

### The effect of unilateral hand contractions on psychophysiological activity during motor performance: Evidence of verbal-analytical engagement Hoskens, Merel; Bellomo, Eduardo; Uiga, Liis; Cooke, Andrew; Masters, Rich

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# The effect of unilateral hand contractions on psychophysiological activity during motor performance

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#### Abstract

**Objectives:** Conscious engagement in movement control can influence motor performance. In most cases, the left hemisphere of the brain plays an important role in verbal-analytical processing and reasoning, so changes in the balance of hemispheric activation may influence conscious engagement in movement. Evidence suggests that unilateral hand contractions influence hemispheric activation, but no study has investigated whether there is an associated effect of hand contractions on verbal-analytical processing and psychophysiological activity during motor performance. This study was designed to examine whether pre-performance unilateral hand contraction protocols change verbal-analytical involvement and psychophysiological activity during motor performance. Design: A repeated measures crossover design was employed. Methods: Twenty-eight participants completed three hand contraction protocols in a randomised order: left, right and no-hand contractions. Electroencephalography (EEG) measures of hemispheric asymmetry were computed during hand contractions. A golf putting task was conducted after each protocol. EEG connectivity between sites overlying the left verbal-analytical temporal region (T7) and the motor planning region (Fz) was computed for the 3-sec prior to movement initiation. Additionally, electrocardiography (ECG) and electromyography (EMG) signals were analysed 6-sec prior to movement initiation until 6-sec after. Golf putting performance was obtained by distance from the target and putter swing kinematics. Results: Contralateral hemisphere activity was revealed for the left and right-hand contraction conditions. During motor planning, the lefthand contraction protocol led to significantly lower T7-Fz connectivity, and the right-hand contraction protocol led to significantly higher T7-Fz connectivity than the other conditions. EMG, ECG and kinematic measures did not differ as a function of condition. Importantly, T7-Fz connectivity mediated the relationship between hand squeezing and motor performance (distance from the target). Conclusion: The EEG results suggest that pre-

performance unilateral hand contractions influence the extent of verbal-analytical engagement in motor planning, which in turn influences motor performance. However, the hand contractions did not influence cardiac activity, muscle activity or kinematics.

*Key words: hand contraction protocol; hemisphere-specific priming; EEG; heart rate; movement kinematics* 

Journal Prevention

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# Journal Pre-proof

## Introduction

2	A link between conscious processes and motor performance is found in studies using
3	electroencephalography (EEG) to examine communication (synchronization) between
4	different regions of the brain (Babiloni et al., 2011; Deeny, Hillman, Janelle, & Hatfield,
5	2003; Gallicchio, Cooke, & Ring, 2016; Zhu, Poolton, Wilson, Maxwell, & Masters, 2011).
6	Evidence from these studies suggests that high conscious engagement in motor performance
7	is associated with more synchronous neuronal activity, indexing greater functional
8	communication between the left temporal T7 region of the brain (involved in verbal-
9	analytical processing), and the frontal midline Fz region of the brain (involved in motor
10	planning) (Babiloni et al., 2011; Deeny et al., 2003; Gallicchio et al., 2016; Zhu et al., 2011).
11	Compelling evidence for the link between conscious control of movements and
12	verbal-analytical processes has been reported by Zhu et al. (2011, Experiment 1). They
13	measured propensity to consciously control motor skills using the Movement Specific
14	Reinvestment Scale (MSRS, Masters, Eves, & Maxwell, 2005). Participants with a lower
15	propensity to consciously control movements displayed lower T7-Fz communication (e.g.,
16	coherence) than participants with a higher propensity for conscious control, during the 4-sec
17	preceding golf putts (Zhu et al., 2011). Co-activation between the left temporal and frontal
18	regions is also associated with motor performance. For example, Gallicchio et al. (2016)
19	reported that T7-Fz connectivity was lower in the final seconds preceding successful golf
20	putts compared to unsuccessful golf putts, suggesting that reduced or suppressed verbal-
21	analytical processing is a feature of effective motor performance. In sum, reduced left
22	temporal-frontal synchronicity may be associated with less verbal, more procedural,
23	processing of movements.

Attempts to reduce verbal-analytical engagement during motor performance have used neuro-stimulation to suppress activity in the left hemisphere (Landers et al., 1991;

