Peer-reviewed version available at Brain Sci. 2019, 9, 41; doi:10.3390/brainsci9020041

Article

Corticospinal excitability to the biceps brachii is not different when arm cycling at a self-selected or fixed cadence

Evan J. Lockyer [2], Anna P. Nippard [1], Kaitlyn Kean [1], Nicole Hollohan [1], Duane C. Button [1,2], and Kevin E. Power [1,2]*

[1] School of Human Kinetics and Recreation
[2] Faculty of Medicine, Memorial University of Newfoundland, St. John's, Newfoundland, Canada
* Correspondence: kevin.power@mun.ca; Tel.: +709-864-7275

Abstract: Background: The present study compared corticospinal excitability to the biceps brachii muscle during arm cycling at a self-selected and a fixed cadence (SSC and FC, respectively). We hypothesized that corticospinal excitability would not be different between the two conditions. Methods: The SSC was initially performed and the cycling cadence was recorded every 5 seconds for one minute. The average cadence of the SSC cycling trial was then used as a target for FC of cycling that the participants were instructed to maintain. Motor evoked potentials (MEPs) elicited via transcranial magnetic stimulation (TMS) of the motor cortex were recorded from the biceps brachii during each trial of SSC and FC arm cycling. Results: Corticospinal excitability as assessed via normalized MEP amplitudes (MEPs were made relative to a maximal compound muscle action potential) were not different between groups. Conclusions: Focusing on maintaining a FC cadence during arm cycling does not influence corticospinal excitability as assessed via TMS-evoked MEPs.

Keywords: motor evoked potential; MEP; arm cranking; pedaling; exercise

1. Introduction

It is well established that rhythmic locomotor outputs in non-human animals (e.g. cat, rat, dog) are partially controlled by neural circuits located in the spinal cord, referred to as central pattern generators (CPGs) [1-2]. Evidence, albeit indirect, has shown that the CPG also contributes to the production of rhythmic motor outputs in humans by integrating descending and afferent input [3-4] though it is believed that descending input is of greater importance in the control of human locomotor outputs [5].

Arm cycling has been introduced as a model of locomotor output for examining changes in neural excitability during rhythmic movement, with the vast majority of these studies using a set cadence and power output for each participant [4-5]. While this may be necessary to maintain experimental stringency, it is also acknowledged that: first, arm cycling may be regarded as a novel task for some participants and second, that by setting the cadence at 60 rpm for example, participants may not be cycling at a preferred cadence. Taken together, these two factors may act to alter attentional demands, thus influencing measures of corticospinal excitability.

When humans engage in a novel motor task, they typically focus on how to perform said task, placing them in what is known as the *cognitive stage* of motor learning according to the Fitts and Posner model [6]. This suggests that the level of cognitive effort, and thus, in all likelihood descending input, would be greater during this stage of learning. This is supported by work examining the time course of changes in corticospinal excitability when learning a novel motor task, albeit non-locomotor [7]. Holland et al. (2015) showed that the slope of the transcranial magnetic stimulation (TMS) evoked input/output (I/O) curve decreased as learning progressed, with the majority of the change occurring

Peer-reviewed version available at Brain Sci. 2019, 9, 41; doi:10.3390/brainsci9020041

on the first of two training days. This suggests that as participants began the novel task, greater cognitive effort was required thus enhancing corticospinal excitability, an effect that decreased as the task lost its' novelty.

Arm cycling is a motor task that may be considered novel and a number of studies have been published examining corticospinal excitability during cycling in humans [8-14]. Work from our lab has shown that corticospinal excitability, assessed via TMS of the motor cortex projecting to the biceps brachii, was shown to be higher during arm cycling in humans when the elbow was flexed (bottom dead centre) compared to an intensity- and position-matched tonic contraction [15]. This effect was due to enhanced supraspinal excitability as there were no differences in measures of spinal excitability. In that study, participants were required to maintain a predetermined cadence (60 rpm) throughout the trial by observing their cadence on the ergometer monitor and it was possible that this increased the attentional demand of the task. Research has shown that directed visual attention can induce an increase in neural activity in the fronto-parietal network as evidenced in functional brain imaging studies [16]. It is thus possible that an increase in attention may increase corticospinal excitability during arm cycling, though we hypothesized that the difference was task-dependent and not simply due to increased attentional demands of arm cycling [15].

Several studies have examined the influence of cycling cadence on neuromuscular activation. Marias et al., (2004) examined the effects of a spontaneous chosen crank rate (SCCR) and crank rates 20% higher and lower than the SCCR during arm cycling on integrated electromyography (iEMG) levels in the biceps brachii muscles in humans. The researchers concluded that there were no significant differences in iEMG between the crank rate conditions of the biceps brachii, suggesting that the SCCR is not chosen to minimize the level of muscle activity and that the degree of muscle activation was similar between the two groups [17]. This finding is supported by research that showed no reduction in lower extremity muscle activation at a SCCR during leg cycling [18]. The iEMG assessed in these studies is a measure of the electrical activity in the muscle representing the overall output of the motoneurone pool and does not necessarily represent corticospinal excitability [8, 13-14]. Therefore, it is unknown how a SSC during arm cycling influences corticospinal excitability in comparison to a FC.

