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Research Report

Corticospinal excitability is reduced in a simple reaction time task requiring complex timing

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ABSTRACT

Increasing the complexity of a movement has been shown to result in longer simple reaction time (RT), which has been attributed to sequencing or timing requirements following the go-signal. However, RT differences may also be due to differences in corticospinal excitability (CE) as previous studies have found an enhanced excitatory state of corticospinal neurons in complex tasks. Transcranial magnetic stimulation (TMS) was used in the present study to probe the excitability of the motor pathway during the simple RT interval for single (simple) versus multiple (complex) key press responses. Premotor RT data indicated that participants responded significantly ($p < .001$) faster in the simple task compared to the complex task, confirming response complexity was manipulated appropriately. Analysis of the CE data indicated that motor evoked potential (MEP) amplitudes increased with time following the go-signal in both conditions and that MEP amplitudes in the simple task were significantly larger than those in the complex task when evoked within 75 ms of movement onset ($p = .009$). These findings suggest that the rate of increase for initiation-related neural activation is reduced for complex as compared to simple movements, which may partially explain differences in RT.

1. Introduction

The effects of response complexity on the time taken to react to a stimulus has a long history of research, with the common finding that an increase in number of response elements leads to a longer reaction time (RT). Many explanations have been offered for this response complexity effect such as an increased amount of time required to program and retrieve the response from memory (Henry and Rogers, 1960), or an increase in the number of processes occurring *after* the presentation of the imperative go-signal, such as sequencing or timing (Klapp, 1995; Maslovat et al., 2014). More recent studies have suggested that complexity dependent RT differences may instead relate to levels of neural activation. Models of neural activation have suggested that motor preparation can be envisioned as increasing the activation state of neural networks to a level that is held below the threshold for initiation (Hanes and Schall, 1996; Wickens et al., 1994). Reaction time is thus indicative of the time required to increase neural activation from this preparatory state to a level beyond threshold. Thus differences in RT can be attributed to different rates of activation accumulation (Carpenter and Williams, 1995; Hanes and Schall, 1996), differences in threshold levels (Nazir and Jacobs, 1991), or a hybrid of the two (Pacut, 1977). In terms of RT differences due to movement complexity, response initiation may be delayed due to either reduced rate of increase in activation, or a greater amount of required activation. Furthermore, an increased activation requirement could be due to either a higher initiation threshold (Maslovat et al., 2011), or activation beginning from a lower state (or level) of preparatory activation at the time of the imperative signal (Carlsen et al., 2012; Maslovat et al., 2014).

Although response complexity effects have been considered within a neural activation context, few studies have directly assessed cortical activation associated with various movement complexities, and results have been mixed. For example, Kitamura et al. (1993) found no activation differences during simple and complex sequential finger movements using electroencephalography, while Shibasaki et al. (1993) showed differences in motor cortical cerebral blood blow between simple and complex sequential finger movements through the use of positron emission tomography. The effect of response complexity on

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corticospinal excitability (CE) has also been examined using transcranial magnetic stimulation (TMS) during static as well as continuous motor tasks, although not in the context of a RT paradigm. TMS applied over primary motor cortex can evoke a short latency excitatory response in a targeted muscle (motor evoked potential, MEP), and activates corticospinal neurons both directly and indirectly through cortico-cortical synapses (Taylor, 2006). Flament et al. (1993) compared CE levels between a simple static finger abduction and a variety of more complex static gripping tasks and showed that MEPs were larger in the complex tasks compared to those in the simple finger abduction task. Similarly, Abbruzzese et al. (1996) found increased MEP amplitudes for more complex movements during both the production of, or mental simulation of continuous repetitive and sequential finger movements (see also Roosink and Zijdewind (2010)).

The effects of response complexity on CE in a RT paradigm were recently examined by Greenhouse et al. (2015), who used TMS to assess transient motor inhibition during the response preparation phase of a movement in both a simple and choice RT paradigm. The authors varied the complexity of these movements by increasing either the number of muscles or number of elements involved in performing a movement. When the number of muscles involved increased, there was no corresponding increase in RT; however, CE was suppressed for the more complex response. Conversely when the number of movement elements was increased, both RT and CE increased for the more complex movement. While this provides evidence that motor system excitability during movement preparation is sensitive to response complexity, it is unclear why an increase in CE would be associated with longer RT for the sequenced movements. This result appears to be in contrast to the predictions of neural activation models, which predict longer RTs for complex movements related to *lower* levels of activation with respect to an initiation threshold.

