-handed adults. *Journal of the neurological sciences*, *269*(1-2), 96-104.

Waters, S., Wiestler, T., & Diedrichsen, J. (2017). Cooperation not competition: bihemispheric tDCS and fMRI show role for ipsilateral hemisphere in motor learning. *Journal of Neuroscience*, *37*(31), 7500-7512.

Waters-Metenier, S., Husain, M., Wiestler, T., & Diedrichsen, J. (2014). Bihemispheric transcranial direct current stimulation enhances effector-independent representations of motor synergy and sequence learning. *Journal of Neuroscience*, *34*(3), 1037-1050.

Weightman, M., Brittain, J. S., Punt, D., Miall, R. C., & Jenkinson, N. (2020). Targeted tDCS selectively improves motor adaptation with the proximal and distal upper limb. *Brain Stimulation*.

Weltman, K., & Lavidor, M. (2013). Modulating lexical and semantic processing by transcranial direct current stimulation. *Experimental brain research*, *226*(1), 121-135.

West, R., Tiernan, B. N., Kieffaber, P. D., Bailey, K., & Anderson, S. (2014). The effects of age on the neural correlates of feedback processing in a naturalistic gambling game. *Psychophysiology*, *51*(8), 734-745.

Yamaguchi, T., Moriya, K., Tanabe, S., Kondo, K., Otaka, Y., & Tanaka, S. (2020). Transcranial direct-current stimulation combined with attention increases cortical excitability and improves motor learning in healthy volunteers. *Journal of neuroengineering and rehabilitation*, *17*(1), 1-13.

Yekta, M., Rostami, R., & Fayyaz, E. (2015). Transcranial direct current stimulation of dorsolateral prefrontal cortex in patients with obsessive compulsive disorder to improve decision making and reduce obsession symptoms.

Yozbatiran, N., Keser, Z., Davis, M., Stampas, A., O'Malley, M., Cooper-Hay, C., ... & Francisco, G. E. (2016). Transcranial direct current stimulation (tDCS) of the primary motor cortex and robot-assisted arm training in chronic incomplete cervical spinal cord injury: a proof of concept sham-randomized clinical study. *NeuroRehabilitation*, *39*(3), 401-411.

Zandvliet, S. B., Meskers, C. G., Kwakkel, G., & van Wegen, E. E. (2018). Short-term effects of cerebellar tDCS on standing balance performance in patients with chronic stroke and healthy age-matched elderly. *The Cerebellum*, *17*(5), 575-589.

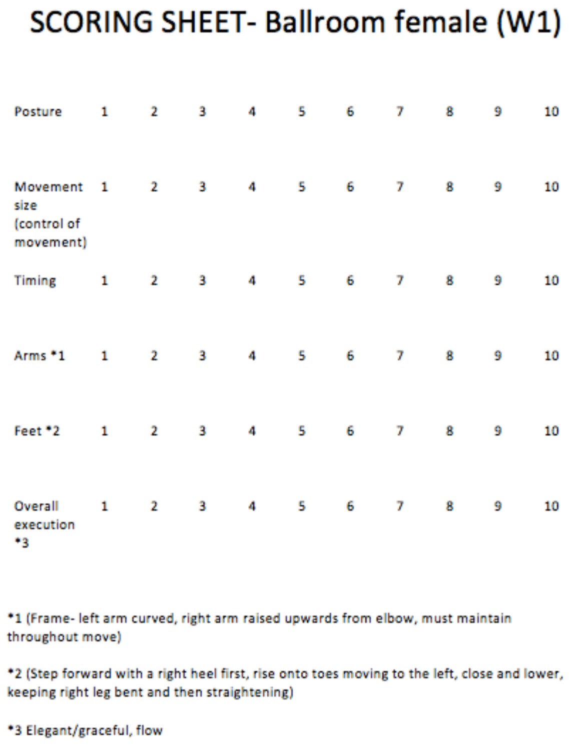
Zarahn, E., Rakitin, B., Abela, D., Flynn, J., & Stern, Y. (2007). Age-related changes in brain activation during a delayed item recognition task. *Neurobiology of aging*, *28*(5), 784-798.