The purpose of the current study was thus to determine if corticospinal excitability between SSC and FC arm cycling were different. It was hypothesized that corticospinal excitability as assessed via the amplitude of motor evoked potentials (MEPs) elicited via TMS of the motor cortex would not be different between a SSC and FC.

2. Materials and Methods

Ethical approval

Prior to the experiment all participants were informed of the experimental protocol and written informed consent was obtained. This study was in accordance with the Helsinki declaration and experimental procedures were approved by the Interdisciplinary Committee on Ethics in Human Research at Memorial University of Newfoundland (ICEHR #20171250). All experimental procedures were in accordance with the Tri-Council guideline in Canada and potential risks of participation were disclosed to all participants.

Participants

Eleven participants (7 male and 4 female; 22 ± 2.14 years of age) were recruited from the School of Human Kinetics and Recreation (HKR) at Memorial University using a convenience sampling technique. Prior to testing each participant completed a magnetic stimulation safety-checklist to screen for existing contraindications to magnetic stimulation (Rossi et al, 2009). To determine hand dominance participants completed an Edinburg handedness inventory questionnaire to ensure that all evoked responses were recorded from the dominant arm [19]. Additionally, to screen for existing contraindications to physical activity each participant completed a Physical Activity Readiness

Questionnaire (PAR- Q+) [20]. Participants were excluded if they had any neurological deficits or contraindications to magnetic stimulation and physical activity.

Experimental Set-up

A one-group within-subjects design was used. Participants attended two lab sessions with at least 24 hours in between visits: the first visit was for a half-hour familiarization session and the second was the testing session, lasting approximately 1 hour. The experiment was completed on an arm cycle ergometer (SCIFIT ergometer, model PRO2 Total Body) with the arm cranks set at 180 degrees out of phase (see Figure 1). Each participant was advised to sit upright at a comfortable position from the arm cranks to ensure that they could maintain an upright posture throughout each cycling protocol. The seat height was adjusted to ensure the participants shoulders were in line with the center of the arm shaft. The participants were informed to lightly grip the handles with their forearms in pronation. Each participant was required to wear wrist braces to limit wrist joint movement during cycling to reduce the effects of the heteronymous reflex connections that exist between the wrist flexor muscles and the biceps brachii muscle [21].

All measurements were taken at a single position; 6 o'clock relative to a clock face. This position was relative to the participants dominant hand, such that TMS would be triggered when the right or left hand was at the 6 o'clock position for a right or left-handed dominant individual, respectively. We have examined this position previously [8-13, 15], as it corresponds to a period of high bicep brachii EMG activity during arm cycling since it occurs during mid-elbow flexion (i.e., movement from 3 o'clock to 9 o'clock).

The study required participants to cycle at two different cadences, both at a constant workload of 25 W. The cadences (FC and SSC) served as the independent variable in the study. TMS and Erb's point stimulation were delivered at the 6 o'clock position to elicit MEPs and M_{max} in the biceps brachii muscle in each condition. MEP amplitude made relative to M_{max} and bEMG (see below), as a measure of corticospinal excitability, served as the dependent variable. The SSC trial was completed first followed by the FC trial and responses were triggered as the arm crank of the dominant arm passed the 6 o'clock position.

Electromyography (EMG) recordings

EMG activity was recorded from the biceps brachii and lateral head of the triceps brachii of the dominant arm using pairs of surface electrodes (Kendall™ 130 conductive adhesive electrodes, Covidien IIC, Massachusetts, USA). EMG was recorded using a bi-polar configuration with an interelectrode distance of 2 cm. Electrodes were placed in the middle of the muscle belly of the biceps brachii. A ground electrode was placed over the lateral epicondyle on the dominant arm. Prior to electrode placement the skin at the recording site was shaved to remove hair, abraded using an abrasive pad to remove dead epithelial cells and cleaned with an isopropyl alcohol swab to reduce impedance for EMG recordings. Signals were sampled online at 5 kHz using CED 1401 interface and Signal 5.11 software (Cambridge Electronic Design (CED) Ltd., Cambridge, UK). EMG signals were amplified (gain of 300) and filtered using a 3-pole Butterworth band-pass filter (10-1000 Hz) using a CED 1902 amplifier.

Peer-reviewed version available at Brain Sci. 2019, 9, 41; doi:10.3390/brainsci9020041