Snyder et al., 2003; Zhu et al., 2015). For instance, Zhu et al. (2015) found that cathodal (i.e., 26 27 inhibitory) transcranial Direct Current Stimulation (tDCS) over the left dorsolateral prefrontal 28 cortex promoted lower verbal-analytical engagement when practicing a golf putting task, 29 compared to sham stimulation (i.e., placebo). However, tDCS is not a practical or accessible 30 training method for the majority of performers, and ethical concerns about such extreme 31 training methods have been raised (Davis, 2013). Using a slightly less shocking method, Beckmann, Gröpel, and Ehrlenspiel (2013) and 32 33 Gröpel and Beckmann (2017) asked semi-professional athletes (gymnastics, soccer, 34 badminton and taekwondo) to squeeze a stress ball in either the left hand or the right hand for 35 45-sec before performing under competitive pressure. They reasoned that due to the 36 contralateral coupling between our hands and our brain (i.e., the brain area controlling the 37 right hand resides in left hemisphere, and vice-versa), squeezing the right hand should prime 38 the left (verbal-analytic) hemisphere and squeezing the left hand should prime the right (visual-spatial) hemisphere. Results showed that left-hand contractions resulted in more 39 40 stable performance under pressure than right-hand contractions. The authors argued that left-41 hand contractions prevented breakdown under pressure by activating the right hemisphere and deactivating the left hemisphere, which reduced disruptive verbal-analytical control of 42 43 the movements (Beckmann et al., 2013; Gröpel & Beckmann, 2017). Beckmann et al. (2013, Experiment 3) additionally found that right-hand contractions magnified the effect of 44 45 pressure, with participants performing worse when they carried out right-hand contractions 46 prior to performing. They suggested that since right-hand contractions activated the left 47 hemisphere, they potentially increased the likelihood that pressure would cause disruptive 48 verbal-analytical involvement in performance. However, it is important to note that this 49 interpretation cannot be confirmed since Beckmann and colleagues did not directly measure cortical activity in their studies. 50

51	Studies that did record cortical activity during unilateral hand contractions have
52	revealed inconsistent results. For example, some studies revealed that unilateral hand
53	contractions result in lower alpha power (i.e., increased brain activity) in the contralateral
54	hemisphere (Gable, Poole, & Cook, 2013; Harmon-Jones, 2006; Peterson, Shackman, &
55	Harmon-Jones, 2008; Schiff, Guirguis, Kenwood, & Herman, 1998). However, Cross-
56	Villasana, Gropel, Doppelmayr, and Beckmann (2015) revealed that unilateral hand
57	contractions produced lower alpha power over both hemispheres. Furthermore, they revealed
58	that immediately after left-hand contractions ceased, whole scalp alpha power increased,
59	indicating widespread deactivation (Cross-Villasana et al., 2015). This latter finding
60	challenges Beckmann and colleagues suggestion that left-hand contractions are beneficial
61	because they activate the right hemisphere. However, it does support the argument that left-
62	hand contractions can deactivate the left hemisphere, perhaps suppressing verbal-analytical
63	engagement in motor planning. Taken together, these findings indicate that hemispheric
64	activity can be altered by hand contraction protocols. However, their effects on verbal-
65	analytical processes have yet to be established. Specifically, no study has examined the effect
66	of unilateral hand contractions on T7-Fz connectivity during the final moments of motor
67	preparation. These final moments are important for establishing the level of conscious
68	monitoring and control of the movement (e.g., Deeny et al., 2003; Gallicchio et al., 2016; Zhu
69	et al., 2011). Therefore, measurement of cortical activity, especially T7-Fz connectivity, is
70	required to more rigorously examine the proposed relations between left-hand contractions,
71	verbal-analytical engagement and motor performance.
72	Finally, no studies have investigated the effects of hand contraction protocols on

physiological and kinematic measures that may also relate to verbal-analytical engagement
and motor performance outcomes (Cooke, Kavussanu, McIntyre, & Ring, 2010). Although
Cooke et al. (2014) did not examine hand contractions, they did report greater heart rate

76 deceleration during the 6-sec preceding motor performance in skilled versus low skilled 77 golfers. Therefore, heart rate deceleration could offer another corroborative physiological measure that is sensitive to the amount of verbal-analytical engagement during motor 78 79 planning (Cooke et al., 2014; Neumann & Thomas, 2009; Neumann & Thomas, 2011; Radlo, 80 Steinberg, Singer, Barba, & Melnikov, 2002). Similarly, more automatic motor control is also 81 associated with lower muscle activity (Lohse, Sherwood, & Healy, 2010; Vance, Wulf, Tollner, McNevin, & Mercer, 2004; Zachry, Wulf, Mercer, & Bezodis, 2005). For example, 82 Lohse et al. (2010) revealed lower muscle activity when participants adopted an external 83 focus of attention while throwing darts, compared to when they consciously monitored their 84 85 technique. Finally, movement kinematics can also be linked to verbal-analytical engagement 86 in motor planning (Cooke et al., 2014; Malhotra, Poolton, Wilson, Omuro, & Masters, 2015; 87 Masters, Poolton, Maxwell, & Raab, 2008; Maxwell, Masters, & Eves, 2003). For example, 88 Maxwell et al. (2003) revealed that verbal-analytic engagement in motor planning was associated with a less fluid technique. The assessment of such measures alongside T7-Fz 89 90 connectivity may therefore provide new insight into the mechanisms underpinning the effects 91 of unilateral hand contraction protocols on performance. 92 The present study is the first to investigate the effect of unilateral hand contraction