The evidence above suggests that response complexity can affect neural activation levels; yet the relationship between CE and response latency as a function of complexity of the required movement is still unclear. Therefore, the purpose of the current study was to investigate how response complexity affects CE in a simple RT paradigm. Participants performed simple RT tasks requiring either a single key press or a three key press sequence with a non-isochronous timing structure, as this has shown to be a robust method to manipulate response complexity and thus increase simple RT (Maslovat et al., 2014). TMS was used to probe CE in 25 ms intervals between 0 and 125 ms following the go-signal (i.e., during the RT interval) in order to quantify changes in the time course of excitability during the response initiation phase, rather than assessing excitability during the preparation phase (e.g., Greenhouse et al., 2015). It was expected that the more complex movement would result in longer simple RTs, and that CE would increase prior to the onset of both simple and complex movements. However, of greater interest was a comparison between activation curves for the two movements between the go-signal and response onset. Based on neural activation models (Carlsen et al., 2012; Maslovat et al., 2014), it was hypothesized that if the MEP amplitude was lower at presentation of the imperative stimulus (IS) the longer RTs observed for more complex movements could be attributed to a lower overall preparatory level. In contrast, if preparatory MEPs were not different between tasks, longer RTs observed in a more complex task may be attributed to either differences in activation onset latencies or accumulation rates – evidenced by either a later increase from baseline MEP or activation increase occurring at slower rate following the IS.

2. Results

2.1. Voluntary response measures

In order to determine if the complexity manipulation led to differences in RT and/or EMG characteristics, response output measures for the simple and complex movements were compared at the baseline time point (i.e., TMS stimulation at the IS – see Section 4.7 for details). Analysis of mean premotor RT (Fig. 1A) confirmed that RT in the complex task was significantly longer ($T(15)=4.24$, $p<.001$, $r=.74$) than in the simple task, similar to what has been shown previously (Maslovat et al., 2014). Analysis of peak EMG between simple and complex conditions (Fig. 1B) revealed that peak EMG was significantly greater ($T(15)=3.25$, $p=.005$, $r=.64$) in the simple compared to the complex movement. Similarly, the simple movement had a significantly larger ($T(15)=3.06$, $p=.008$, $r=.62$) integrated EMG over the entire burst (iEMG) as compared to the more complex movement (Fig. 1C). Finally, analysis of integrated muscle activation in the rising phase (first 30 ms) of the EMG burst (Q30) also revealed that the early rate of increase in the simple movement was significantly greater ($T(15)=5.57$, $p<.001$, $r=.82$) than that of the complex movement (Fig. 1D).

2.2. MEP measures

Representative individual EMG traces from a single participant at each analyzed stimulation time point (0–75 ms, see Section 4.7), for both simple and complex movement tasks are shown in Fig. 2. Mean MEP amplitudes for the stimulation time points 0 to 75 ms following the IS are shown in Fig. 3. Although there was no significant main effect for task ($F(1,15)=0.890$, $p=.361$, $\eta_p^2=.056$), there was a significant main effect for time ($F(3,45)=20.346$, $p<.001$, $\eta_p^2=.576$) indicating that MEP amplitudes increased along with time following the go-signal. Post-hoc tests analyzing differences in MEP amplitude between baseline (0 ms) and subsequent time points (collapsed across movement type) indicated that there were no significant differences between the 0 ms and 25 ms time point ($p=.319$), but MEP amplitude increased significantly compared to all previous time points for the 50 ms and 75 ms TMS stimulation times (all t ratios >3.36, all corrected p values $<.026$).

There was no significant Task x Time interaction for MEP amplitude with respect to the IS, although the result approached conventional levels of significance ($F(3,45)=2.519$, $p=.070$, $\eta_p^2=.144$). Thus in order to directly test the hypothesis that CE would be lower for the complex task at the time of the go-signal, peak-to-peak MEP amplitudes measured at baseline (IS onset, 0 ms) were analyzed separately. No difference was observed ($T(15)=0.09$, $p=.927$, $r=.02$) in MEP amplitude between the simple ($M=0.389$ mV, SD = 0.27) and the complex (M=0.388 mV, SD = 0.27) movements (see Fig. 3, time 0).

Normalized MEP amplitudes in time bins prior to EMG onset are shown in Fig. 4. Analysis at each time bin confirmed a significant difference between the simple and the complex condition only at 75 ms prior to EMG onset ($U=8553$, $z=-2.62$, $p=.009$, $r=-.154$) with all other p values $>.35$.

3. Discussion

The purpose of this study was to examine the relationship between simple RT and the excitability of the motor pathways prior to initiation of movements, as a function of differing levels of complexity. Previous work has shown that RT for a complex task is typically longer than that for a simple task, a result that has been