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Corticospinal Facilitation of Erector Spinae and Rectus Abdominis Muscles During Graded Voluntary Contractions is Task Specific: A Pilot Study on Healthy Individuals

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ABSTRACT

Introduction: In this study we compared transcranial magnetic stimulation (TMS) elicited motor evoked potentials (MEPs) in a postural (bilateral low back extension: BLBE) and a respiratory (forced expiration during breath holding: FEBH) task.

Methods: Using TMS of the left motor cortex, simultaneous patterns of corticospinal facilitation of the contralateral erector spinae (ES) and rectus abdominis (RA) muscles during graded voluntary activation were compared in seven healthy subjects.

Result: The facilitation pattern demonstrated task dependency by showing that MEP amplitudes in the ES muscle tended to be smaller at any given contraction level in the FEBH task than in the BLBE task.

Discussion: The results suggested a linear-type relationship between the size of MEPs with increasing background contraction of ES and RA in the BLBE task. However, both muscles showed a plateau effect with higher background contractions (>50% of maximum) during the FEBH task. The varied response of ES and RA across these two tasks reinforces the importance of task specific training in clinical settings.

1. Introduction

Transcranial magnetic stimulation (TMS) is a non-invasive and pain free tool for the assessment of an individual muscle or a muscle group's pattern of corticomotor facilitation. (Lagan, Lang, & Strutton, 2008; Mortifee, Stewart, Schulzer, & Eisen, 1994). TMS studies suggest the existence of direct corticomotor input to the abdominal muscles (Plassman & Gandevia, 1989), and back muscles (Ferbert, Caramia, Priori, Bertolasi, & Rothwell, 1992). The role of these muscles in fine control trunk movements and their role in providing core stability of the spine make it of interest to examine their corticomotor excitability during graded voluntary tasks.

Corticomotor excitability of trunk muscles can be studied by examining the amplitude of motor-evoked-potentials (MEPs) by TMS during graded voluntary contractions of these muscles. An increase in corticomotor excitability produces synaptic facilitation which coincides with an increase in MEP amplitude (Mazzocchio, Rothwell, Day, & Thompson, 1994; Nielsen & Petersen, 1995). The observed facilitatory modification could reflect changes in synaptic excitability in the cortex, in the spinal cord or at both sites.

Literature indicates that the pattern of corticomotor facilitation varies for different muscles across a range of voluntary background contractions. For example, maximum facilitation of the first dorsal interosseus (FDI)

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muscle (Hess, Mills, & Murray, 1987) in the hand and tibialis anterior (Turton & Lemon, 1999) in the lower limb occurs at less than 20% of the maximum voluntary contraction (MVC). TMS studies on abdominal muscles to date have produced conflicting results. While some studies indicate a similarity between facilitation patterns of the abdominal oblique muscles and intrinsic hand muscles (Plassman & Gandevia, 1989), other studies suggest a more linear facilitation profile, reaching a peak between 30-40% MVC (Tunstill, Wynn-Davies, Nowicky, McGregor, & Davey, 2001). A similar facilitation pattern illustrating a gradual increase in facilitation profile has also been reported for the erector spinae (ES) muscle (Nowicky, McGregor, & Davey, 2001).

A number of studies have indicated that the facilitation patterns of muscles may also vary according to the voluntary task (Gandevia, McKenzie, & Plassman, 1990; Hauptmann, Skrotzki, & Hummelsheim, 1997). According to Datta and colleagues, simple abduction of the index finger resulted in larger MEPs of the FDI than a power grip (Datta, Harrison, & Stephens, 1989). Additionally, Flament and colleagues found larger MEPs of the FDI during complex tasks compared to simple index finger abduction (Flament, Goldsmith, Buckley, & Lemon, 1993). In both studies, the voluntary activation of the FDI was kept constant by monitoring the surface electromyogram (sEMG). In a more recent study, Hasegawa and colleagues described a lower TMS threshold and larger MEP amplitudes in the FDI during the precision grip compared with the power grip (Hasegawa, Kasai, Tsuji, & Yahagi, 2001). This suggests that the type and nature of a voluntary task can have a considerable impact on facilitation patterns of involved muscles. Clinical literature has developed a large body of evidence supporting the presence of task specificity in trunk activation and core stability within functional tasks (Hall, Tsao, MacDonald, Coppieters, & Hodges, 2009; McCook, Vicenzino, & Hodges, 2009). However, the extent to which corticomotor patterns of activation reflect this functional bias is not known.