93 protocols on psychophysiological and behavioural markers of golf putting performance. The 94 aim was to gain a better understanding of whether pre-performance unilateral hand 95 contractions have an effect on verbal-analytical processes involved in motor performance. 96 Three hand contraction protocols (left, right and no-hand) were performed in a repeated 97 measures crossover design, before performance of a golf putting task. Measures of alpha power (8-12 Hz) between homologous electrode pairs were first computed during the hand 98 99 contraction protocols to verify that left-hand contractions activated the right hemisphere, and that right-hand contractions activated the left hemisphere. Cortical activity was then 100

101 examined further by measuring the high-alpha power (10-12 Hz) connectivity level between 102 the verbal-analytical left temporal (T7) region and the motor planning (Fz) region during preparation for each golf putt. Cardiac activity (electrocardiography), muscle activity 103 104 (electromyography), kinematics, and golf performance were tested as supporting measures of 105 verbal-analytical engagement in motor planning. Mediation analyses were employed to examine whether our EEG and psychophysiological indices of verbal-analytic engagement 106 107 are the mechanisms underpinning any effect of hand contractions on performance. 108 Based on the behavioural findings of Beckmann et al. (2013) and Gröpel and Beckmann (2017), we predicted that unilateral hand contractions would influence verbal-109 110 analytical involvement (i.e., inferred by changes in T7-Fz connectivity) during movement 111 planning. Specifically, we predicted that the left-hand contractions would lower verbalanalytical involvement during motor planning compared to right-hand and no-hand 112 113 contractions, and that right-hand contractions would raise verbal-analytical involvement in motor planning compared to left-hand and no-hand contractions. Consequently, lower verbal-114 115 analytical engagement during the left-hand contraction protocol was expected to promote 116 greater heart rate deceleration, lower muscular activity, smoother kinematics when initiating the golf putt and better outcome performance compared to the right-hand and no-hand 117 118 contraction protocols (Cooke et al., 2014; Lohse et al., 2010; Neumann & Thomas, 2009; 119 Radlo et al., 2002; Zachry et al., 2005). The opposite effects were predicted for the right-hand contraction protocol. Finally, we predicted that the effects of hand contractions on T7-Fz 120 121 connectivity and our ECG, EMG and kinematic measures would mediate the relationship between hand contraction protocols and performance. 122

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#### Methods

#### 124 **Participants and design**

125 Twenty-eight people were recruited to participate in the experiment. Three 126 participants who had major artefacts in their EEG signal were excluded from further analysis, resulting in a final sample of twenty-five participants (mean age = 26.52, SD = 5.08, female = 127 128 15). To control for handedness, only right-handed participants were included (> 70, Edinburgh Handedness Inventory, Oldfield, 1971). All participants had normal/corrected 129 130 vision. The participants were instructed not to consume alcohol or drugs 24-hours prior to 131 testing or caffeine 3-hours prior to testing, and to obtain at least 6-hours of sleep the night 132 before testing. A repeated measures crossover design was adopted, with participants 133 performing three different protocols (right, left and no-hand contractions). The order of protocols was counterbalanced within participants. This study was approved by the 134 University (Human) Research ethics committee. 135 136 Task 137 The experiment consisted of a pre-performance hand contraction protocol followed by a golf putting task. The hand contraction protocol required participants to firmly contract a 138 139 stress ball at a self-paced rate for 45-sec either with their left hand or right hand, or to place 140 their hands on their lap and hold them still for 45-sec (no-hand contraction condition). The

researcher instructed the participants to sit quietly and to not talk or make large movementsduring these protocols, in order to control for muscle activity artefacts.

After each protocol, participants performed 25 golf putts on an artificial grass surface,
using a standard length (90-cm) golf putter and a regular-size (diameter 4.7-cm) golf ball.
The target was a 1-cm diameter white sticker on the putting surface positioned 2.4-m from
the initial starting point. Mean radial error (mean distance in any direction from the target)
was assessed.

#### 148 Measures

149 **Psychophysiological measures.** 

150 EEG data was used to assess cortical activity during the pre-performance hand 151 contraction protocols (e.g., Gable et al., 2013) and during preparation of the golf putts (e.g., 152 Zhu et al., 2011). EEG was recorded from thirty-two (32) active electrodes positioned using 153 the 10-20 system (Jaspers, 1958): Fp1, Fp2, AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO3, PO4, O1, Oz, and 154 155 O2. Additionally, active electrodes were positioned on each mastoid, at the outer canthus and below each eye to record vertical and horizontal electrooculogram (EOG). Monopolar 156 157 recorded signals were sampled at 1024 Hz, without an online filter, using an ActiveTwo 158 amplifier (Biosemi, The Netherlands). During the pre-performance protocols, we were primarily interested in cortical 159 asymmetry (i.e., right hemisphere minus left hemisphere) in the broad alpha band frequency 160 (i.e., 8-12 Hz), as previous studies have demonstrated the effects of unilateral hand 161 162 contractions on broad-band alpha (Cross-Villasana et al., 2015; Gable et al., 2013; Harmon-163 Jones, 2006; Peterson et al., 2008). During preparation of the golf putt, we were interested in connectivity in the high-alpha frequency band (i.e., 10-12 Hz), as this portion of the alpha 164

165 frequency is thought to be specifically related to task specific attentional processes and

166 cortico-communication (Smith, McEvoy, & Gevins, 1999; for a review see Klimesch, 1999).

