No effect of transcranial direct current stimulation of frontal, motor or visual cortex on performance of a self-paced visuomotor skill

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Abstract

Objectives. Transcranial direct current stimulation (tDCS) is a form of neurostimulation that can modulate neural activity in targeted brain regions through electrical current applied directly to the scalp. Previous findings have shown cognitive enhancement and improved motor learning following tDCS. Consequently, there has been growing interest in direct brain stimulation for enhancing sporting skills. We aimed to assess the effect of tDCS on golf putting performance and control of visual attention.

Design. Using a mixed factorial design, the effect of stimulation (between-participants) was assessed at baseline, following stimulation and in a pressure test (within-participants).

Methods. 74 novice golfers were randomly assigned to transcranial direct current stimulation of frontal, motor or visual cortex, or sham stimulation. Participants first performed a series of golf putts at baseline, then while receiving tDCS and finally under pressurised conditions. Putting performance (distance from the hole) and control of visual attention (quiet eye duration) was assessed.

Results. There was no effect of real tDCS stimulation compared to sham stimulation on either performance or visual attention (quiet eye durations), for any stimulation site.

Conclusions. While beneficial effects of tDCS have been found in computerised cognitive tests and simple motor tasks, there is currently little evidence that this will transfer to real-world sporting performance.

Keywords; quiet eye; tDCS; brain stimulation; neurodoping; neurostimulation; sport

No effect of transcranial direct current stimulation of frontal, motor or visual cortex on performance of a self-paced visuomotor skill

Success in self-paced visuomotor tasks, such as golf putting, depends largely on maintaining goal-directed attention and programming an appropriate motor response. Recently, interest has grown in the use of transcranial direct current stimulation (tDCS) as a method of enhancing these functions due to accessibility of equipment and a range of promising findings (Banissy & Muggleton, 2013). tDCS aims to produce changes in cerebral excitability by applying a weak electrical current (0.5-2.0 mA) between two electrodes (anode and cathode) across the scalp (Nitsche & Paulus, 2000; Purpura & McMurtry, 1965). This stimulation is thought to modulate neural activity near the electrode and, to a lesser extent, diffuse locations nearby (Nitsche et al., 2008). tDCS stimulation can facilitate activity through anodal stimulation (by reducing the negative polarisation across the neural membrane) or inhibit activity through cathodal stimulation (through hyperpolarisation).

The excitatory and inhibitory effects of tDCS on cortical areas have been shown to subsequently influence motor and cognitive performance (Jacobson, Koslowsky, & Lavidor, 2012), which has led to interest in tDCS as a training tool. A range of findings demonstrate anodal facilitation of cognitive functions, such as working memory (Fregni et al., 2005), verbal fluency (Meinzer et al., 2012) and inhibitory control (Loftus, Yalcin, Baughman, Vanman, & Hagger, 2015; for review see Jacobson et al., 2012). There are also early, but promising, findings for motor skill learning. Firstly, tDCS facilitation of activity in a targeted region may help to reduce a deficit, such as improvement of upper limb function following a stroke, through anodal stimulation of the motor cortex (Butler et al., 2013). Additionally, anodal stimulation of motor areas has been found to aid observational learning of a simple motor sequence (Wade & Hammond, 2015). Finally, Antal et al. (2004) found tDCS over visual cortex to improve performance in a visuomotor tracking task and perception of motion, both during and immediately following stimulation. Overall, while findings are somewhat inconsistent, there is potential for tDCS to benefit both the learning (e.g., Clark et al., 2012; Wade & Hammond, 2015) and performance (e.g. Antal et al., 2004; Boggio et al., 2006) of cognitive and visuo-motor aspects of sporting skills.

In the golf putt, successful performance requires visual information to be processed, a motor response programmed, and for attention to be directed towards task-relevant information. Consequently, visual, motor and higher-level executive processing are all potentially relevant targets for tDCS facilitation. tDCS stimulation of cortical areas related to these functions has produced positive performance effects in lab-based tests (Antal et al., 2004; Choe, Coffman, Bergstedt, Ziegler, & Phillips, 2016; Reis et al., 2009). There has, however, been limited exploration of tDCS in more complex visuomotor tasks. The most notable study to date found cathodal stimulation of the left DLPFC to support implicit learning in the golf putt (Zhu et al., 2015), indicating that effects may be detectable in more complex sporting skills, but it is unclear how other stimulation sites and parameters may affect performance.