Research using TMS has demonstrated evidence of independent task specific activation of trunk musculature (Hodges, Butler, Taylor, & Gandevia, 2003; Kuppuswamy et al., 2008). However, there is no supporting evidence illustrating simultaneous (co-contraction/co-activation) patterns driven centrally for antagonistic muscle groups of the trunk for specific functions.

This study was designed to explore the relationship between the facilitation patterns and level of background voluntary contraction in two different tasks. Specifically, it was aimed to compare the pattern of corticomotor facilitation of the contralateral erector spinae and rectus abdominis (RA) muscles during graded voluntary activation in a postural (bilateral low back extension - BLBE) and a respiratory task (forced expiration during breath holding - FEBH).

Hypotheses

Within the BLBE experimental task, there will be a linear relationship between the facilitation pattern of a single muscle (ES and RA) and the intensity of the background voluntary contraction.

Within the FEBH experimental task, there will be a non-linear relationship between the facilitation pattern of a single muscle (ES and RA) and the intensity of the background voluntary contraction.

2. Methods

2.1. Subjects

Ethical approval for this study was obtained from the Monash University Human Research Ethics Committee. All subjects gave their written informed consent, in accordance with the Declaration of Helsinki. Seven healthy subjects (3 male, 4 female), all right-handed, aged 31-48 years (38.28 ± 7.3), with no history of neurological disease or back pain, were recruited for the study.

2.2. Electromyographic Recordings

Prior to the application of electrodes, the skin was prepared using a standard procedure. Surface electromyography (sEMG) was recorded using 2cm round self-adhesive pre-gelled surface electrodes (Skintact®, Innsbruck, Austria) positioned on the right RA muscle at the mid trunk level immediately superior to the umbilicus and approximately 3 cm from the midline, and right erector spinae muscle 5cm lateral to the midline at the level of L2-L3. sEMGs were filtered (below 10 Hz and above 500 Hz) and amplified (x 1000) before being sampled (1 kHz) by a computer for storage and analysis (Powerlab, AD instruments Pty Ltd, Australia). The possibility that the electrodes picked up sEMG from other muscles cannot be excluded but is thought to be minimal.

2.3. Transcranial Magnetic Stimulation (TMS)

TMS was delivered with MagStim 200 stimulator (Magstim Company, Ltd, UK) through a 20cm figure-of-eight hand-held flat coil. The optimal stimulation position ('hot spot') was searched over the left cortex (1.5 cm anterior and 3 cm lateral to vertex) at which the MEPs could be simultaneously recorded from both ES and RA muscles.

Figure 2A illustrates the individual (small circles) and the average (square symbol +/- SD) optimal stimulation locations (hot spots) over the left motor cortex (referenced to vertex).

As in previous TMS studies reporting difficulties in eliciting resting MEPs in trunk muscles (Ferbert, et al., 1992; Nowicky, et al., 2001; Taniguchi & Tani, 1999), intentional voluntary contraction of trunk muscles was used to facilitate the elicitation of MEPs by TMS (Strutton, Theodorou, Catley, McGregor, & Davey, 2005).

Threshold to TMS was determined for each task with the subject in a seated position maintaining a weak contraction (15% MVC) of the specified muscle, i.e. ES for the BLBE task and RA for the FEBH task. Threshold was assessed as the lowest intensity of TMS that produced 3 out of 5 successive MEPs of both muscles (ES and RA) exceeding 50 µV peak-to-peak amplitude (Rossini et al., 1994). Subsequent experimental trials were conducted using a stimulus intensity of 1.2 times this threshold value.

2.4. Experimental Protocol

Pilot work determined the best position to produce reliable, sustained, and graded levels of two different tasks: BLBE and FEBH. The most comfortable position for activation was supported sitting in a semi-reclined podiatry chair (Figure 1). In both tasks subjects were instructed to vary their effort between randomly nominated intensities of 0% MVC, 25% MVC, 50% MVC, 75% MVC and a maximum (100%) contraction. Maximum contraction was defined as the maximum voluntary contraction output achievable in that session. Subjects used feedback of the EMG signal from the primary muscle relative to the task (ES for the BLBE task and RA for the FEBH task) to modulate their effort through the specified contraction forces. Subjects underwent a brief training session, and then practiced both tasks before each experimental trial. The task order was varied randomly between subjects.

