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Research article

Time course of corticospinal excitability changes following a novel motor training task

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HIGHLIGHTS

- Dominant hand motor performance improved continuously over two days following a novel motor tracing task.
- The slope of TMS input–output curves decreased following the novel tracing task.
- The main decrease in slope occurred on day one of training although slope continued to decrease.
- Dominant hand motor training lead to improvement in performance with a concomitant decrease in corticospinal excitability.
- This work is significant because it shows that corticospinal and motor performance changes do not always occur in parallel.

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ABSTRACT

Motor learning is known to take place over several days, and there are a number of studies investigating the time course of improvements in motor performance, yet only a limited number that have investigated the time course of neurophysiological changes that accompany motor learning. The aim of this study was to investigate the time course of changes to corticospinal excitability, following novel motor training in the dominant hand, during two sessions of motor training and testing. This study used the slope of transcranial magnetic stimulation (TMS) input–output (I/O) curves elicited at stimulator intensities between 90 and 150% of resting motor threshold for the first dorsal interosseous (FDI) muscle in order to measure corticospinal excitability. The I/O curves for 12 right-handed males (M age: 21.9 + –0.5 years, [Laterality Index] = 83.42 SD = 4.9) were elicited before and after the performance of novel motor tracing task performed with the right hand on two different testing days. Participants had significant improvements in motor performance during both the initial (mean error improvement = 31%, SD = 7%, $F(1, 11) = 22.439$ with $p = 0.001$) and follow up session (mean error improvement = 19%, SD = 6%, $F(1, 11) = 17.85$ with $p = 0.001$). The slope of the TMS I/O curve decreased significantly over the four training blocks, $F(1,11) = 8.149$, $p = 0.016$, however pre-planned contrasts within the repeated measures ANOVA indicated that the decrease was only significant relative to baseline following the first day of training $F(1,11) = 10.476$, $p = 0.008$. This study found that corticospinal excitability measured using I/O curves decreases in response to performance of a novel motor training task, and the majority of this excitability change occurs on the first training day.

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1. Introduction

The primary motor cortex (M1) is involved in dynamically modulating descending motor signals in order to fine tune motor output. The M1 is a dynamic structure with the ability to reorganize itself depending on use-dependent plasticity remodeling the cortical map [1]. These changes are augmented with the use of complex motor training tasks which can require the participant to use either repetitive ballistic [2,3] or less rapid and more accurate [4] finger movement tasks. Only one study, to our knowledge [4], has adopted a rapid and accurate finger movement motor training protocol similar to the one suggested in our present study. However, this study measured ballistic finger movements, rather than more refined movements and intracortical inhibition and facilitation was assessed over a single day of training. Motor training tasks can induce both fast [5] and slow [6,7] changes to neural connections within the M1 with rapid onset of motor training and prolonged

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repetition of a given movement, respectively. Fine motor skill of the right and left hands are controlled by the contralateral motor cortices.

Changes in corticospinal excitability as a result of these motor training tasks can be identified using stimulus response (input–output) curves with single pulse TMS. Stimulus response curves [8] may represent a more global measure of corticospinal excitability than other methods, such as comparing changes in motor evoked potential (MEP) amplitudes due to either inhibitory or facilitatory mechanisms [4,9,10], or other methodologies which rely on changes to MEPs at a single intensity [11]. The resulting linear portion of a stimulus response curve gives a direct indication of the level of global corticospinal excitability [12], with increases or decreases to the slope indicating increases or decrease to excitability, respectively.

Several studies in the past have employed motor training tasks in order to characterise changes to corticospinal excitability, however they often have gross movements involving multiple muscles and joints [13] or movements involving non-skilled ballistic finger movements [3,8]. We recently developed a novel tracing task that varied both amplitude and frequency of a sinusoid to create a single joint task that was sufficiently complex to allow gains in performance to occur even when motor training continued on separate days [16]. We found significant and similar improvements in motor performance across two days of training for both the right and left hands. However, this was accompanied by a significant decrease in excitability for the dominant hand only, with no change in the excitability of the non-dominant M1. However excitability was only measured at baseline of the first training session and at the end of the second training session. Therefore, in this current study, we sought to investigate the time course of the modulation in neural excitability over two sessions of motor training for the dominant hand. We hypothesized that motor corticospinal excitability would decrease progressively over the two days in tandem with continued improvements in motor performance. We used the slope of TMS input/output (IO) curves to measure excitability because the slope is a more robust measure of excitability which is not affected by slight changes in electrode or coil position as we were measuring excitability on different days.