Zmigrod, S., Colzato, L. S., & Hommel, B. (2015). Stimulating creativity: modulation of convergent and divergent thinking by transcranial direct current stimulation (tDCS). *Creativity Research Journal*, *27*(4), 353-36

6 Appendices

6.1 Appendix A

6.1.1 Dance Scoring Sheets



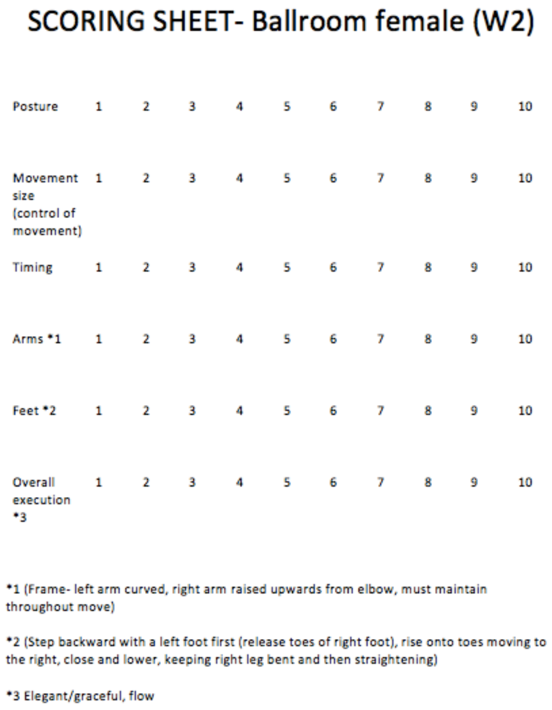
SCORING SHEET- Ballroom female (W1)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Frame- left arm curved, right arm raised upwards from elbow, must maintain throughout move)

*2 (Step forward with a right heel first, rise onto toes moving to the left, close and lower, keeping right leg bent and then straightening)

*3 Elegant/graceful, flow



SCORING SHEET- Ballroom female (W2)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Frame- left arm curved, right arm raised upwards from elbow, must maintain throughout move)

*2 (Step backward with a left foot first (release toes of right foot), rise onto toes moving to the right, close and lower, keeping right leg bent and then straightening)

*3 Elegant/graceful, flow

SCORING SHEET- Ballroom female (W3)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Frame- left arm curved, right arm raised upwards from elbow, must maintain throughout move)

*2 (Step forward with a right heel first (curved to the right), rise onto toes moving to the left to straighten out at a 45 degree turn to the right, close and lower, keeping right leg bent and then straightening)

*3 Elegant/graceful, flow

SCORING SHEET- Ballroom female (W4)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Frame- left arm curved, right arm raised upwards from elbow, must maintain throughout move)

*2 (Step backward with a left foot first (releasing the toes of the right foot), rise onto toes moving to the right to straighten out at a 45 degree turn to the right, close and lower, keeping right leg bent and then straightening)

*3 Elegant/graceful, flow

SCORING SHEET- Latin female (C5)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Latin hand hold into right arm outstretched from body, other hand remains in hold and outstretched hand forms Latin fingers)

*2 (Cha cha basic to the right into a new York, stepping through with the left foot which is slightly turned outward, weight is switched from front to back foot)

*3 Hips, energy

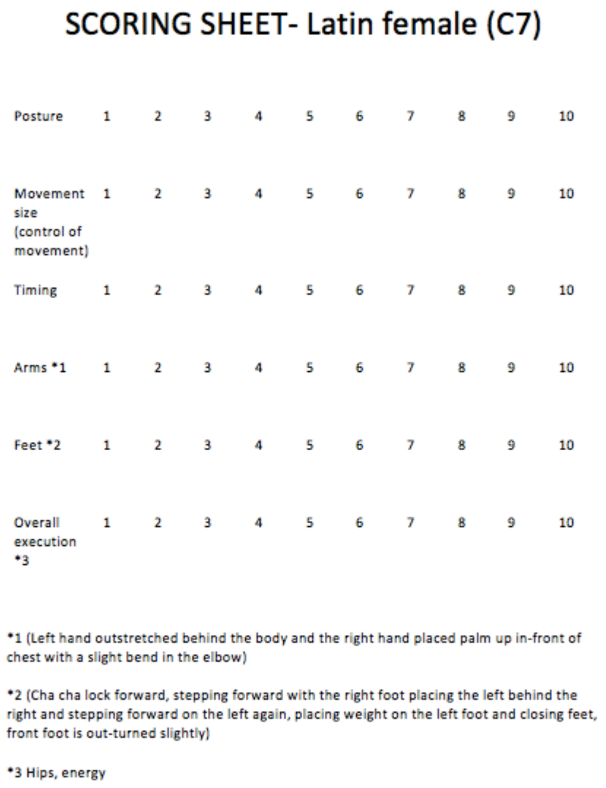
SCORING SHEET- Latin female (C6)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Latin hand hold into left arm outstretched from body, other hand remains in a fist close to body)

*2 (Cha cha basic to the right into a spot turn, stepping through with the left foot then pivoting to the right, placing weight on the right foot and closing feet)