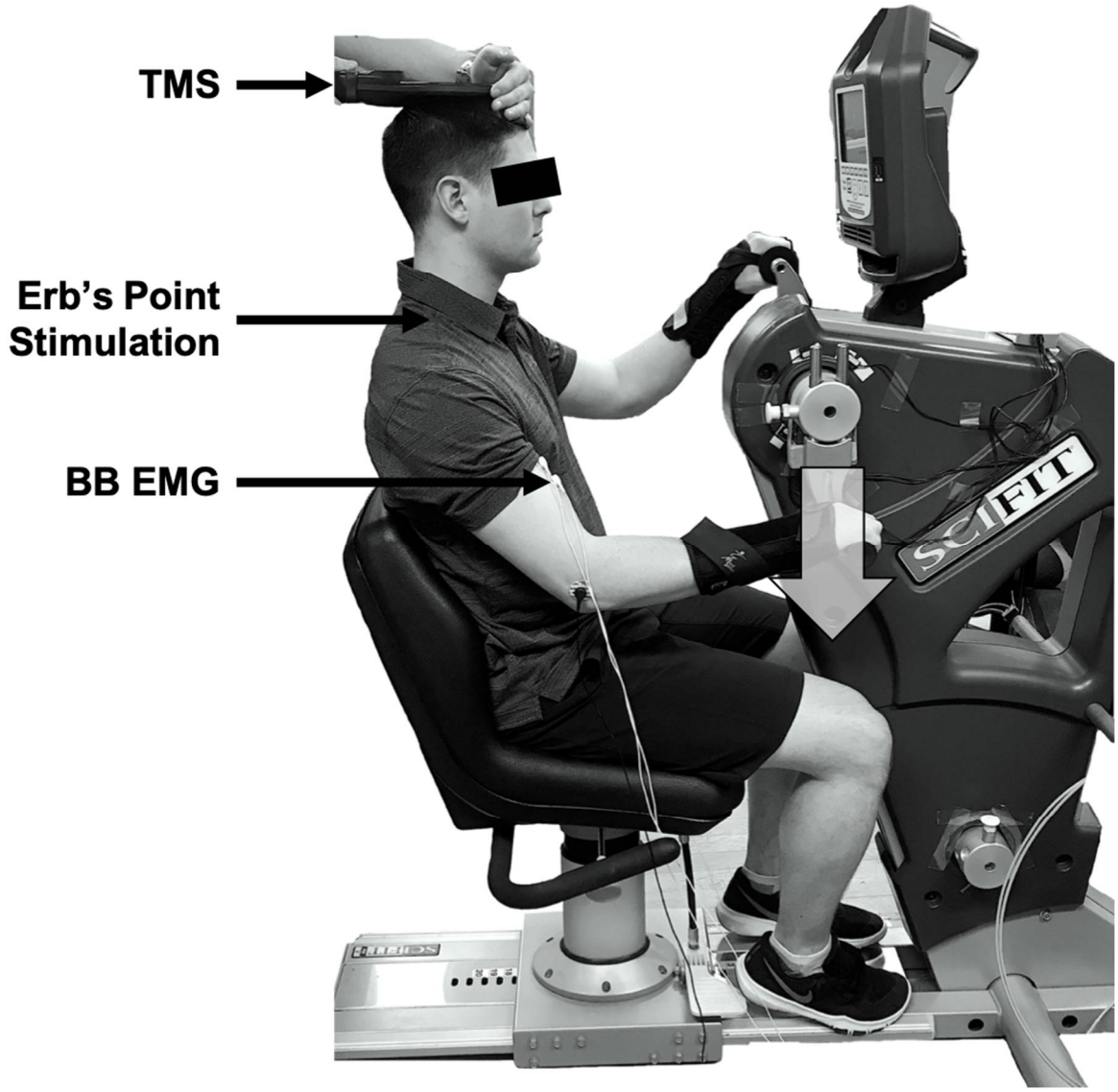


Figure 1. Experimental setup. Arm cycling was performed in the forward direction, with stimulations occurring when the dominant arm passed the 6 o'clock position (i.e. bottom-dead centre) when the biceps brachii is active. This position is denoted by the large grey downwards arrow.

Simulation Conditions

Brachial plexus stimulation

Electrical stimulation of the brachial plexus at Erb's point was used to measure M_{max} (maximal M-wave) (DS7AH, Digitimer Ltd., Welwyn Garden City, Hertfordshire, UK). The anode was placed on the acromion process and the cathode was placed over the skin in the supraclavicular fossa. A pulse duration of 200 μs was utilized and the stimulation intensity was gradually increased until the M-wave amplitude of the biceps brachii reached a plateau, referred to as M_{max}. This stimulation intensity was increased by 10% and used for the remainder of the experiment to ensure maximal M-waves were elicited during each trial [22].

Transcranial magnetic stimulation (TMS)

Motor evoked potentials (MEPs) were measured during both cycling trials from the biceps brachii and served as the dependent variable in the study. TMS (Magstim 200, Dyfed, UK) was used to elicit MEPs in the biceps brachii by placing a circular coil (13.5 cm outside diameter) over the vertex. TMS is a valid and reliable technique for eliciting MEPs, which are recorded from the muscle

as a measure of the excitability of the corticospinal tract (Rothwell et al., 1991). The vertex was located by measuring the mid-point between the nasion and the inion and between participants tragi and marks were placed for both measurements directly on the scalp. The intersection of the measurements was defined as the vertex [13, 15, 23-24]. The same researcher held the coil for each trial and was vigilant with ensuring the coil was held parallel to the floor and remained aligned with the vertex throughout each trial. The current preferentially activated the right or left motor cortex, depending on hand dominance. Stimulation intensity was set during cycling (60 rpm and 25W) with MEPs evoked when the dominant hand was at the 6 o'clock position. The stimulus intensity was measured as a percentage of the maximum stimulator output (MSO) and intensity was increased until the participants active motor threshold (AMT) was found. AMT was defined as the lowest stimulus intensity required to evoke 5 clearly discernable MEPs (~ 200 μV) in 10 trials during cycling. Once AMT was found, MSO was increased by 10% to ensure clearly discernable MEPs were recorded and this stimulation intensity was then used for all trials.