167 Electrocardiography (ECG) was used during golf putting performance, to assess
168 cardiac activity (Cooke et al., 2014; Cooke, Kavussanu, McIntyre, Boardley, & Ring, 2011).
169 Silver/silver chloride spot electrodes (BlueSensor SP, Ambu, Cambridgeshire, UK) were
170 placed on each clavicle and on the lowest left rib. The ECG signal was amplified (Bagnoli-4,

171 Delsys, Boston, MA), filtered (1-100 Hz) and digitized at 2500 Hz with 16-bits resolution

172 (CED Power 1401, Cambridge Electronic Design, Cambridge, UK) using Spike2 software

173 (version 5, Cambridge Electronic Design).

174 Electromyography (EMG) was used to obtain muscle activity during golf putting for 175 the extensor carpi radialis and flexor carpi ulnaris muscles in the left arm (Cooke et al., 2014; Cooke et al., 2011). Differential surface electrodes (DE 2.1, Delsys) were placed on the belly 176 177 of the muscles and a ground electrode (BleuSensor SP, Ambu, Cambridgeshire, UK) was placed on the left collarbone. The EMG signal was amplified (Bagnoli-4, Delsys), filtered 178 179 (20-45 Hz), and digitized at 2500 Hz with 16-bit resolution (Power 1401) using Spike2 180 software. 181 Golf putting performance measures.

182 The golf putting performance was determined by the mean radial error (cm), 183 representing the mean distance between the final position of the ball and the centre of the 184 target. This measure was computed with *ScorePutting* software (written in National 185 Instruments LabVIEW), which uses the photographs from a camera system directly placed 186 above the targets to control for angle differences (Neumann & Thomas, 2008).

### 187 **Golf kinematics.**

A triaxial accelerometer (LIS3L06AL, ST Microelectronics, Geneva, Switzerland) and amplifier (frequency response of DC to 15 Hz) were attached to the rear of the putter head in order to measure movement kinematics (Cooke et al., 2014; Cooke et al., 2011). Acceleration of the golf putter from downswing until ball contact was calculated for the x, y and z-axes (representing the lateral, vertical and back-and-forth movement of the club head), to determine club head orientation, swing height and impact force (Spike2, version 5, Cambridge Electronic Design).

#### 195 **Procedure**

Participants were informed about the context of the study and signed an informed
consent form prior to the start of the experimental procedure. The EEG, ECG and EMG
equipment were set up and a 2-min EEG resting state measurement was performed (1-min
open eyes and 1-min closed eyes).

200 Participants first completed 130 putts as part of a separate investigation of the psychophysiological corollaries of practice (data not reported here). The putts served to 201 202 familiarise participants with the task. This was followed by performing one of the three pre-203 performance hand-contraction protocols (left, right or no-hand contractions) while seated. 204 Immediately after each protocol, participants were instructed to stand-up and perform 25 self-205 paced golf putts, aiming for the target as accurately as possible. The time lag between the end of the squeezing protocol and the start of the putting task was approximately 10-sec. A 206 207 photograph of the final position of the golf ball was taken after each trial. The researcher then 208 collected the golf ball and positioned it for the next trial, thereby standardising the inter-trial 209 interval, and reducing the need for participants to move in-between putts. This procedure was 210 repeated for all conditions (three times in total) and took on average 5-min and 53-sec per 211 condition.

#### 212 Analysis

#### 213

#### Pre-performance hand contraction protocols.

EEG signals captured during the hand contraction protocols were processed offline with EEGLAB software (Delorme & Makeig, 2004) running on MATLAB (Mathwork, Inc., USA version 2018b) to compute the power asymmetry. The signals were first resampled to 250 Hz, re-referenced to the average of all electrodes, and filtered (.01-30 Hz bandpass filter). The IAF toolbox was used to adjust the alpha frequency band for each participant based on

their individual alpha frequency peak, determined from the baseline measure (Corcoran,

220 Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2018).