2. Methods

2.1. Participants

Testing was completed on 12 right-handed males (M age: 21.9 + −0.5 years, [LI] = 83.42 SD = 4.9) who had no previous experience completing the custom motor training task. Participants were recruited from the student population at the University of Ontario Institute of Technology (UOIT), which was the site of data collection. The experiment was approved by the Research and Ethics Board at UOIT and followed the guidelines for human research as detailed by the Declaration of Helenski. As the purpose of this experiment was to establish the time course of excitability changes in response to a novel training task, we purposely selected a homogenous group of young male students who had similar technology exposure in their daily life such as through text messaging and typing. Females were excluded because hormonal fluctuations throughout the menstrual cycle are known to alter motor performance and co-ordination [17] and could have created a confounding effect on motor performance and corticospinal excitability measures. All 12 participants completed both days of the experiment and the same researcher collected the data. Excitability measures were recorded before and after motor training on both the initial and second day of testing, totalling four measures of excitability in total with two training sessions.

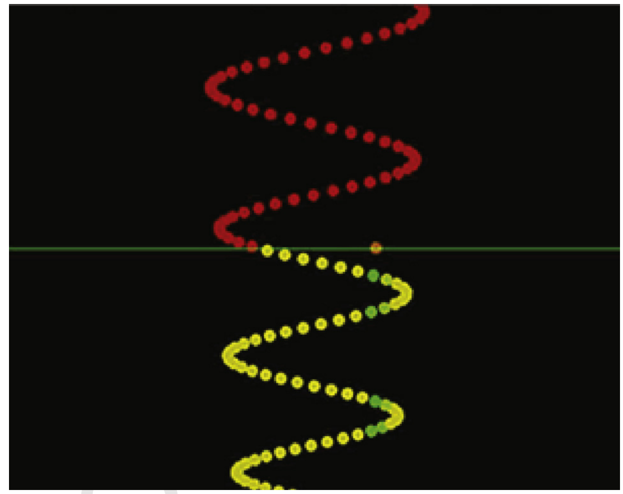

Fig. 1. An illustration of the motor training task completed by each participant on the initial and retention day of training is shown. The continuous sinusoidal wave would move vertically down the screen while the participant would copy the trace with the horizontal cursor, having limited motion to the horizontal axis. The dots composing the trace would change color when crossing the horizontal axis, green for correctly following the trace or yellow for missing the trace. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) Q5

2.2. Motor training methodology

The participant was seated in front of a desk, which held a monitor that presented the tracing task. The participant's arm was bound to the chair's arm-rest with Velcro straps to minimize upper limb movement during testing. Custom written software (written in C++) was used to both run the task and analyze task performance. Participants used an external wireless touchpad (Logitech, Inc., Fremont, CA) to follow the trace presented on a laptop screen. The participants were instructed to trace a vertical sinusoidal wave using only the index finger on a wireless tracking pad. The participant's virtual movement was limited to a horizontal line, with sinusoidal waves moving vertically down the monitor. As the waveforms would pass the horizontal axis, the participants would attempt to copy the trace using repetitive abduction and adduction of the index finger. Each vertical sinusoidal wave was composed of color-coded dots to indicate the accuracy of the trace (Fig. 1). The horizontal axis that the participant's cursor occupied had a single dot with the same radius as the dots composing the sinusoidal waves. Each trial required the participant to constantly adjust velocity and degree of abduction/adduction as the frequency and amplitude changed with each successive sinusoidal wave in a given task trial. There were 4 different levels of the task with varying levels of difficulty as the degree of frequency and amplitude was different for each version to ensure that the task was sufficiently complex to allow for continued improvement over the two training sessions. At each training session the participant completed three blocks of training, with each block including all four versions of the task. The order of the task versions in each block was pseudo-randomized prior to the start of the first experiment for each participant in order to control for any possible order effects of performing the different task versions. The participant completed the same order of task versions as they progressed through the training blocks.

Motor error was determined by the software as the average distance of the participant's attempted trace from the presented sinusoidal wave. The training software captured the distance that the participant's cursor dot was from the 'perfect' trace and recorded the average distance the cursor was from each dot as it

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