*3 Hips, energy



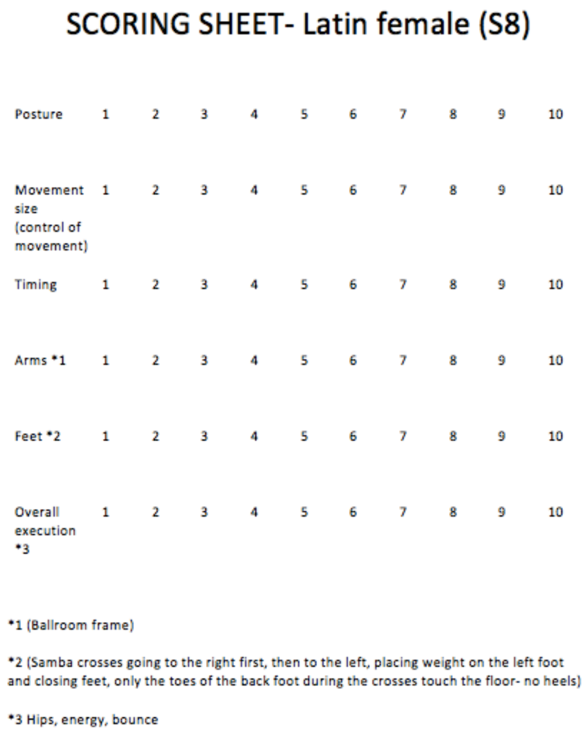
SCORING SHEET- Latin female (C7)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Left hand outstretched behind the body and the right hand placed palm up in-front of chest with a slight bend in the elbow)

*2 (Cha cha lock forward, stepping forward with the right foot placing the left behind the right and stepping forward on the left again, placing weight on the left foot and closing feet, front foot is out-turned slightly)

*3 Hips, energy



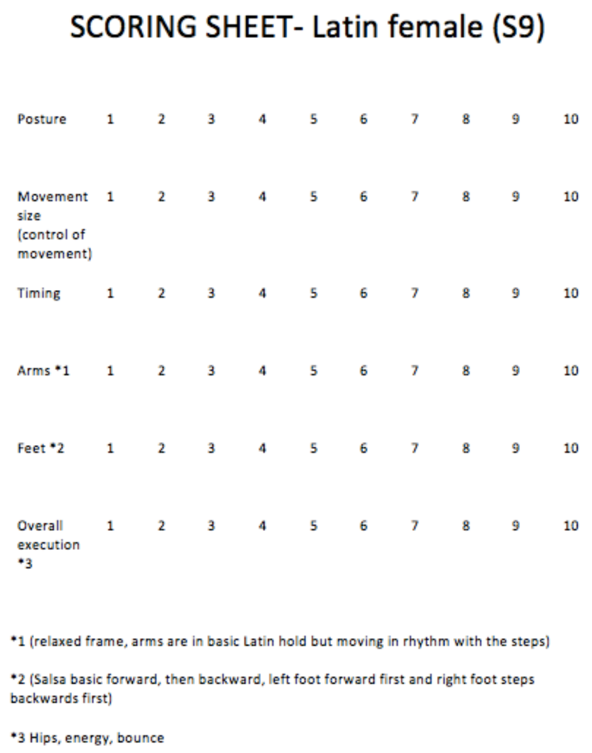
SCORING SHEET- Latin female (S8)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (Ballroom frame)

*2 (Samba crosses going to the right first, then to the left, placing weight on the left foot and closing feet, only the toes of the back foot during the crosses touch the floor- no heels)

*3 Hips, energy, bounce



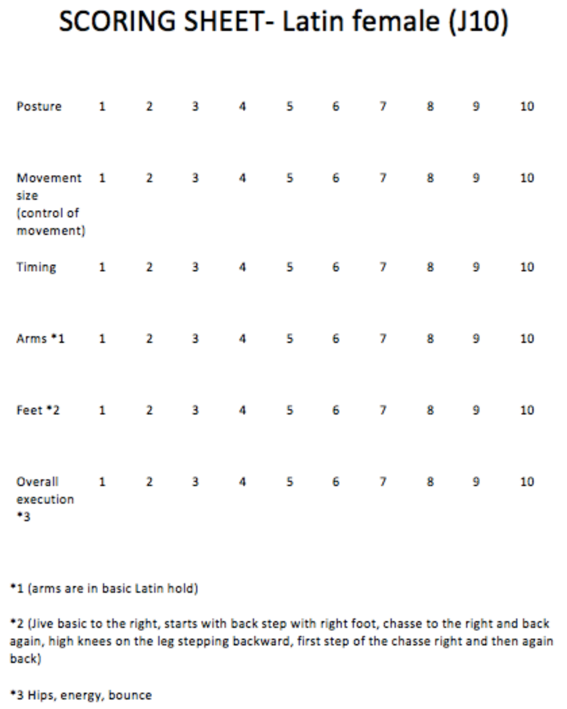
SCORING SHEET- Latin female (S9)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (relaxed frame, arms are in basic Latin hold but moving in rhythm with the steps)