In order to explore potential mechanisms by which tDCS may influence performance in golf putting, we also examined a measure of visual attentional control, known as ‘quiet eye’ (QE; Vickers, 1996). QE is a gaze behaviour – the final fixation prior to movement execution – that has been identified as an important determinant of performance in many target and aiming tasks (Lebeau et al., 2016; Vickers, 2007). QE reflects effective attentional control and is proposed to facilitate task relevant processing and inhibition of distractions (Vickers, 1996; Vine & Wilson, 2011). Therefore, effects of frontal stimulation, as a crucial area for higher attentional mechanisms (Corbetta & Shulman, 2002), may be evidenced via changes in QE.

tDCS provides a potential means of performance enhancement in many areas, but there has been limited exploration in the context of complex sporting skills (but see Zhu et al., 2015). Additionally, not only are there general concerns regarding the reliability of many tDCS effects (Horvath, Forte, & Carter, 2015a, 2015b) but the mechanisms by which the advantages arise have been largely ignored. Therefore, we aimed to explore how direct stimulation of frontal (DLFPC), motor (M1), or visual (V1) cortex may impact the performance of a golf putt. As a key element of skilled performance is the ability to perform under pressure, we also created a pressurised condition, where we subjected participants to ego-threatening instructions (e.g.Moore, Vine, Cooke, Ring, & Wilson, 2012). This enabled us to explore if the site of the stimulation might have differential effects on performance under low and high pressure.

As there have been few studies examining the effect of tDCS in more complex visuomotor skills the present study was somewhat exploratory. The underlying rationale for this work was to examine whether stimulation of brain areas linked to the major facets of the task (motor, visual and higher cognitive processing) could have performance enhancing effects. Firstly, it was hypothesised that frontal stimulation would have beneficial effects for both golf putting performance *and* QE duration, due to facilitation of executive areas involved in attentional control (Corbetta & Shulman, 2002). Previous positive effects of frontal stimulation on golf putting have been reported by Zhu et al. (2015), although they utilised cathodal stimulation to inhibit explicit rule generation and support implicit processes over a learning period. In contrast, we aim to examine immediate performance effects as a result of enhancing attention control, hence anodal stimulation was chosen to facilitate frontal activity. Previous research supports a facilitatory effect of anodal stimulation of the DLPFC on working memory (Fregni et al., 2005) and inhibitory control (Loftus et al., 2015), both of which are fundamental aspects of attention control.

Additionally, anodal stimulation has been shown to aid cognitive control during emotion regulation (Feeser, Prehn, Kazzer, Mungee, & Bajbouj, 2014) and to modify attentional bias (Clarke, Browning, Hammond, Notebaert, & MacLeod, 2014). Hence, anodal facilitation may have beneficial effects in a visuomotor task heavily dependent on attention control (Vine & Wilson, 2011). In particular, it was hypothesised that when performance pressure was introduced, frontal stimulation would help maintain attention (QE) and performance more effectively than other stimulation sites. Previous work has shown that maintenance of attentional control serves to mitigate against the disruptive effects of pressure on attention and performance (Eysenck, Derakshan, Santos, & Calvo, 2007; Vine & Wilson, 2011) and frontal tDCS has been show to modify attentional bias towards threat (Clarke et al., 2014). Stimulation of executive areas may therefore promote goal-directed control of attention and reduce pressure related breakdowns (Eysenck & Wilson, 2016). Consequently, an interaction effect was hypothesised, whereby frontal stimulation was expected to promote better maintenance of attention (QE) and performance under pressure than other stimulation groups.