During the BLBE or FEBH task, subjects were able to view the integrated EMG response for performance feedback on the ES or RA muscles via a computer screen directly in front of them (Figure 1), whilst MEPs were simultaneously recorded from both ES and RA muscles. Target levels were indicated on the integrated EMG screen to demonstrate the required contraction intensity for the primary muscle for each specific task. A second investigator was present throughout to encourage the subject to produce optimal levels of stable contraction. In the FEBH task subjects were instructed to breathe out forcefully against their closed glottis in an expiratory Valsalva manoeuvre for about 3 seconds. In the BLBE task subjects were instructed to arch the low back by contracting the ES muscle. They were instructed not to hold their breath during the BLBE task. Five contraction levels (0, 25, 50, 75 and 100% MVC in a random order) were conducted in each of the two tasks. Eight magnetic stimuli were delivered per contraction level with a random interval averaging approximately one stimulus every 4 seconds, totalling in 5 x 8 stimuli per task. An auditory signal cued the subject into a 2.6 second lead time to perform the desired output for the appropriate muscle activation prior to magnetic stimulation. Subjects were given a short rest period in between stimuli and between contraction levels.

Figure 1. Experimental setup illustrating subject positioned in semi-reclined chair viewing EMG feedback on computer monitor and task specific cues whilst undergoing TMS on the left motor cortex.

2.5. sEMG Analysis and Statistics

sEMG signals were analysed using LabChart 7 data acquisition software (Adinstruments Pty Ltd, Australia). Eight raw MEP responses together with corresponding full-wave rectified records at each contraction level were averaged. The mean voltage levels of the averaged rectified MEP were measured at each level of contraction. The latency of the MEP was determined as the interval between the stimulus and the first positive inflection, above background sEMG levels, of the rectified MEP.

Facilitation patterns were produced by plotting the mean voltage level of the rectified MEP against the mean voltage level of the pre-stimulus sEMG. Statistical comparisons were made using a three-factor repeated measure ANOVA (2 muscles × 2 tasks × 5 background contractions), alpha level was set at 0.05.

3. Results

3.1. Active olds and Latency of Responses

In all seven subjects it was possible to evoke simultaneous responses in both ES and RA muscles while maintaining a weak contraction (15% MVC). Mean (±SE) threshold stimulation used to produce MEPs, while maintaining a weak contraction (15% MVC) of the specified muscles was 71.0±4.7. This ranged from 55 to 81% of the maximum stimulator output (MSO). The mean (±SE) magnetic stimulation intensities used to produce MEPs during experimental tasks was 85±5.7 % MSO.

Compared to reported latencies at rest, voluntary contraction of the ES and RA muscles resulted in a reduction in MEP latencies as follows (Figure 2B): Right ES: 15.4±0.75 ms (BLBE task) and 16.49±0.95 ms (FEBH task), Right RA: 18.17±1.3 ms (BLBE task) and 18.64±0.95 ms (FEBH task).