221 The signals were then subjected to a threshold-based artefact removal procedure, 222 where any 250-ms window containing signal fluctuations exceeding  $\pm 150 \,\mu V$  was rejected 223 (ERPLAB Toolbox, Lopez-Calderon & Luck, 2014). Independent Component Analyses were 224 then performed via the RunICA infomax algorithm (Makeig, Bell, Jung, & Sejnowski, 1996) to identify and remove any remaining artefacts and non-neural activity (e.g., eye-blinks) from 225 226 the signal. An average of 5.76 components were rejected. The clean signal was then subjected to a time frequency analysis, to obtain the estimate of instantaneous alpha power for the 38-227 228 sec of the hand contraction protocols. The total of 45-sec was reduced by 7-sec, due to some 229 participants showing increased artefacts at the end. This analysis was performed by convolving the Fast-Fourier Transform (FFT) power spectrum of the signal with a family of 230 complex Morlet wavelets and eventually taking the inverse FFT (Cohen, 2014). All power 231 232 values were then log transformed to control for skewness and inter-individual differences. 233 Finally, the transformed values were used to compute the asymmetry scores of the 234 homologous electrode pairs close to the cortical regions involved in hand movements (e.g., 235 Grefkes, Eickhoff, Nowak, Dafotakis, & Fink, 2008): T8-T7, P4-P3, P8-P7, F4-F3, F8-F7, C4-C3, FC2-FC1, FC6-FC5, CP2-CP1, CP6-CP5 (right – left). This is a common way of 236 calculating alpha asymmetry to identify the effects of a state manipulation (e.g., unilateral 237 238 hand contractions) on the relative activation of the right hemisphere versus left hemisphere of 239 the brain (e.g., Harmon-Jones, 2006). A higher asymmetry score signifies more activity in the 240 left hemisphere (inverse of alpha activity) compared to the right hemisphere (Harmon-Jones, 241 2006; Wolf et al., 2015).

Golf putting task.

243	An optical sensor and microphone were used to mark movement initiation and ball
244	contact in the continuous data (Spike2 and Actiview software, Biosemi), in order to analyse
245	the psychophysiological measures prior to and during the golf putts. The optical sensor (S51-
246	PA-2-C10PK, Datasensor, Monte San Pietro, Italy) was used to identify swing-onset by
247	detecting when the infrared beam was broken by movement of the putter head. The
248	microphone (NT1, Rode, Silverwater, Australia) was linked to a mixing desk (Club 2000,
249	Studiomaster, Leighton Buzzard, UK) to detect putter-to-ball contact.
250	Connectivity prior to movement initiation was computed offline by processing the
251	EEG signals (EEGLAB software) computed during the golf putt preparation. The signals
252	were cut into epochs of 5-sec (4-sec prior to and 1-sec after movement initiation). Thereafter,
253	the signals were filtered and cleaned with the same methods as for the hand contraction
254	<i>protocols</i> . The signals were then baseline corrected (2 to 0-sec, where $0 =$ movement
255	initiation; Ring et al., 2015) and time-frequency analysis was performed (see hand
256	contraction protocols) to obtain the phase angles. These phase angles were then used to
257	compute connectivity between the left temporal (T7) and frontal (Fz) regions for the 3-sec
258	prior to movement initiation, by calculating inter-site phase clustering (ISPC, Cohen, 2014). <sup>1</sup>
259	We calculated ISPC <sub>time</sub> measuring phase angle differences across the electrodes over time: $^{2}$

$$ISPC_{xy}(f) = \left| n^{-1} \sum_{t=1}^{n} e^{i(\theta_x(tf) - \theta_y(tf))} \right|$$

<sup>&</sup>lt;sup>1</sup> Two different methods have been used to measure synchronization in the sport science literature. Earlier work (e.g., Deeny et al., 2003) measured magnitude squared *coherence;* however, more recent research has measured inter-site phase *connectivity* (ISPC). ISPC is based on phase information only, which makes it independent of fluctuations in absolute power (Gallicchio et al., 2016).

 $<sup>^{2}</sup>$  Cohen (2014) suggests that the ISPC *time* measure is appropriate when having relatively long epochs, with 3-sec considered as long.

260	<i>N</i> is the number of data points; <i>i</i> is the imaginary operator; $\theta_x$ and $\theta_y$ are the phase angles of
261	the recorded signal at two different scalp locations; $t$ is the time point and $f$ is the frequency
262	bin. The $e^{i(\theta_x(tf)-\theta_y(tf))}$ represents the complex vector with magnitude 1 and angle $\theta_x - \theta_y$ ;
263	$n^{-1}\sum_{t=1}^{n}(.)$ denotes averaging over time points, and $ . $ is the module of the averaged vector
264	(Cohen, 2014; Lachaux, Rodriguez, Martinerie, & Varela, 1999). ISPC is given as a value
265	between 0 (no functional connection) and 1 (perfect functional connection). Finally, values
266	were Z-transformed (inverse hyperbolic tangent) to ensure normal distribution (Gallicchio et
267	al., 2016).
268	The EMG and ECG signals 6-sec prior to until 6-sec after movement initiation were

analysed offline in epochs of 1-sec (Cooke et al., 2014; Moore, Vine, Cooke, Ring, & Wilson,
2012; Neumann & Thomas, 2011). Heart rate was corrected for artefacts and R-wave peaks
were identified. The intervals between the successive R-waves peaks were calculated and
instantaneous heart rate (beats per minute, BPM) was calculated as 6000/(R-R interval).
Muscle activity was assessed by rectifying the EMG signal and averaging over 0.5-sec
windows, such that the mean activity between 6.25 and 5.75-sec prior to movement was used
to calculate muscle activity 6-sec before movement, and so on (Cooke et al., 2014).