Secondly, as visual acuity is related to visuomotor performance (O'Connor, Birch, Andersen & Draper, 2010), it was hypothesised that stimulation of V1, as a primary region for processing of visual information, could also improve putting performance. Stimulation of early visual areas (V5) has previously enhanced visuomotor coordination (Antal et al., 2004) and stimulation of V1 has shown a range of effects in modifying visual perception (Antal & Paulus, 2008; Spiegel, Hansen, Byblow, & Thompson, 2012). Therefore, stimulation of early visual areas may influence visuomotor performance. Finally, it was hypothesised that M1 stimulation would also have beneficial effects on golf putting performance through facilitation of motor control, as has been found in simple motor tasks (Boggio et al., 2006; Hummel et al., 2005) and bimanual learning (Ciechanski & Kirton, 2017).

Methods

Participants

73 healthy participants (see Table 1) were recruited from the University of Exeter undergraduate student population by ‘word of mouth’. Participants were all right-handed novice golfers. Participants with any of the following were excluded; personal or family history of epilepsy, history of skull trauma, metal fragments in the head or eyes, recent neuro-active drug use, recent participation in brain stimulation or possible pregnancy (Davis, Gold, Pascual-Leone, & Bracewell, 2013). As this was an exploratory study, with little previous work on which to base a formal power calculation, we aimed to exceed the sample of 14 participants per group used by Zhu et al. (2015). Participants were allocated, using computerised randomisation, to one of four independent groups: (1 - *Frontal*) anodal right DLPFC stimulation; (2 - *Motor*) anodal right M1 stimulation; (3 - *Visual*) anodal V1 stimulation; (4 - *Sham*) sham stimulation at M1 (Table 1). All participants attended testing individually, and signed consent forms, with details of the study explained to them verbally and in writing. University ethics committee approval was obtained prior to participant recruitment.

Table 1 - Demographics by group (mean and standard deviation)

	Frontal	***Motor***	***Visual***	***Sham***
N	19	19	16	19
Age	21.7± 2.8	21.6± 2.9	20.5±1.0	22.0± 3.7
Sex	6M/13F	14M/5F	9M/7F	8M/11F

Materials

Golf putting was performed on an indoor artificial putting green (length = 6m, width = 2.5m) from a distance of (175cm) from the hole. All participants used a standard size putter (90cm) steel-shafted blade style putter (Sedona 2, Ping, Phoneix, AZ) with standard (4.27cm diameter) yellow golf balls. Eye movements were recorded using an ASL (Applied Science Laboratories; Bedford, MA) Mobile Eye Tracker, which comprises a pair of glasses carrying a forward facing scene camera and an eye camera. The glasses employ dark pupil tracking and record at 33Hz (±0.5° visual angle; 0.1° precision). Gaze videos were recorded onto a Lenvovo R500 ThinkPad laptop for offline analysis. tDCS electrical stimulation was delivered through two 5x5cm electrodes using the HDCStim (HDCKit, Newronika, Italy).

Measures

Performance. Golf putting performance was assessed using radial error of the ball from the hole as in Walters-Symons, Wilson, Klosterman and Vine (2018) (i.e. the two-dimensional Euclidean distance between the top of the ball and the edge of the target; in cm). The distance was measured with a tape measure following each attempt.

Quiet eye period. The QE period was defined as the final fixation directed to the ball, with an onset prior to the critical movement (club backswing). QE offset occurred when gaze deviated from the ball by 1° of visual angle, for more than 100ms (Vickers, 2007; Walters-Symons et al., 2018). If the cursor disappeared for 1 or 2 frames (e.g., a blink) and then returned to the same location, the quiet eye duration resumed. The absence of a QE period (i.e. no fixation was made on the ball prior to the backswing) was scored as a zero, while the absence of any fixations due to tracking issues was assigned a missing value. Gaze videos were fully blinded for analysis, which was conducted by two experimenters using Quiet Eye Solutions software (Quiet Eye Solutions Inc.). Inter-rater reliability was checked using the intra-class correlation coefficient (as recommended in Shrout & Fleiss, 1979). There was found to be a high degree of agreement, *r*=0.99, p<.001, across 105 shots.