*2 (Salsa basic forward, then backward, left foot forward first and right foot steps backwards first)

*3 Hips, energy, bounce



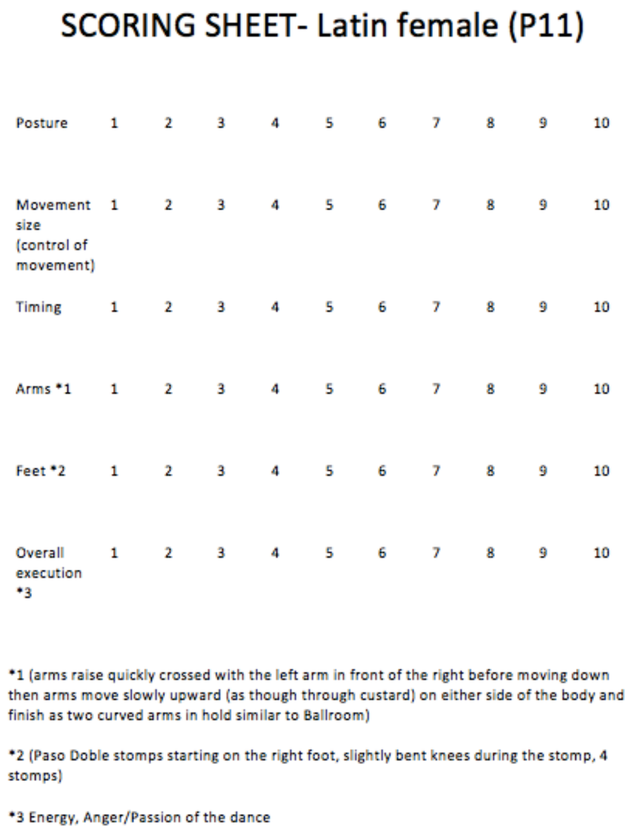
SCORING SHEET- Latin female (J10)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (arms are in basic Latin hold)

*2 (Jive basic to the right, starts with back step with right foot, chasse to the right and back again, high knees on the leg stepping backward, first step of the chasse right and then again back)

*3 Hips, energy, bounce



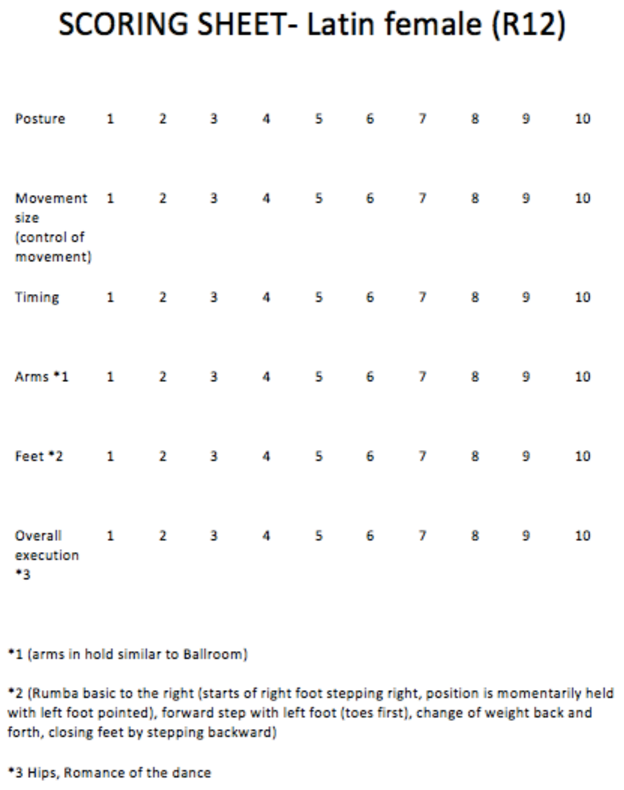
SCORING SHEET- Latin female (P11)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (arms raise quickly crossed with the left arm in front of the right before moving down then arms move slowly upward (as though through custard) on either side of the body and finish as two curved arms in hold similar to Ballroom)

*2 (Paso Doble stomps starting on the right foot, slightly bent knees during the stomp, 4 stomps)