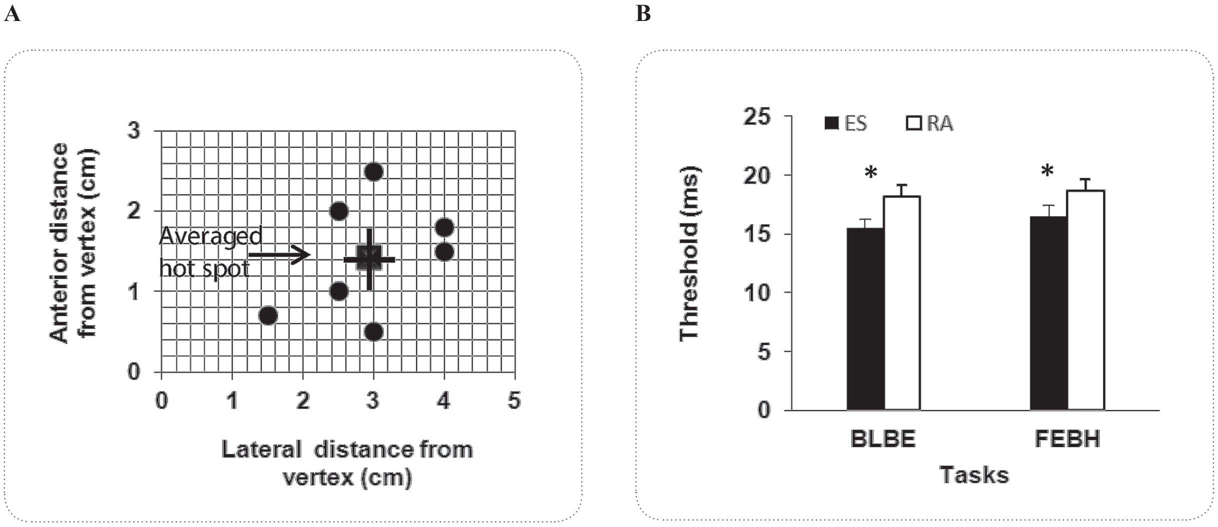

Figure 2. (A) Location of optimal stimulation for the elicitation of maximum MEPs from both ES and RA muscles in sitting position. The small circles represent individual stimulation locations (n = 7) and the square (+/- 1 SD) represents an average stimulation location. (B) Group mean latencies of MEP responses for BLBE and FEBH tasks in the right ES and RA muscles. Error bars indicate 1 S.E.M. * indicates P<0.05.

3.2. Facilitation of MEPs

Figure 3 illustrates single subject averaged MEP responses from ES and RA muscles during both BLBE and FEBH tasks at different background contraction levels. Voluntary contraction of the trunk muscles in the two tasks produced an increase in MEP amplitude with increasing voluntary contraction. In this representative example, the MEPs appear to increase more linearly with contraction force during the BLBE task than the FEBH task.

3.3. Task Dependent Differences in Voluntary Activation

The normalized facilitation patterns were determined for each subject individually as a percentage of the maximum MEP amplitude achieved over both tasks. During the BLBE task, there was a linear relationship between voluntary contraction of the ES and RA muscles and size of MEPs (Figure 4A and 4B, middle panels). Any increase in background voluntary contractions coincided with an increase in MEP amplitude. For the FEBH task this increase plateaued during the last three levels of voluntary contractions (50, 75 and 100% of MVC)

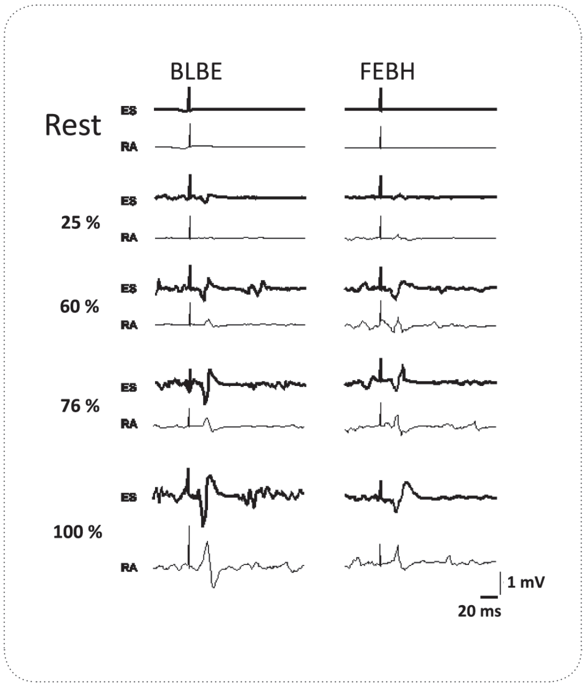

Figure 3. Single unrectified MEP responses to TMS of the left motor cortex at increasing levels of voluntary contraction in the right erector spinae (ES) and rectus abdominis (RA) muscles in a representative subject. Left column illustrates MEP responses during the BLBE task; right column illustrates MEP responses during the FEBH task. Increasing levels of EMG and MEP amplitude can be seen over the four levels of voluntary contraction during the BLBE task. For the FEBH task this increase plateaued during the highest two levels of voluntary contractions.

(Figure 4A and 4B, middle panels). When normalized to the maximum level of contraction achieved over both tasks, the MEP amplitudes in the facilitation pattern for the right ES during BLBE were consistently higher in the BLBE than in the FEBH task. This difference was only significant ($p<0.05$) in higher levels of background contractions (75 and 100% of MVC) (Figure 4A upper panel). RA muscle follows a similar trend at 100% of MVC ($p<0.05$) but this facilitation pattern has an opposite trend during lower levels of background contraction. Accordingly, the MEP amplitudes in the facilitation pattern for the right RA during FEBH were significantly higher ($p<0.05$) at 25 and 50% MVC than during the BLBE task (Figure 4B upper panel).