Anxiety. To ensure the efficacy of the pressure manipulation, competitive state anxiety was measured using the the Immediate Anxiety Measurement Scale (IAMS; Thomas, Hanton, & Jones, 2002). The IAMS measures self-reported cognitive and somatic anxiety on a 7-point Likert scale ranging from 1 (*not at all*) to 7 (*extremely*). Questions take the form: '*To what extent are you experiencing cognitive anxiety right now*'. Participants completed the questionnaire at the start of the testing, post tDCS stimulation and before the final putting condition. The validity and reliability of this measure is evidenced by Thomas et al. (2002) and has been used previously as an anxiety measure in golf putting studies (e.g. Moore, Vine, Wilson, & Freeman, 2012).

Experimental procedure

Participants attended testing on one occasion for 45-60 minutes. All participants completed the informed consent form and had the experiment explained verbally. First, participants were fitted with the tDCS electrodes and eye tracking glasses, which were calibrated over 5 points in the visual scene. The international 10-20 EEG system was used to determine electrode placement sites for frontal (F4), motor (C4) and visual (Oz) sites (see Figure 1). The reference electrode was placed above the contralateral (left) supraorbital area. A 1.5mA current was induced through two saline soaked sponges (each 5x5 cm) with a 5 second ramp up and ramp down. Sham stimulation consisted of 5 second ramp up stimulation only.

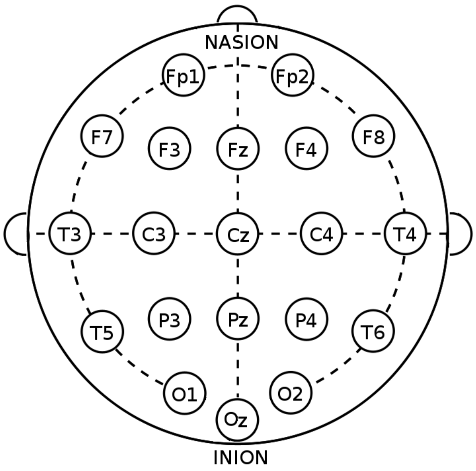
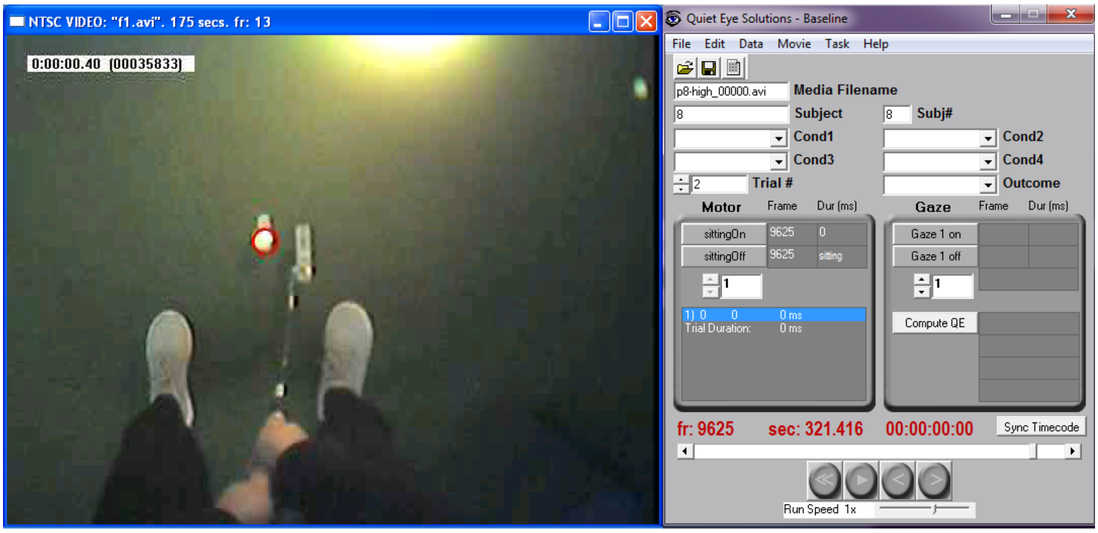


Figure 1. International 10-20 EEG electrode placement system

Participants initially completed 5 familiarization putts, followed by a baseline assessment of 10 putts where eye tracking and performance were recorded, and participants completed the IAMS questionnaire (no stimulation). Participants then had 5 minutes of direct current stimulation while seated, followed by an additional 10 putts (low pressure test), while stimulation continued. Finally, to test performance under increased anxiety, participants completed 10 more putts following a pressure inducing script (high pressure test), again with continuing stimulation. tDCS electrodes were worn for the whole procedure, but only became active for the 5 minutes of seated stimulation and during the low and high pressure conditions.