Experimental Protocol

After the stimulation intensities were set for TMS and Erb's point stimulation the cycling trials were completed. The participant was first instructed to cycle forwards at a comfortable pace and the monitor displaying the cycling cadence was moved out of the participants sight, such that the participant was blinded to their cycling cadence. When the participant reached a steady cadence, as observed by the researcher, the trial was started. Steady cadence was defined as a cadence that fluctuated no more than ±1 rpm over a 5 second period. While the participant was cycling the researcher recorded the cadence every 5 seconds and calculated the average cadence over the duration of the trial. After a 1- minute break the participant was instructed to cycle forward maintaining a target cadence, as specified by the researcher, by observing their cadence on the monitor. This target cadence (FC) was equal to the average of the cadence over the duration of the SSC trial. During both trials the arm ergometer was set to a fixed power output of 25 W. While cycling each participant received 12 MEPs and 2 M-waves per trial, which were delivered when the dominate hand passed the 6 o'clock position. The order of the stimulations was randomized during the trial, and the stimulations were evoked every 7-8 s. To prevent anticipation of the stimulation 2 frames without stimulation were added. The total length of cycling was approximately 2 minutes per trial.

Data Analysis

Data was analyzed off-line using Signal 5.11 software (Cambridge Electronic Design Ltd., Cambridge, UK). To determine if central motor drive projecting to the biceps brachii was similar between the two arm cycling conditions the mean rectified EMG 50 ms prior to TMS stimulus artifact was measured (Forman et al., 2014). The peak-to-peak amplitude of all evoked responses (MEP and M-wave) were measured from the initial deflection of the voltage trace from background EMG to the return of the trace to the baseline level. MEP amplitudes can change as a result of changes to M_{max}, thus MEPs were normalized to M_{max} evoked during the same trial to account for potential changes in peripheral excitability. All measurements were taken from the averaged files of all 12 MEPs and 2 M-waves. All measurements were made from the dominant arm.

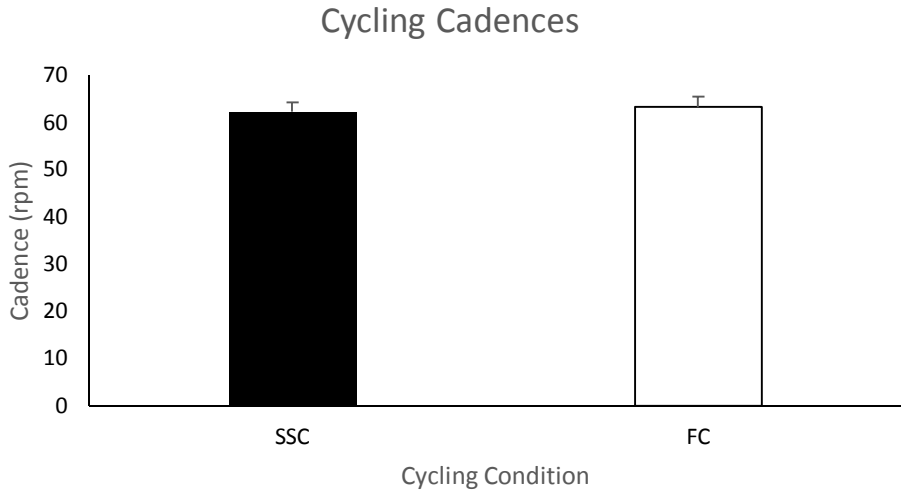
Statistical analysis

To compare pre-stimulus EMG between conditions (SSC and FC) paired- samples *t*- tests were utilized. Additionally, paired-samples *t*-tests were used to assess whether statistically significant differences in MEP amplitudes normalized to M_{max} occurred between the SSC and FC conditions. All statistics were completed on group data with a significance level of $p < .05$. All data is reported as mean ± *SE* in Figures.

3. Results

Peer-reviewed version available at Brain Sci. 2019, 9, 41; doi:10.3390/brainsci9020041

196 *Cycling cadence.* Figure 2 shows the group mean cycling cadence in revolutions per minute (rpm)
197 during the SSC and FC arm cycling trials. The cycling cadences for each condition were not
198 significantly different (mean cadence: SSC: 62 ± 6.4 rpm and FC 63 ± 6.9 rpm; p = .118).



199

200 **Figure 2.** Mean cycling cadences for each group (SSC = black and FC = white). Data (n=11) is shown
201 as mean ± SE.

202 ***MEP amplitude.*** Figure 3A shows representative data for MEP amplitudes from one participant
203 for both the SSC and FC cycling conditions. Figure 3B shows the group mean MEP amplitudes
204 expressed as a percentage of M_{max} of the biceps brachii during the SSC and FC arm cycling trials. The
205 average MEP amplitude (normalized/standardized to M_{max}) when cycling at a SSC and FC was 16.2
206 % (*SD* = 12.25) and 14.1% (*SD* = 11.75), respectively, with a mean difference of 2.1 %. This difference
207 was not statistically significant (*p* = .146).