Since the maximum levels of voluntary EMG produced in the two tasks were different, comparison of normalized facilitation patterns between the two tasks may be misleading. The facilitation patterns were examined based on the absolute values of the responses (Figure 4A and 4B, lower panels). Similar to the normalized results for the BLBE task, a linear relationship between the absolute MEP amplitude and the absolute background EMG activity was observed (Figure 4A and 4B lower panels). A plateau effect in absolute MEP amplitude was also observed with increasing absolute background EMG activity in the FEBH task (Figure 4A and 4B lower panels). These results mimic the facilitation patterns observed in the normalized data.

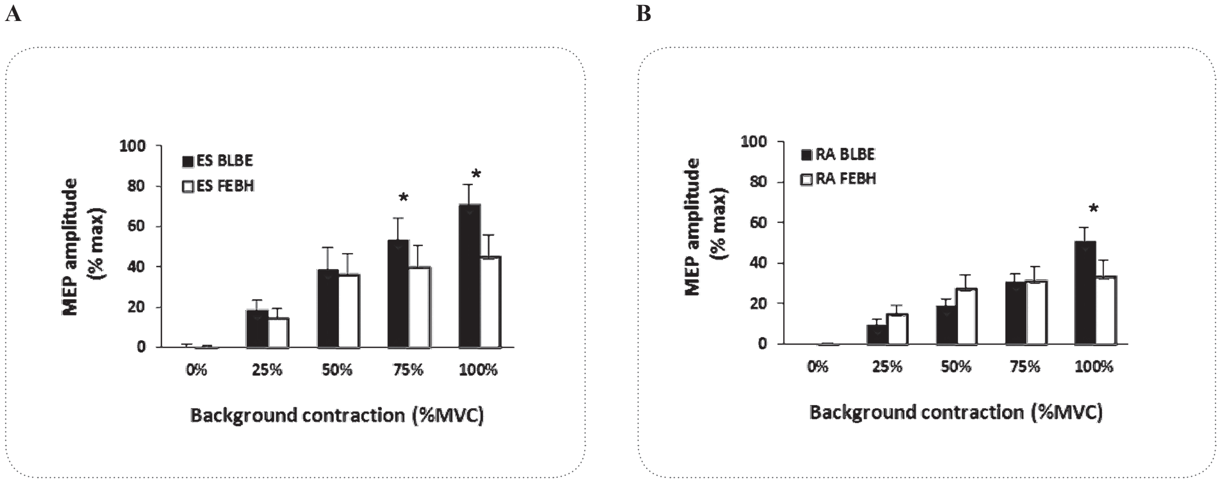

Figure 4. Normalized group mean patterns of facilitation of MEPs at different levels of voluntary activation in the right ES muscle (4A, upper panel), and in the right RA muscle (4B, upper panel); Same data presented in a way to better visualise task differences in the right ES muscle (4A, middle panel) and in the right RA muscle (4B, middle panel); Note that the facilitation pattern during the FEBH task tends towards a plateau at around 50% MVC levels. Absolute group mean pattern of facilitation of MEPs with increasing voluntary effort in the right ES (4A, lower panel) and in the right RA muscle (4B, lower panel). Distance (double arrow) indicates relative EMG amplitudes at the MVC for the two muscles across the BLBE and FEBH tasks. Error bars indicate 1 S.E.M. * indicates $P<0.05$.

As expected, for the BLBE task where the ES is the prime mover, higher levels of ES contraction were produced compared to the FEBH task. The voluntary EMG amplitude of ES at MVC was significantly larger for the BLBE task (1.4± 0.06 mV) than for the FEBH task (1.1±0.01 mV) (Figure 4A, lower panel, double arrow).

Similarly, in the FEBH task, where the RA plays a major role, higher levels of contraction of RA were produced compared to during the BLBE task. The voluntary EMG amplitude of RA at MVC was significantly larger for the FEBH task (0.86± 0.02mV) compared to the BLBE task (0.44±0.01 mV) (Figure 4B, lower panel, double arrow).