Pressure was induced using a verbal script which has been used previously to induce anxiety in golf putting tasks (Moore et al., 2012). The pressure script informed participants that their performance would be entered into a leaderboard that would be circulated to all participants at the end of the experiment, to induce social comparison. Additionally they were informed that their baseline performance was poor (in the bottom 30% of all participants tested so far), and that they were now being filmed. Participants completed the IAMS prior to each block of 10 putts to check the effectiveness of the manipulation. At the end of the experiment participants were asked to report whether they believed they were in the real or sham stimulation group, and whether they had experienced any adverse symptoms.



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Subject: 8
Subj#: 8
Trial #: 2

Motor	Frame	Dur (ms)
sittingOn	9625	0
sittingOff	9625	sitting

1) 0 0 0 ms
Trial Duration: 0 ms

fr: 9625 sec: 321.416 00:00:00:00

Run Speed 1x

Figure 2. Screenshot from Quiet Eye Solutions. The red cursor indicates participants' point of gaze.

Data Analysis

Gaze data were analyzed using Quiet Eye Solutions software (Quiet Eye Solutions Inc.) which allows frame by frame analysis of the gaze video to calculate the duration of the QE in relation to movement execution (Figure 2). All gaze data from 4 participants, and single conditions from a further 2 participants, were excluded from the analysis due to poor calibration. Outlying putting performance values, more than three standard deviations from the mean, were removed for 2 participants.

Statistical analysis was performed in Jamovi (v0.9.1.11; jamovi project, 2018). Data was checked for homogeneity of variance (Levene's test), and skewness and kurtosis. Violations of sphericity were corrected for using a Greehouse-Geisser correction factor. Analysis of Covariance was used to assess the effect of stimulation using group (frontal, motor, visual, sham) and condition (low v high pressure) as primary factors, and baseline performance as a covariate. One sided t-tests were used to explore null effects (see Lakens, 2017). All data is available through the Open Science Framework (https://osf.io/xdkm6/).

Results

To check that participants were blind to the type of stimulation, a chi-square test was run on participants' report of which stimulation they believed they had received (real or sham) (Table 2). There was found to be no association between group membership and whether participants believed the stimulation to be real or sham, $\chi^2(3)=3.34$, $p=0.34$, indicating that they were blind to the type of stimulation.

Table 2 - Frequencies of participants' believed group membership

GROUP		*Frequency*
Frontal	Real	16
	Sham	3
Motor	Real	15
	Sham	4
Visual	Real	10
	Sham	6
Sham	Real	12
	Sham	7

To examine the effect of the pressure manipulation, a one way repeated-measures ANOVA was run on combined cognitive and somatic anxiety scores, revealing a significant effect of condition, $F(2,144)=11.93$, $p<.001$, $\eta^2=.142$. Follow up tests showed an increase in anxiety in the high pressure condition, with no difference in anxiety between baseline and low pressure ($p=.59$, $d=0.064$), but significant increases from low to high pressure ($p<.001$, $d=0.462$) and baseline to high pressure ($p<.001$, $d=0.473$). Consequently, we provide support for the efficacy of the pressure manipulation.