Peer-reviewed version available at Brain Sci. 2019, 9, 41; doi:10.3390/brainsci9020041

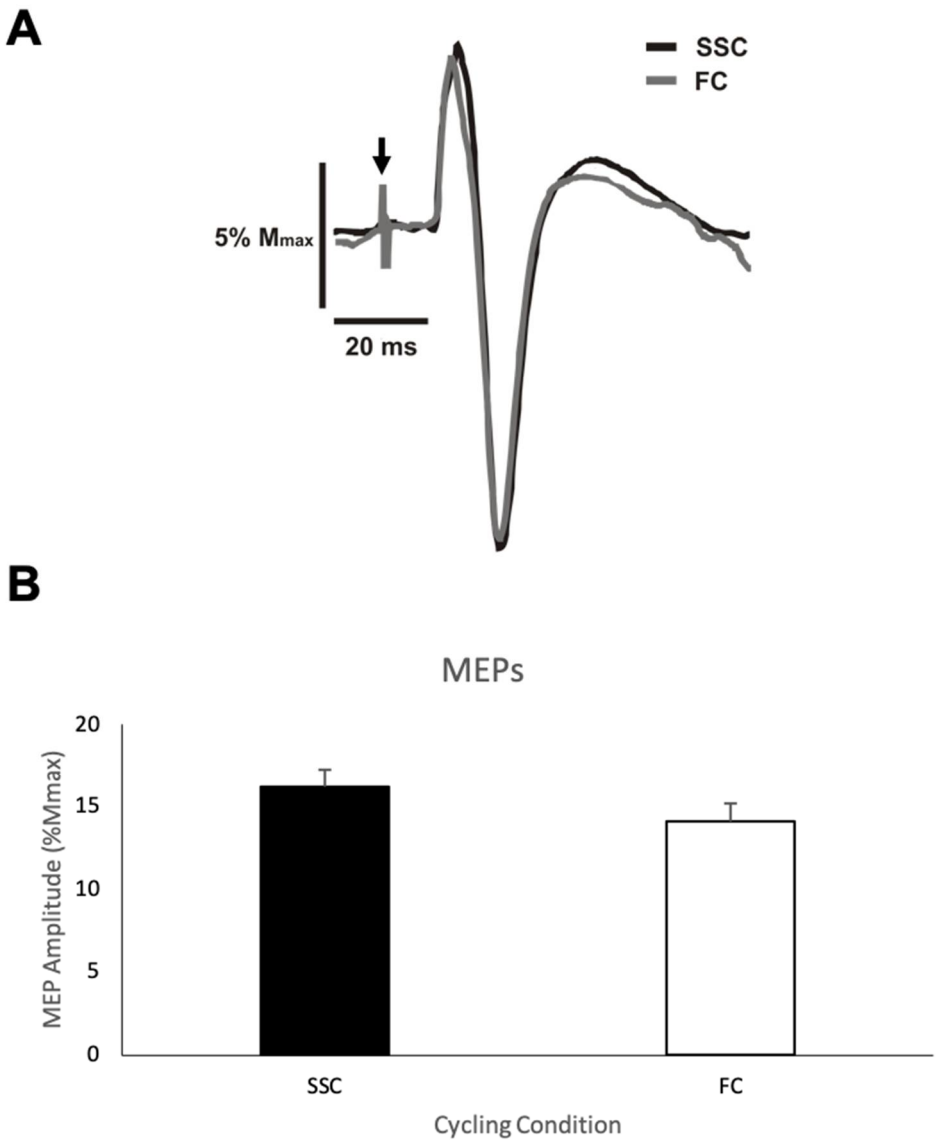


Figure 3. (A) Representative MEP amplitudes from one participant for each cycling condition (SSC = black and FC = grey). Downward arrow indicates location of stimulus artefacts that have been adjusted in size for figure clarity. **(B)** Mean TMS evoked MEP amplitudes as a percentage of Mmax for each group (SSC = black and FC = white). Data (n=11) is shown as mean ± SE.

Pre-stimulus EMG of the biceps brachii for MEPs. The group mean (n = 11) pre-stimulus EMG of the biceps brachii prior to the TMS stimulus artifact during SSC and FC arm cycling can be seen in Figure 4. As a group, the mean pre-stimulus EMG for SSC and FC arm cycling trials was 30.2 ± 4.58 µV and 32.1 ± 5.82 µV, respectively. There was no significant difference between the values (p = .061).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 February 2019 doi:10.20944/preprints201901.0196.v2

Peer-reviewed version available at Brain Sci. 2019, 9, 41; doi:10.3390/brainsci9020041