*3 Energy, Anger/Passion of the dance



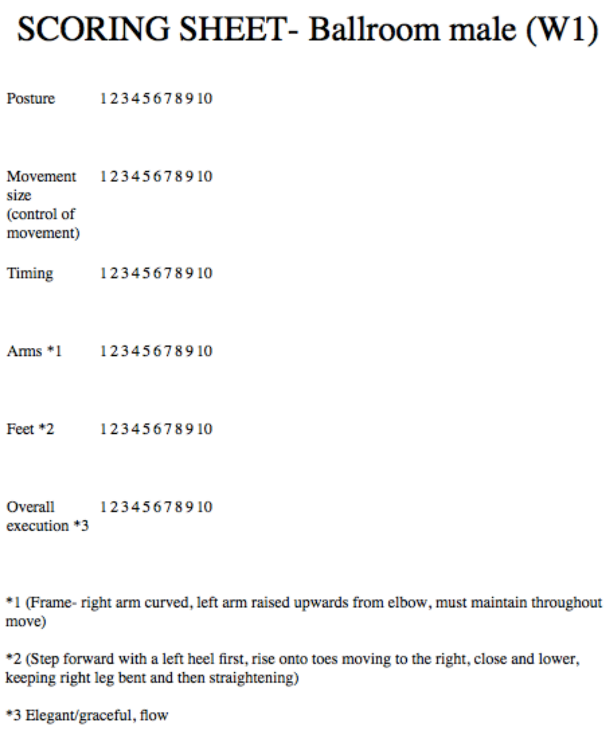
SCORING SHEET- Latin female (R12)

Posture	1	2	3	4	5	6	7	8	9	10
Movement size (control of movement)	1	2	3	4	5	6	7	8	9	10
Timing	1	2	3	4	5	6	7	8	9	10
Arms *1	1	2	3	4	5	6	7	8	9	10
Feet *2	1	2	3	4	5	6	7	8	9	10
Overall execution *3	1	2	3	4	5	6	7	8	9	10

*1 (arms in hold similar to Ballroom)

*2 (Rumba basic to the right (starts of right foot stepping right, position is momentarily held with left foot pointed), forward step with left foot (toes first), change of weight back and forth, closing feet by stepping backward)

*3 Hips, Romance of the dance



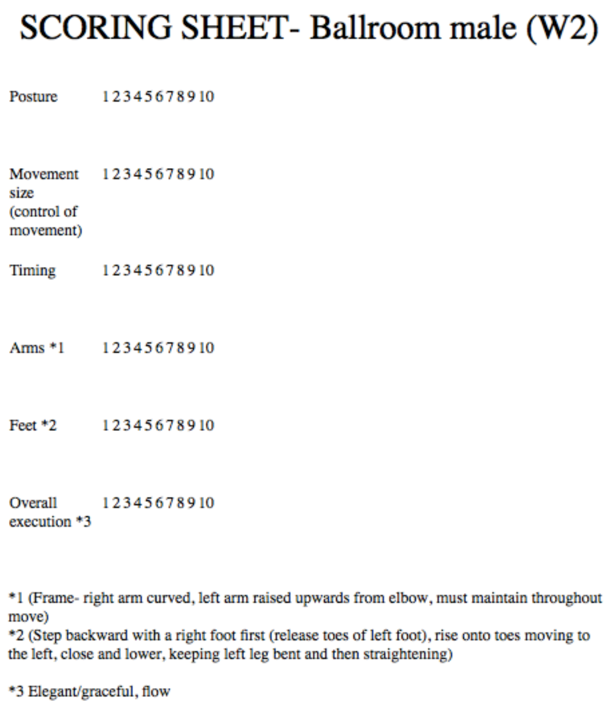
SCORING SHEET- Ballroom male (W1)

Posture	1 2 3 4 5 6 7 8 9 10
Movement size (control of movement)	1 2 3 4 5 6 7 8 9 10
Timing	1 2 3 4 5 6 7 8 9 10
Arms *1	1 2 3 4 5 6 7 8 9 10
Feet *2	1 2 3 4 5 6 7 8 9 10
Overall execution *3	1 2 3 4 5 6 7 8 9 10

*1 (Frame- right arm curved, left arm raised upwards from elbow, must maintain throughout move)

*2 (Step forward with a left heel first, rise onto toes moving to the right, close and lower, keeping right leg bent and then straightening)

*3 Elegant/graceful, flow

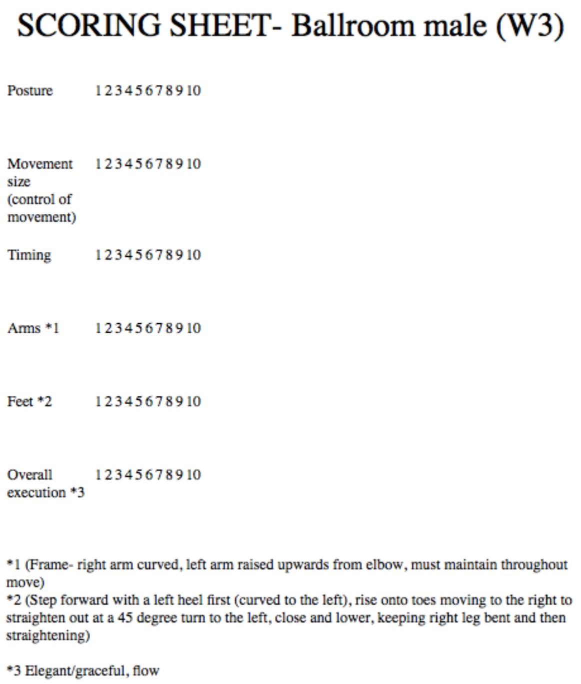


SCORING SHEET- Ballroom male (W2)