Table 3 – Summary data (means and standard deviations) for all groups and conditions

		Anxiety (IAMS)	*Performance (radial error)*	*Quiet eye (ms)*
Frontal	**Baseline**	5.16(2.17)	44.34(31.23)	341.65(271.67)
	Low pressure	5.26(2.26)	31.51(14.96)	542.04(391.74)
	High pressure	6.37(1.92)	25.72(17.97)	557.34(476.00)
Motor	**Baseline**	4.00(1.92)	40.73(25.05)	726.41(686.56)
	Low pressure	4.21(1.87)	39.98(28.14)	923.75(718.65)
	High pressure	5.00(2.38)	37.02(24.59)	835.07(723.16)
Visual	**Baseline**	5.19(2.59)	33.82(20.39)	756.19(485.24)
	Low pressure	5.06(2.59)	27.24(13.30)	886.88(561.46)
	High pressure	5.69(2.50)	26.19(17.47)	1057.81(761.97)
Sham	**Baseline**	4.53(2.25)	56.59(29.02)	658.93(424.90)
	Low pressure	4.74(2.10)	49.40(27.88)	818.87(641.25)
	High pressure	5.79(2.28)	41.99(25.99)	673.29(575.85)

To examine the effect of stimulation group on golf putting performance a 4 (group) x 2 (condition) ANCOVA was conducted on radial error scores, controlling for baseline performance. There was a significant effect of the covariate, $F(1,66)=46.02$, $p<.001$, $\eta^2=.389$, but no effect of condition, $F(1,66)=0.06$, $p=.80$, $\eta^2=.001$, no effect of group, $F(3,66)=2.09$, $p=.11$, $\eta^2=.053$, and no group by condition interaction, $F(3,66)=0.23$, $p=.87$, $\eta^2=.010$. To further explore the null results, one-sided t-tests were used to assess equivalence of groups in low and high-pressure conditions. Based on recommendations from Lakens (2017), one-sided tests were used to test the null hypothesis that effects were larger than a conventionally small effect ($d=0.3$). It was not possible to reject an effect size larger than $d=0.3$ for any group pairing in either low or high pressure conditions (see Table 3).

Table 4 - One sided equivalence tests for performance, displaying higher p-value from each pair of one-sided tests.

	Low pressure (p value)	***High Pressure (p value)***
Frontal v Motor	.59	.75
Frontal v Sham	.93	.90
Frontal v Visual	.50	.22
Sham v Motor	.54	.37
Visual v Motor	.77	.71
Visual v Sham	.97	.87

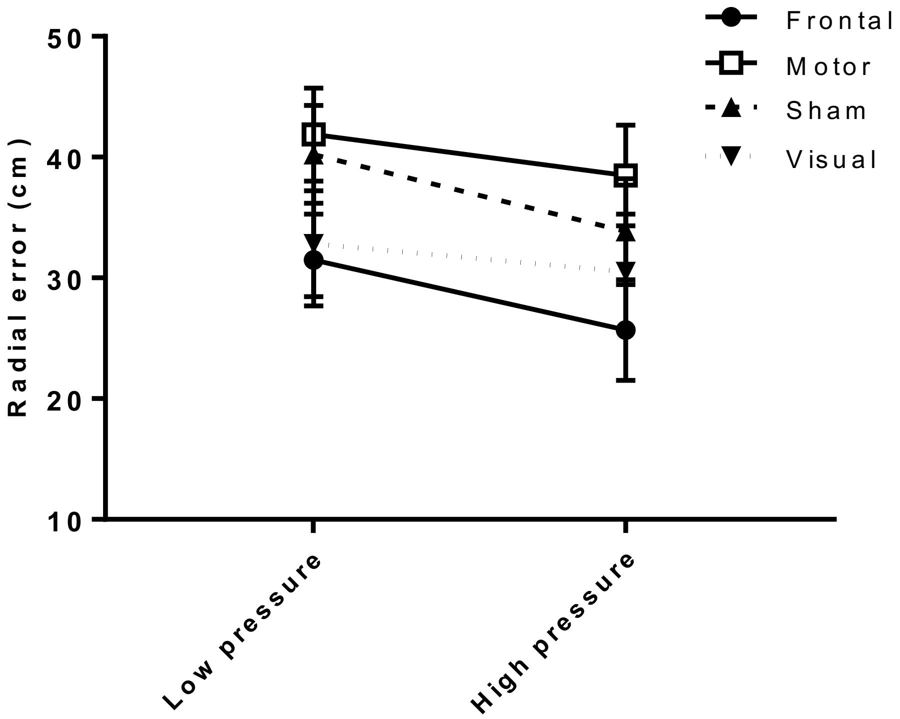

Figure 3 - Mean (and standard error) radial error scores across conditions, adjusted for baseline values.