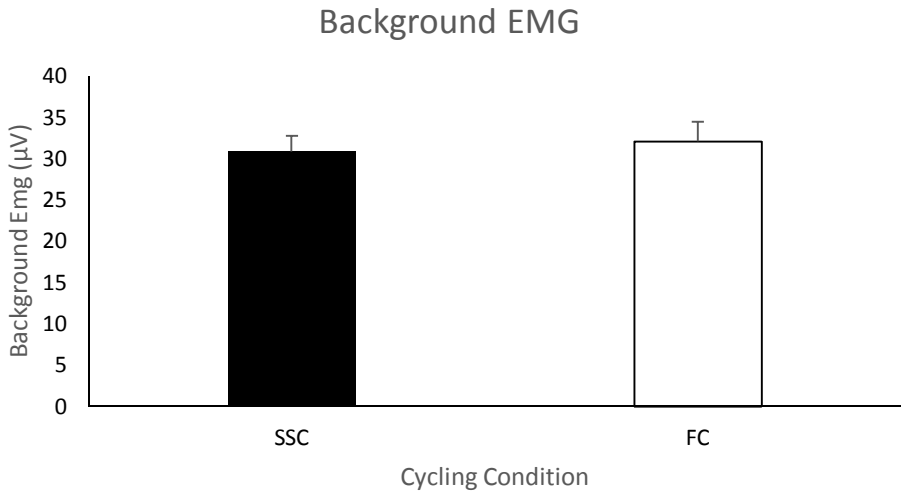


Figure 4. Mean of the average rectified EMG amplitude for the biceps brachii prior to TMS-evoked MEPs for each group (SSC = black and FC = white). Data (n=11) is shown as mean ± SE.

Pre-stimulus EMG of the triceps brachii for MEPs. The group mean (n = 11) pre-stimulus EMG of the triceps brachii prior to the TMS stimulus artifact during SSC and FC arm cycling can be seen in Figure 5. As a group, the mean pre-stimulus EMG for SSC and FC arm cycling trials was 8.9 ± 2.12 µV and 9.4 ± 2.68 µV, respectively. There was no significant difference between the values (p = .58).

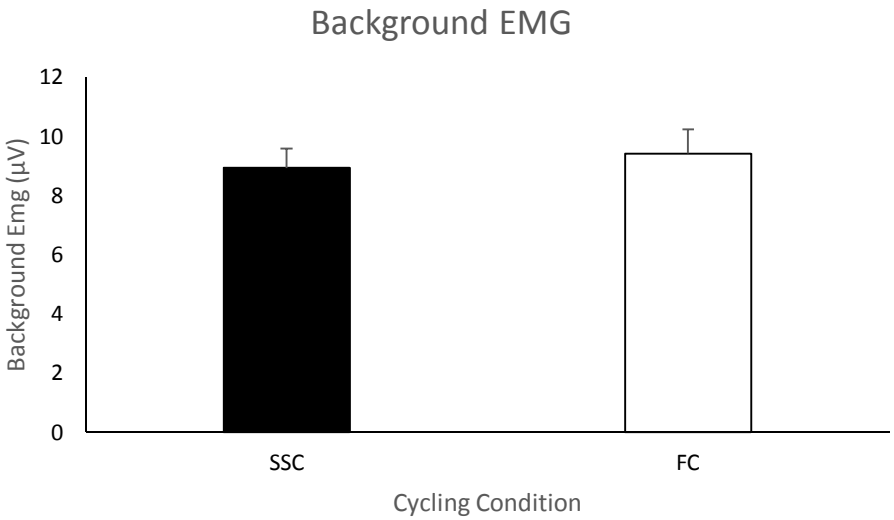


Figure 5. Mean of the average rectified EMG amplitude for the triceps brachii prior to TMS-evoked MEPs for each group (SSC = black and FC = white). Data (n=11) is shown as mean ± SE.

4. Discussion

This is the first study to compare corticospinal excitability projecting to the biceps brachii between self-selected (SSC) and fixed cadence (FC) arm cycling. There were no significant differences in corticospinal excitability as assessed via TMS-evoked MEP amplitudes recorded from the biceps brachii between the two arm cycling conditions. Maintaining a predetermined cadence (FC) during arm cycling does not increase corticospinal excitability when compared to cycling at a voluntarily chosen cadence (SSC).

A prior concern in studies from our lab and also the work of others was that the attentional demands of maintaining a set cadence could inadvertently alter (likely increase) measures of

Peer-reviewed version available at Brain Sci. 2019, 9, 41; doi:10.3390/brainsci9020041

corticospinal excitability. The current finding that corticospinal excitability is not different between SSC and FC arm cycling lends support to our previous finding that corticospinal excitability is task-dependent and is higher during arm cycling than an intensity- and position- matched tonic contraction [15]. In that study the participants were required to maintain a pre-determined cadence (60 rpm) while arm cycling rather than a voluntarily chosen cadence (Forman et al., 2014). Thus, it was unknown if the increase in supraspinal excitability projecting the biceps brachii at the 6 o'clock position was due to the arm cycling task or if it resulted from a greater attentional demand to maintain the set cadence. The results from the current study indicate that focusing on maintaining a fixed cadence does not increase the overall excitability of the corticospinal tract compared to arm cycling at a SSC. Thus, the increase in corticospinal excitability during arm cycling that we reported was likely task-dependent and not attributable to the fact that the participants had to focus on maintaining a cadence of 60 rpm [15]. This is indirectly supported by prior work assessing EMG of both arm and leg muscles during either arm [17] or leg [18] cycling, respectively. In the aforementioned studies, there was no influence of SSC or FC on EMG amplitudes, though there were no measures of corticospinal excitability.