The acceleration of each putt was determined from the initiation of the downswing phase until the point of contact (Cooke et al., 2014; Cooke et al., 2010; Moore et al., 2012). Average acceleration was calculated for the x, y, and z-axes. Besides impact velocity, Root Mean Square (RMS) jerk and smoothness on the z-axis were computed, as the z-axis is the main axis involved in the putting swing (Cooke et al., 2011; Maxwell et al., 2003).

281

#### Statistical analysis.

The cortical activity manipulation check was subjected to a 3 x 10 repeated measures analysis of variance (ANOVA): Condition (Left, Right, No-hand) x Homologous electrode pairs (T8-T7, P4-P3, P8-P7, F4-F3, F8–F7, C4-C3, FC2-FC1, FC6-FC5, CP2-CP1, CP6-

301	Results
300	CI (low and high) were reported (Montoya & Hayes, 2017).
299	swing height and impact force). The mediation effect (B), standard error (BootSE) and 95%
298	individually tested and included EEG, EMG, ECG and kinematics (i.e., club head orientation,
297	putting performance associated with left-hand and right-hand contractions. Mediators were
296	designs, Montoya & Hayes, 2017) was used to test within-subject mediation effects on golf
295	MEMORE for SPSS (MEdiation and MOderation analysis for REpeated measure
294	software. Significance was set at $p = .05$ for all statistical tests.
293	squared $(\eta_p^2)$ . The statistical tests were performed using SPSS (IBM, version 25.0) computer
292	performed when main effects or interactions were found. Effect sizes are reported as partial $\boldsymbol{\eta}$
291	necessary. Separate ANOVAs with Bonferroni corrections or polynomial trend analysis were
290	Sphericity was checked and corrected using the Huynh-Feldt correction when
289	performance were both subjected to a one-way ANOVA of Condition (Left, Right, No-hand).
288	Bin (-6, -5, -4, -3, -2, -1, 0, +1, +2, +3, +4, +5, +6). Golf putting kinematics and golf putting
287	subjected to a 3 x 13 repeated measures ANOVA: Condition (Left, Right, No-hand) x Time
286	one-way ANOVA of Condition (Left, Right, No-hand). Cardiac and muscle activity were
285	CP5). The T7-Fz connectivity measure during preparation of the golf putt was subjected to a

#### 302 Manipulation check

The results revealed a main effect of Condition, F(2,42) = 3.95, p = .027,  $\eta_p^2 = .16$ , with post-hoc analysis revealing a significantly lower asymmetry score for left-hand contractions compared with right-hand contractions (p = .015, see Fig. 1). No significant effects were revealed for left-hand contractions compared with no-hand contractions (p= .180) or right-hand contractions compared with no-hand contractions (p = 1.00). No main effect was found for Homologous electrode pairs, F(3.20,67.15) = 0.93, p = .438,  $\eta_p^2 = .04$ .





Fig. 1. Alpha power asymmetry score per condition. Asymmetry score was calculated by: right hemisphere –
 left hemisphere (positive values represent higher right-hemisphere power and negative values represent higher

312 left-hemisphere power). Error bars represent standard error of the mean. (\* p < .05).

## 313 Cortical activity preceding golf putts

314 The results revealed a main effect of Condition, F(2,48) = 122.5, p < .001,  $\eta_p^2 = .84$ .

315 Post-hoc tests revealed that left-hand contractions led to significantly lower T7-Fz

- 316 connectivity, than right-hand contractions (p < .001) or no-hand contractions (p < .001, see
- 317 Fig. 2). Right-hand contractions revealed the opposite effect with significantly higher T7-Fz
- 318 connectivity compared to left-hand contractions (p < .001) and no-hand contractions (p
- 319 < .001, see Fig. 2).



Fig. 2. T7-Fz ISPCtime connectivity during each condition and time bin. Error bars represent standard error of
the mean. (\*\* p < .001).</li>

#### 323 Muscle activity

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No Condition x Time Bin interactions were evident for the extensor carpi radialis, 324  $(F(24,432) = 1.15, p = .290, \eta_p^2 = .06, or the flexor carpi ulnaris, F(24,480) = 0.82, p = .715,$ 325  $\eta_p^2 = .04$ . A main effect of Time Bin was evident for the extensor carpi radialis, F(3.73,67.11) 326 = 9.99, p < .001,  $\eta_p^2 = .36$ , and the flexor carpi ulnaris, F(4.18,83.61) = 13.51, p < .001,  $\eta_p^2$ 327 = .40. Post-hoc analysis revealed that for the extensor carpi radialis the variance for Time Bin 328 was best described by a quadratic trend (p < .001,  $\eta_p^2 = .53$ ), with a gradual increase of 329 330 activity until peak in activity during movement initiation (time zero), which quickly drops back to baseline (see Fig. 3). For the flexor carpi ulnaris, variance for Time Bin was also best 331 described by a quadratic trend (p < .001,  $\eta_p^2 = .68$ ), with similar trends to the extensor carpi 332 333 radialis (see Fig. 4). Main effects of Condition were not evident for the extensor carpi radialis, F(2,36) = 1.74, p = .191,  $\eta_p^2 = .09$ , or the flexor carpi ulnaris, F(2,40) = 0.69, p = .510,  $\eta_p^2$ 334 335 = .03.