To examine the effect of stimulation group on control of visual attention a 4 (group) x 2 (condition) ANCOVA was conducted on QE durations (ms), controlling for baseline QE. There was a significant effect of the covariate, $F(1,62)=81.82$, $p<.001$, $\eta^2=.564$, but no effect of condition, $F(1,62)=1.11$, $p=.30$, $\eta^2=.017$, no effect of group, $F(3,62)=0.44$, $p=.73$, $\eta^2=.009$, and no group by condition interaction, $F(3,62)=0.61$, $p=.61$, $\eta^2=.028$. To explore the null effect, one-sided t-tests were used to assess equivalence of groups in low and high-pressure condition, using upper and lower bounds of $d=0.3$. It was not possible to reject an effect larger than $d=0.3$ for any group pairing, in either low or high pressure conditions (Table 4).

Table 5 - One sided equivalence tests for QE duration, displaying higher p-value from each pair of one-sided tests.

	Low pressure (p value)	***High Pressure (p value)***
Frontal v Motor	.84	.67
Frontal v Sham	.73	.41
Frontal v Visual	.87	.91
Sham v Motor	.33	.44
Visual v Motor	.25	.50
Visual v Sham	.30	.79

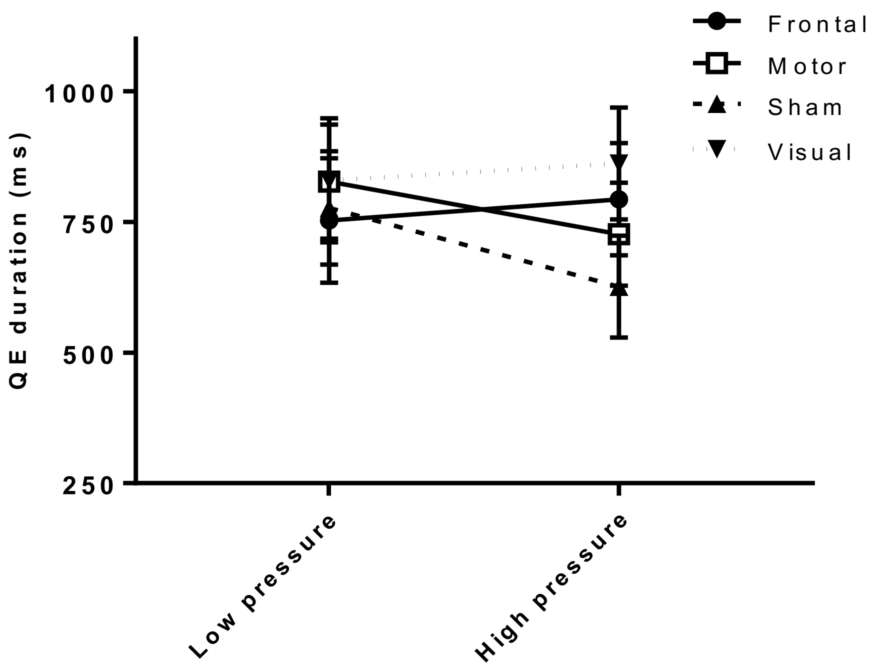

Figure 4. Mean (and standard error) QE durations across conditions, adjusted for baseline values.

Discussion

There is growing interest in tDCS as a neuroscientific approach to enhancing sporting skills (Banissy & Muggleton, 2013), with recent findings showing beneficial effects of direct brain stimulation for cognitive performance (Fregni et al., 2005) and motor learning (Butler et al., 2013; Reis et al., 2009). Despite this interest, it remains unclear whether tDCS can aid the performance of complex sporting skills. Here, we investigated the use of tDCS for improving immediate performance in a complex visuomotor task, the golf putt.