Attentional Focus and Corticospinal Excitability

Prior work has shown that visual attention modulates corticospinal excitability and directing visual attention towards specific features of an observed action facilitates corticospinal excitability more than passive observation [25-26]. Attention can be directed to highly salient stimuli based on their physical properties (i.e. brightness, colour, speed) or towards stimuli that is important for one's current task [27]. In this study during the FC condition participants were instructed to focus on the monitor that displayed the cadence they were cycling at and were instructed to maintain a set cadence and speed up or slow down based on the observed cadence. In contrast, during the SSC condition participants were not able to see the monitor and were not instructed to focus on any particular object in the external environment. Although participants were instructed to focus on the cadence on the monitor throughout the FC trial, corticospinal excitability projecting to the biceps brachii was not increased when compared to the SSC trial. A possible explanation for the lack of increase in corticospinal excitability during the FC trial is that it is unknown if the participant maintained their focus on the cadence displayed on the monitor throughout the entire trial as eye tracking devices were not used. Also, much of the literature regarding increases in corticospinal excitability with focused attention has been on the observation of human movement and the activity in the putative mirror neuron system. Notably, corticospinal excitability is facilitated during action observation and more so during goal-directed actions (i.e. grasping an object) when attention is directed to task-relevant features of the observed action [28]. In this study, the participants were not observing an action but were rather observing numbers on a monitor that were relevant to their behavioural goal (maintaining a set cadence). Thus, the theory that corticospinal excitability is facilitated during action observation due to the increased activity in the mirror neuron system may not apply in the present study.

Methodological Considerations

Additional factors should be considered when interpreting the present results. This study assessed MEP amplitudes and therefore conclusions can only be made regarding the overall excitability of the corticospinal tract. In future research assessing spinal excitability, with TMES for example, to the target muscle to determine if changes in corticospinal excitability are occurring at the spinal and/or supraspinal level may be of interest [29]. For instance, it is possible that supraspinal excitability increased during the FC trial and the increase was masked by a reduction in spinal excitability, resulting in no change in the overall excitability of the corticospinal tract. In order to decipher between supraspinal and spinal excitability both TMES and TMS need to be utilized. The reason we chose the 6 o'clock position, however, was because in our prior work we have shown that corticospinal excitability is higher during arm cycling than a tonic contraction at that position while spinal excitability is not. Thus, it is unlikely that spinal excitability was different in the present study.

Additionally, some participants in this study had previous experience with arm cycling and therefore may have required less attentional focus to execute the task. However, we purposely included a familiarization session for all participants to minimize this threat to internal validity by allowing participants to practice arm cycling.

5. Conclusions

The novel finding in this study is that corticospinal excitability, as assessed by changes in MEP amplitude, projecting to the biceps brachii is not different between SSC and FC arm cycling. We can indirectly (because attention was not directly measured) conclude that corticospinal excitability during arm cycling is independent of attentional demands as corticospinal excitability is not different when focusing attention on maintaining a set cadence compared to cycling at a voluntarily chosen cadence.

ACKNOWLEDGEMENTS: This study was supported by CGS-M NSERC funding to E.J.L. as well as NSERC Discovery Grant to K.E.P. We would like to thank Dr. Thamir Alkanani for technical support and the participants for volunteering their time.

AUTHOR CONTRIBUTIONS: All authors participated in data collection, analysis and manuscript preparation. All authors have approved the submitted version of this manuscript.

CONFLICTS OF INTEREST: The authors declare no conflict of interest.

Funding: This research was funded by the Natural Sciences and Engineering Research Council of Canada, grant number (NSERC-#RGPIN-2015-05765).

References

1. Brown, T. G., The intrinsic factors in the act of progression in the mammal. *Proc. R. Soc. London Ser.* **1911,** *84*, 308-319.
2. Grillner, S., Control of locomotion in bipeds, tetrapods, and fish. 1981; Vol. 2, pp 1179-1236.
3. Zehr, E. P.; Carroll, T. J.; Chua, R.; Collins, D. F.; Frigon, A.; Haridas, C.; Hundza, S. R.; Thompson, A. K., Possible contributions of CPG activity to the control of rhythmic human arm movement. *Can J Physiol Pharmacol* **2004,** *82* (8-9), 556-68.
4. Zehr, E. P.; Barss, T. S.; Dragert, K.; Frigon, A.; Vasudevan, E. V.; Haridas, C.; Hundza, S.; Kaupp, C.; Klarner, T.; Klimstra, M.; Komiyama, T.; Loadman, P. M.; Mezzarane, R. A.; Nakajima, T.; Pearcey, G. E.; Sun, Y., Neuromechanical interactions between the limbs during human locomotion: an evolutionary perspective with translation to rehabilitation. *Exp Brain Res* **2016,** *234* (11), 3059-3081.
5. Power, K. E.; Lockyer, E. J.; Forman, D. A.; Button, D. C., Modulation of motoneurone excitability during rhythmic motor outputs. *Appl Physiol Nutr Metab* **2018**, 1-10.
6. Fitts, P. M. a. P., M.I., *Human Performance*. Belmont, Calif. : Brooks/Cole Pub. Co., [1967]: 1967.
7. Holland, L.; Murphy, B.; Passmore, S.; Yielder, P., Time course of corticospinal excitability changes following a novel motor training task. *Neurosci Lett* **2015,** *591*, 81-5.
8. Lockyer, E. J.; Benson, R. J.; Hynes, A. P.; Alcock, L. R.; Spence, A. J.; Button, D. C.; Power, K. E., Intensity matters: effects of cadence and power output on corticospinal excitability during arm cycling are phase- and muscle-dependent. *J Neurophysiol* **2018**.
9. Forman, D. A.; Monks, M.; Power, K. E., Corticospinal excitability, assessed through stimulus response curves, is phase-, task-, and muscle-dependent during arm cycling. *Neurosci Lett* **2018**.
10. Spence, A. J.; Alcock, L. R.; Lockyer, E. J.; Button, D. C.; Power, K. E., Phase- and Workload-Dependent Changes in Corticospinal Excitability to the Biceps and Triceps Brachii during Arm Cycling. *Brain Sci* **2016,** *6* (4).
11. Forman, D. A.; Richards, M.; Forman, G. N.; Holmes, M. W.; Power, K. E., Changes in Corticospinal and Spinal Excitability to the Biceps Brachii with a Neutral vs. Pronated Handgrip Position Differ between Arm Cycling and Tonic Elbow Flexion. *Front Hum Neurosci* **2016,** *10*, 543.
12. Forman, D. A.; Philpott, D. T.; Button, D. C.; Power, K. E., Differences in corticospinal excitability to the biceps brachii between arm cycling and tonic contraction are not evident at the immediate onset of movement. *Exp Brain Res* **2016,** *234* (8), 2339-49.