337 Fig. 3. Activity of the extensor carpi radialis in each condition over time. Error bars represent standard error of

the mean.

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Fig. 4. Activity for of the flexor carpi ulnaris in each condition over time. Error bars represent standard error ofthe mean.

#### 342 Cardiac activity

The ECG analysis did not reveal a Condition x Time Bin interaction, F(24,567) = 0.95, p = .532,  $\eta_p^2 = .04$ , or a main effect of Condition, F(2,48) = 0.62, p = .542,  $\eta_p^2 = .03$ . A main effect of Time Bin was evident, F(1.57,37.61) = 17.26, p < .001,  $\eta_p^2 = .42$ . Post-hoc analysis revealed that heart rate differences over time was best described by a cubic trend (p < .001,  $\eta_p^2 = .56$ ). Heart rate decreased during approximately 2-sec preceding movement initiation and then gradually retrurned to baseline in the 6-sec after movement initiation (see Fig. 5).



Fig. 5. Heart rate in each condition over time (6-sec before until 6-sec after movement initiation). Error bars
represent standard error of the mean.

#### **352 Golf kinematics**

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No differences were evident between conditions for any of the kinematic measures: acceleration on the x-axis, F(2,48) = 2.60, p = .085,  $\eta_p^2 = .10$ ; acceleration on the y-axis, F(1.59,38.26) = 0.65, p = .493,  $\eta_p^2 = .03$ ; acceleration on the z-axis, F(2,44) = 0.55, p = .581,  $\eta_p^2 = .02$ ; impact speed, F(1.52,36.39) = 0.25, p = .718,  $\eta_p^2 = .01$ ; RMS jerk, F(2,46) = 0.31, p= .738,  $\eta_p^2 = .01$ ; smoothness, F(1.59,38.03) = 0.46, p = .592,  $\eta_p^2 = .02$ . **Golf putting performance** 

No differences were evident between conditions for mean radial error, F(2,48) = 1.75, p = .184,  $\eta_p^2 = .07$ .

#### 361 Mediation analysis

362 Mediation analyses were used to examine whether EEG, EMG, ECG or kinematics

363 mediated the relationship between hand contractions and golf putting performance (mean

- 364 radial error). Although there was no significant difference in performance between the
- 365 different hand contraction conditions, there was a significant indirect effect of hand
- 366 squeezing on performance via T7-Fz connectivity. Within-subject changes in performance
- 367 following left-hand versus right-hand contractions were mediated by the changes in EEG T7-

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371 The present study was conducted to examine whether pre-performance unilateral hand 372 contraction protocols influence verbal-analytical engagement in motor performance. A 373 repeated measures crossover design was adopted, measuring psychophysiological markers (neural, cardiovascular and muscular) and performance (distance from the target and 374 375 movement kinematics) of a golf putting task that was completed immediately after performing a hand contraction protocol (left, right and no-hand). During the hand contraction 376 377 protocols, measures of alpha power spectra between homologous electrode pairs were 378 computed as a manipulation check to determine whether hand contractions caused different 379 hemispheric activation.

The manipulation check revealed a significant difference in hemispheric asymmetry between left-hand and right-hand contraction protocols, with the left-hand contraction protocol resulting in more right-hemisphere activity and the right-hand contraction protocol resulting in higher left-hemisphere activity (see Fig. 1). These findings are consistent with previous studies (Gable et al., 2013; Harmon-Jones, 2006; Peterson et al., 2008).

Our study is the first to include a no-hand contractions, which makes it possible to compare the effect of left-hand and right-hand contractions relative to no contractions. Asymmetry during the no-hand contraction protocol was not significantly different from either contraction condition, which suggests that hand contractions did not create different asymmetry compared to no-hand contractions. However, hand contractions did achieve different asymmetry compared to each other. The slight rightward bias evident during the nohand condition is in line with previous studies revealing that right-handedness is related to a

bias to rightward hemisphere asymmetry (greater left-hemisphere activity) for resting state
alpha power (e.g., Ocklenburg et al., 2019).