Posture	1 2 3 4 5 6 7 8 9 10
Movement size (control of movement)	1 2 3 4 5 6 7 8 9 10
Timing	1 2 3 4 5 6 7 8 9 10
Arms *1	1 2 3 4 5 6 7 8 9 10
Feet *2	1 2 3 4 5 6 7 8 9 10
Overall execution *3	1 2 3 4 5 6 7 8 9 10

*1 (Frame- right arm curved, left arm raised upwards from elbow, must maintain throughout move)
*2 (Step backward with a right foot first (release toes of left foot), rise onto toes moving to the left, close and lower, keeping left leg bent and then straightening)

*3 Elegant/graceful, flow



SCORING SHEET- Ballroom male (W3)

Posture	1 2 3 4 5 6 7 8 9 10
Movement size (control of movement)	1 2 3 4 5 6 7 8 9 10
Timing	1 2 3 4 5 6 7 8 9 10
Arms *1	1 2 3 4 5 6 7 8 9 10
Feet *2	1 2 3 4 5 6 7 8 9 10
Overall execution *3	1 2 3 4 5 6 7 8 9 10

*1 (Frame- right arm curved, left arm raised upwards from elbow, must maintain throughout move)
*2 (Step forward with a left heel first (curved to the left), rise onto toes moving to the right to straighten out at a 45 degree turn to the left, close and lower, keeping right leg bent and then straightening)

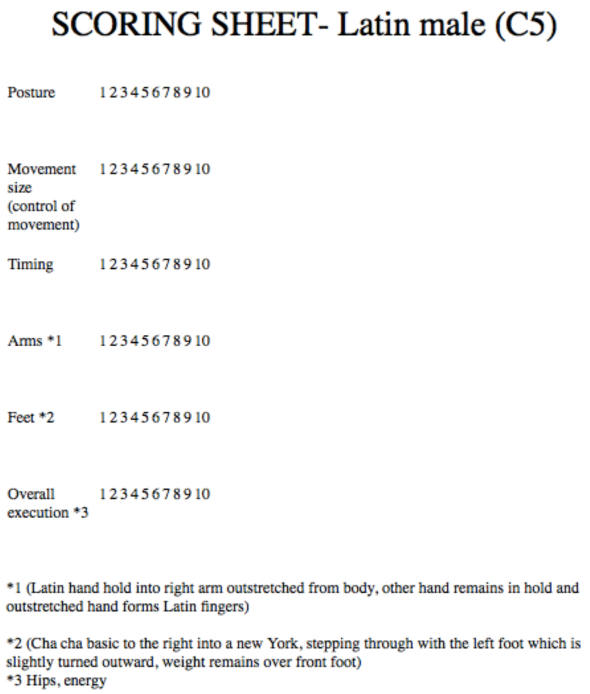
*3 Elegant/graceful, flow

SCORING SHEET- Ballroom male (W4)

Posture	1 2 3 4 5 6 7 8 9 10
Movement size (control of movement)	1 2 3 4 5 6 7 8 9 10
Timing	1 2 3 4 5 6 7 8 9 10
Arms *1	1 2 3 4 5 6 7 8 9 10
Feet *2	1 2 3 4 5 6 7 8 9 10
Overall execution *3	1 2 3 4 5 6 7 8 9 10

*1 (Frame- right arm curved, left arm raised upwards from elbow, must maintain throughout move)
*2 (Step backward with a left foot first (releasing the toes of the right foot), rise onto toes moving to the right to straighten out at a 45 degree turn to the right, close and lower, keeping right leg bent and then straightening)