13. Forman, D. A.; Philpott, D. T.; Button, D. C.; Power, K. E., Cadence-dependent changes in corticospinal excitability of the biceps brachii during arm cycling. *J Neurophysiol* **2015,** *114* (4), 2285-94.
14. Copithorne, D. B.; Forman, D. A.; Power, K. E., Premovement Changes in Corticospinal Excitability of the Biceps Brachii are Not Different Between Arm Cycling and an Intensity-Matched Tonic Contraction. *Motor Control* **2015,** *19* (3), 223-41.
15. Forman, D.; Raj, A.; Button, D. C.; Power, K. E., Corticospinal excitability of the biceps brachii is higher during arm cycling than an intensity-matched tonic contraction. *J Neurophysiol* **2014,** *112* (5), 1142-51.
16. Kastner, S.; Pinsk, M. A.; De Weerd, P.; Desimone, R.; Ungerleider, L. G., Increased activity in human visual cortex during directed attention in the absence of visual stimulation. *Neuron* **1999,** *22* (4), 751-61.
17. Marais, G.; Dupont, L.; Vanvelcenaher, J.; Clarys, J. P.; Pelayo, P., Effects of spontaneously chosen crank rate variations on electromyographic responses in sub-maximal arm exercise in inexperienced subjects. *Eur J Appl Physiol* **2004,** *92* (4-5), 598-601.
18. Marsh, A. P.; Martin, P. E., The Relationship between Cadence and Lower-Extremity Emg in Cyclists and Noncyclists. *Med Sci Sport Exer* **1995,** *27* (2), 217-225.
19. Oldfield, R. C., The Assessment and Analysis of Handedness: The Edinburgh Inventory. *Neuropsychologia* **1971,** *9* (1), 97-113.
20. Bredin, S. S. D.; Gledhill, N.; Jamnik, V. K.; Warburton, D. E. R., PAR-Q plus and ePARmed-X plus New risk stratification and physical activity clearance strategy for physicians and patients alike. *Can Fam Physician* **2013,** *59* (3), 273-277.
21. Manning, C. D.; Bawa, P., Heteronymous reflex connections in human upper limb muscles in response to stretch of forearm muscles. *J Neurophysiol* **2011,** *106* (3), 1489-99.
22. Crone, C.; Johnsen, L. L.; Hultborn, H.; Orsnes, G. B., Amplitude of the maximum motor response (Mmax) in human muscles typically decreases during the course of an experiment. *Exp Brain Res* **1999,** *124* (2), 265-70.
23. Pearcey, G. E.; Power, K. E.; Button, D. C., Differences in supraspinal and spinal excitability during various force outputs of the biceps brachii in chronic- and non-resistance trained individuals. *PLoS One* **2014,** *9* (5), e98468.
24. Taylor, J. L.; Allen, G. M.; Butler, J. E.; Gandevia, S. C., Effect of contraction strength on responses in biceps brachii and adductor pollicis to transcranial magnetic stimulation. *Exp Brain Res* **1997,** *117* (3), 472-8.
25. Puglisi, G.; Leonetti, A.; Landau, A.; Fornia, L.; Cerri, G.; Borroni, P., The role of attention in human motor resonance. *Plos One* **2017,** *12* (5).
26. Leonetti, A.; Puglisi, G.; Siugzdaite, R.; Ferrari, C.; Cerri, G.; Borroni, P., What you see is what you get: motor resonance in peripheral vision. *Exp Brain Res* **2015,** *233* (10), 3013-3022.
27. Buschman, T. J.; Kastner, S., From Behavior to Neural Dynamics: An Integrated Theory of Attention. *Neuron* **2015,** *88* (1), 127-144.
28. Roosink, M.; Zijdewind, I., Corticospinal excitability during observation and imagery of simple and complex hand tasks: implications for motor rehabilitation. *Behav Brain Res* **2010,** *213* (1), 35-41.
29. Taylor, J. L., Stimulation at the cervicomedullary junction in human subjects. *J Electromyogr Kinesiol* **2006,** *16* (3), 215-23.