394 As hypothesized, a lower level of T7-Fz connectivity during preparation for putts was 395 revealed after left-hand contractions, compared to right-hand and no-hand contractions. The opposite effect was found for right-hand contractions, revealing higher T7-Fz connectivity 396 397 compared to left-hand and no-hand contractions. Previous studies have suggested that lower T7-Fz connectivity reflects less verbal-analytical engagement in movements (e.g., Deeny et 398 399 al., 2003; Gallicchio et al., 2016; Zhu et al., 2011). Left-hand contractions in the present study may therefore have lowered T7-Fz connectivity and reduced verbal-analytical 400 401 engagement in the putting task, compared to right-hand and no-hand contractions. 402 Although there was no significant effect of hand contractions on golf putting performance,<sup>3</sup> mediation analysis suggested that hand contractions influenced T7-Fz 403 404 connectivity, which in turn influenced performance. Beckmann et al. (2013) and Gröpel and Beckmann (2017) speculated that top-down verbal-analytical control processes are the 405 406 mechanism by which hand contractions influence performance under pressure. Many 407 explanations of skill failure, such as the theory of reinvestment (Masters, 1992; see Masters & Maxwell, 2008 for a review), suggest that attempts to consciously control movements 408 409 (characterised by verbal-analytical processing), can disrupt normally efficient motor behaviours. Given the hypothesised link between T7-Fz connectivity and conscious verbal 410 411 engagement of movement, our mediation findings provide some support for their speculation. 412 Although the hand contraction protocols clearly influenced neurophysiological activity, their effects did not extend to the cardiac, muscular or kinematic measures. There 413

<sup>&</sup>lt;sup>3</sup>It is acceptable to conduct mediation analysis when there is no significant effect of the independent variable (hand contractions) on the dependent variable (golf putting performance) (see e.g., Kenny, Kashy, & Bolger, 1998).

414 were no condition effects for these variables and there were no mediational effects to implicate any of these variables in the relationship between hand contractions and 415 performance. From a theoretical perspective it makes sense that neural measures should be 416 417 more sensitive to the effects of hand contraction protocols than peripheral measures such as 418 heart rate, because verbal-analytic processes originate from the brain, and any effects they 419 might have on the heart and muscles would be always be secondary. Any effects of psychological processes on cardiac and muscular activity could also have been masked by 420 any physical strain on these variables caused by the golf putting task (e.g., standing posture, 421 422 swinging arms, etc.).

423 Despite the indirect effect of hand contractions on performance through T7-Fz connectivity, there were no significant performance differences between the different hand 424 contraction protocols. Our participants only performed 130 trials prior to the first hand 425 426 contraction condition, so they remained relatively inexperienced novices with high inter and 427 intra person performance variability that may have camouflaged any subtle (direct) hand contraction effects. A more cognitively challenging task may reveal performance differences. 428 429 Zhu et al (2015) also manipulated T7-Fz coherence, using real versus sham tDCS, and also failed to find an effect on golf putting performance alone. However, Zhu et al. (2015) did 430 431 report a differential effect on golf putting performance under dual-task load (e.g., backwards 432 counting). Alternatively, replicating the experiment with more experienced performers could 433 also increase the likelihood of performance differences. For example, the theory of 434 reinvestment (Masters & Maxwell, 2008) argues that verbal-analytic engagement (e.g., right-435 hand contractions) would be more detrimental to the performance of autonomous experts than cognitive novices. Effects of condition on the cardiac, muscular and kinematic measures 436 437 would also be more likely with experienced performers for the same reasons.

438 A limitation of this study is that we did not control force of grip used by participants 439 during the hand contraction protocol. Consequently, differences in hemisphere asymmetry 440 might have been a function of effort or strength. For example, Hirao and Masaki (2018) 441 showed that force and duration of left-hand contractions had differential effects on hemisphere activity. Additionally, a requirement to achieve a specific force during 442 443 contractions may require more cognitive resources (e.g., Derosière et al., 2014; Hirao & Masaki, 2018). One solution might simply be to measure grip force and include it as a 444 covariate in analysis of hemisphere asymmetry. This issue should be addressed in further 445 446 studies.

Another limitation is that we were unable to determine the longevity of the hand contractions with respect to their effect on cortical activity. Studies suggest that the effects of hand contraction protocols last at least 15-min (e.g., Baumer, Munchau, Weiller, and Liepert (2002). Participants in our study completed 25 trials over approximately a 6-min duration, so it is likely that the effects remained. However, there is little doubt that further research is needed to gain greater understanding of the timecourse of hand contraction effects.

To our knowledge this is the first study reporting neural evidence that left-hand contractions lower verbal-analytical engagement in motor planning of a golf putting task. The additional markers (ECG, EMG, kinematics and performance) did not, however, provide supporting evidence of this effect. These secondary markers may have been insufficiently sensitive to reveal the brain's influence over the body. Nevertheless, it appears that the body (the hands) influenced the brain!

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## Highlights:

- The effects of unilateral hand contractions during motor performance was investigated
- Unilateral hand contractions influenced the verbal-analytical engagement in motor planning
- Left-hand contractions caused lower verbal-analytical engagement in motor planning
- It appears that the body (the hands) influenced the brain!

Journal Pression

#### **Declaration of interests**

 $\boxtimes$  The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

□ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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