*3 Elegant/graceful, flow

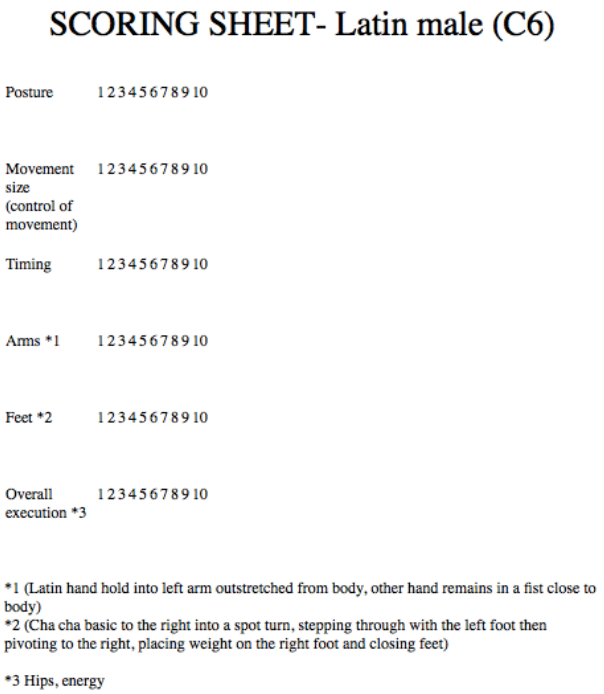


SCORING SHEET- Latin male (C5)

Posture	1 2 3 4 5 6 7 8 9 10
Movement size (control of movement)	1 2 3 4 5 6 7 8 9 10
Timing	1 2 3 4 5 6 7 8 9 10
Arms *1	1 2 3 4 5 6 7 8 9 10
Feet *2	1 2 3 4 5 6 7 8 9 10
Overall execution *3	1 2 3 4 5 6 7 8 9 10

*1 (Latin hand hold into right arm outstretched from body, other hand remains in hold and outstretched hand forms Latin fingers)

*2 (Cha cha basic to the right into a new York, stepping through with the left foot which is slightly turned outward, weight remains over front foot)
*3 Hips, energy



SCORING SHEET- Latin male (C6)

Posture	1 2 3 4 5 6 7 8 9 10
Movement size (control of movement)	1 2 3 4 5 6 7 8 9 10
Timing	1 2 3 4 5 6 7 8 9 10
Arms *1	1 2 3 4 5 6 7 8 9 10
Feet *2	1 2 3 4 5 6 7 8 9 10
Overall execution *3	1 2 3 4 5 6 7 8 9 10

*1 (Latin hand hold into left arm outstretched from body, other hand remains in a fist close to body)
*2 (Cha cha basic to the right into a spot turn, stepping through with the left foot then pivoting to the right, placing weight on the right foot and closing feet)

*3 Hips, energy

SCORING SHEET- Latin male (C7)

Posture 1 2 3 4 5 6 7 8 9 10

Movement size (control of movement) 1 2 3 4 5 6 7 8 9 10

Timing 1 2 3 4 5 6 7 8 9 10

Arms *1 1 2 3 4 5 6 7 8 9 10

Feet *2 1 2 3 4 5 6 7 8 9 10

Overall execution *3 1 2 3 4 5 6 7 8 9 10

*1 (Left hand outstretched behind the body and the right hand placed palm up in-front of chest with a slight bend in the elbow)

*2 (Cha cha lock forward, stepping forward with the left foot placing the right behind the left and stepping forward on the right again, placing weight on the right foot and closing feet, front foot is out-turned slightly)

*3 Hips, energy

SCORING SHEET- Latin male (S8)

Posture 1 2 3 4 5 6 7 8 9 10

Movement size (control of movement) 1 2 3 4 5 6 7 8 9 10

Timing 1 2 3 4 5 6 7 8 9 10

Arms *1 1 2 3 4 5 6 7 8 9 10

Feet *2 1 2 3 4 5 6 7 8 9 10

Overall execution *3 1 2 3 4 5 6 7 8 9 10

*1 (Ballroom frame)

*2 (Samba crosses going to the right first, then to the left, placing weight on the left foot and closing feet, only the toes of the back foot during the crosses touch the floor- no heels)

*3 Hips, energy, bounce

SCORING SHEET- Latin male (S9)

Posture 1 2 3 4 5 6 7 8 9 10

Movement size (control of movement) 1 2 3 4 5 6 7 8 9 10

Timing 1 2 3 4 5 6 7 8 9 10

Arms *1 1 2 3 4 5 6 7 8 9 10

Feet *2 1 2 3 4 5 6 7 8 9 10

Overall execution *3 1 2 3 4 5 6 7 8 9 10

*1 (relaxed frame, arms are in basic Latin hold but moving in rhythm with the steps)
*2 (Salsa basic forward, then backward, left foot forward first and right foot steps backwards first)

*3 Hips, energy, bounce

SCORING SHEET- Latin male (J10)