Frontal stimulation, targeted to the DLFPC, was predicted to aid golf putting performance due to facilitation of attentional control functions associated with prefrontal areas (Corbetta & Shulman, 2002). As there was no effect of stimulation group there was no support for beneficial effects of frontal stimulation in golf putting. Additionally, it was hypothesised that frontal stimulation would help maintain attention control (QE) under pressure, so that the effects of frontal stimulation would be most pronounced at the pressure test, but this was not the case. Attention Control Theory (ACT; Eysenck et al., 2007) suggests that under heightened anxiety, the balance between stimulus driven and goal-directed attention can be disrupted, leading to performance decrements. While previous studies have indeed found performance to be degraded under pressure (Vine & Wilson, 2011), this was not seen here. Overall, the learning effect over trials may well have overpowered any effect of the pressure manipulation on performance, due to the pressure manipulation being carried out last, to avoid carry over effects. Consequently there was no evidence that tDCS aided putting performance or enabled a better maintenance of attention control under pressure.

Based on previous studies showing motor control and visuomotor tracking benefits from tDCS (Antal et al., 2004; Boggio et al., 2006), it was predicted that stimulation of motor areas would also aid golf putting performance. There was, however, no beneficial effect of M1 stimulation for putting performance or QE, in low or high pressure conditions. The current findings provided no evidence that previous effects will transfer to more multifaceted skills, like golf putting. Indeed, similar null effects were also observed by Zhu, Yan, Foo and Leung (2017) in a complex visuomotor skill (laparoscopic surgery).

We also were unable to provide support for the hypothesis that stimulation of visual cortex might also benefit putting performance. Previous work has found stimulation of visual areas to benefit perception of motion and visuomotor tracking (Antal et al., 2004), but here there was no effect on performance or QE. While golf putting is a visually guided task, the demands on visual processing of a lab-based putting task may not have been sufficient for it to be a limiting factor in performance – for example there is no need to interpret shade or slope as would be relevant when ‘reading’ an undulating green. As such, even if stimulation did facilitate activity of visual areas, it may have had no effect on performance.

While tDCS provides a tool for applying neuroscientific methods to the study of sporting skills, there are a number of issues that should be borne in mind when interpreting these, and previous, findings. Firstly, the spatial specificity of tDCS is low. The method of current delivery used in tDCS employs large stimulation sites, and current can further spread across the scalp (Nitsche et al., 2008). There is also a limited understanding of how increased activity in one area will interact with others, leading to unpredictable downstream regulation of activity. Additionally, the wide range of electrode montages and stimulation intensities/durations employed in the tDCS literature means it can be hard to compare effects across studies, or to know the optimal stimulation parameters to induce performance effects (Jacobson et al., 2012; Nitsche et al., 2008).

Consequently, although null effects were seen here, they do not rule out effects from alternative stimulation set ups. In particular, examination of concurrent left and right hemispheric stimulation may be worthwhile for bimanual skills like golf putting, as previous work has shown benefits of bihemispheric tDCS for motor learning (Gomes-Osman & Field-Fote, 2013). Also, initial brain states at the onset of stimulation are known to interact with tDCS (Bortoletto, Pellicciari, Rodella, & Miniussi, 2015; Silvanto, Muggleton, & Walsh, 2008). There is currently little understanding of how elevated anxiety may affect mechanisms of tDCS action. Consequently it is possible that the elevated anxiety in the high pressure condition may have negated the effects of stimulation. Nonetheless, the extensive sample size employed here, and testing of intervening attentional mechanisms, questions whether tDCS is likely to have beneficial effects in the performance of a complex sporting skill.

In summary, we investigated the potential for tDCS, applied to frontal, motor or visual cortex, to improve performance in a visuomotor skill. No performance effects were found, suggesting that previous beneficial effects may not apply to more multifaceted sporting skills (although cf. Beeli, Koeneke, Gasser, & Jancke, 2008). Nonetheless, future work may wish to examine the use of tDCS for enhancing motor learning of sporting skills, which has received more promising support (Colzato, Nitsche, & Kibele, 2016), or in conjunction with cognitive training (Ditye, Jacobson, Walsh, & Lavidor, 2012). At present, however, there is little evidence that it provides immediate benefits for sporting skills.

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