Posture 1 2 3 4 5 6 7 8 9 10

Movement size (control of movement) 1 2 3 4 5 6 7 8 9 10

Timing 1 2 3 4 5 6 7 8 9 10

Arms *1 1 2 3 4 5 6 7 8 9 10

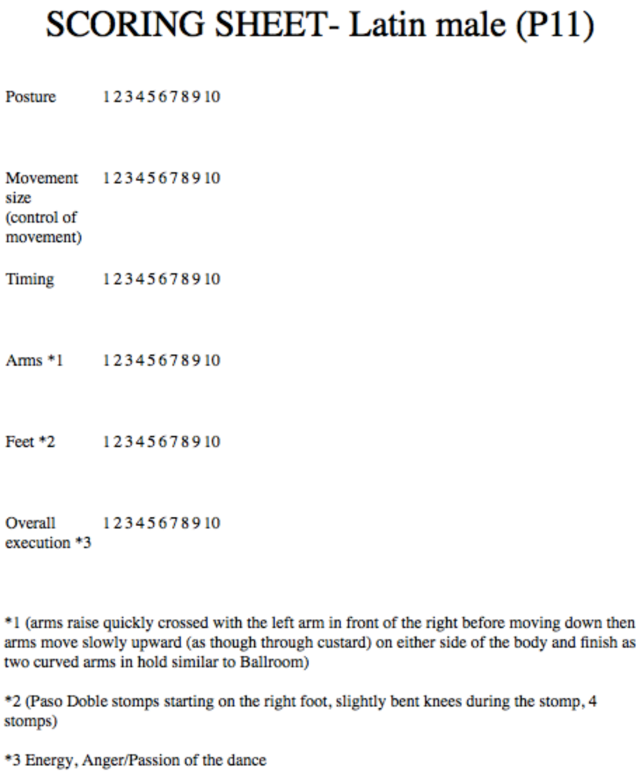
Feet *2 1 2 3 4 5 6 7 8 9 10

Overall execution *3 1 2 3 4 5 6 7 8 9 10

*1 (arms are in basic Latin hold)

*2 (Jive basic to the left, starts with back step with left foot, chasse to the left and back again, high knees on the leg stepping backward, first step of the chasse right and then again back)

*3 Hips, energy, bounce



SCORING SHEET- Latin male (P11)

Posture 1 2 3 4 5 6 7 8 9 10

Movement size (control of movement) 1 2 3 4 5 6 7 8 9 10

Timing 1 2 3 4 5 6 7 8 9 10

Arms *1 1 2 3 4 5 6 7 8 9 10

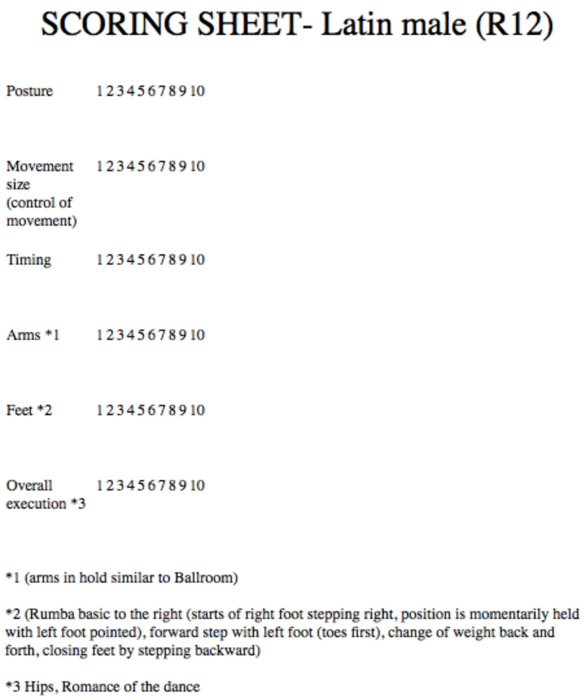
Feet *2 1 2 3 4 5 6 7 8 9 10

Overall execution *3 1 2 3 4 5 6 7 8 9 10

*1 (arms raise quickly crossed with the left arm in front of the right before moving down then arms move slowly upward (as though through custard) on either side of the body and finish as two curved arms in hold similar to Ballroom)

*2 (Paso Doble stomps starting on the right foot, slightly bent knees during the stomp, 4 stomps)

*3 Energy, Anger/Passion of the dance



SCORING SHEET- Latin male (R12)

Posture 1 2 3 4 5 6 7 8 9 10

Movement size (control of movement) 1 2 3 4 5 6 7 8 9 10

Timing 1 2 3 4 5 6 7 8 9 10

Arms *1 1 2 3 4 5 6 7 8 9 10

Feet *2 1 2 3 4 5 6 7 8 9 10

Overall execution *3 1 2 3 4 5 6 7 8 9 10

*1 (arms in hold similar to Ballroom)

*2 (Rumba basic to the right (starts of right foot stepping right, position is momentarily held with left foot pointed), forward step with left foot (toes first), change of weight back and forth, closing feet by stepping backward)

*3 Hips, Romance of the dance