4. Discussion

This study has shown that TMS of the motor cortex can be used to assess simultaneous voluntary activation of the superficial trunk flexor and extensor muscles over a wide range of contraction strengths. The tasks performed in this study are representative of the daily usage of ES and RA muscles.

The results of this study support previous evidence (Ferbert, et al., 1992; Plassman & Gandevia, 1989) demonstrating that corticomotor input to the trunk muscles can be activated by TMS over the motor cortex. Each stimulus produces a descending volley in the corticomotor tract, which can excite different spinal motor neuron pools to produce MEPs in the sEMG recordings from skeletal muscles. The overall excitability of the corticomotor pathway between the stimulus and the target muscle is directly related to the amplitude of the resulting MEPs. Changing inputs to the system (e.g., voluntary contraction of the target muscles) will result in synaptic facilitation, increasing the overall excitability and the amplitude of the resulting MEP (Mazzocchio, et al., 1994; Nielsen & Petersen, 1995).

4.1. Threshold and Latency

It has been suggested that it is more difficult to elicit MEPs in paraspinal and abdominal muscles than in limb muscles (Nowicky, et al., 2001; Taniguchi & Tani, 1999). During a relaxed state, MEPs could not be elicited in all subjects. However, it was possible in all seven subjects to evoke simultaneous responses in both ES and RA muscles while subjects maintained a weak contraction (15% MVC). This finding supports the conclusion of Strutton and colleagues, which indicated that intentional voluntary contraction of paraspinal muscles enabled MEPs to be elicited routinely by TMS (Strutton, et al., 2005). In this study simultaneous MEPs were evoked in both ES and RA muscles using a 20 cm flat figure-of-eight coil placed over the left cortex, an average of 1.5 cm anterior and 3 cm lateral to vertex (Figure 2A), so that the induced current flowed medially and mainly in the left cortex.

In agreement with published literature, latency times during background voluntary activity of both ES and RA in either task were shorter than the latencies of these muscles at rest (Hess, et al., 1987). The latency of MEP to TMS over the motor cortex in active ES and RA suggests that the MEP in these trunk muscles is mediated by a fast conducting corticomotor pathway. This latency is longer in active RA than ES which simply suggests a longer pathway for descending signals. This is consistent with current knowledge of neuroanatomical descending pathways (Ferbert, et al., 1992; Nowicky, et al., 2001).

4.2. Patterns of Facilitation and Task Specificity

It was hypothesized that within the BLBE experimental task, there would be a linear relationship between the facilitation pattern of a single muscle (ES and RA) and the intensity of the background voluntary contraction. This study shows a graded linear pattern of MEP facilitation with increasing voluntary effort in the BLBE task for both ES and RA muscles. This finding supports previous research which proposed linear relationship between levels of background contractions and levels of corticomotor facilitation within a specific task (Nowicky, et al., 2001; Tunstill, et al., 2001).

It was hypothesized that within the FEBH experimental task, there would be a non linear relationship between the facilitation pattern of a single muscle (ES and RA) and the intensity of the background voluntary contraction. During the FEBH task, this study showed a non-linear facilitation pattern with a plateau at higher levels of background voluntary contraction for both ES and RA muscles. This finding suggests task specificity and is in agreement with other research which proposed task dependency of facilitation patterns in trunk muscles (Nowicky, et al., 2001; Tunstill, et al., 2001) and limb muscles (Lemon, Johansson, & Westling, 1995).

A number of studies have previously examined variation in facilitation patterns between proximal and distal limb muscles within a given task (see (Schieppati, Trompetto, & Abbruzzese, 1996; Taylor, Allen, Butlere, & Gandevia, 1997). Turton and Lemon (1999) reported that in the distal first dorsal interosseous (FDI) muscle, the facilitation pattern was greatest at lower levels of voluntary contraction (10% MVC), while the more proximal muscles (biceps and deltoid) had more linear patterns for a specified task. They suggested a distal to proximal gradient of corticomotor innervations. Given that this study only examined responses from axial muscles (ES and RA); we were unable to identify change in facilitation patterns relative to a specific muscle location.

4.3. Limitations of Study

The most significant limitations of this study were its cross-sectional design, imposing restrictions on the interpretation of observed associations. Any cause and effect could not be established. This is a pilot study on seven healthy individuals hence findings cannot be extrapolated to larger populations of healthy individuals or people with neurological or musculoskeletal conditions.

4.4. Clinical Applications

To our knowledge, this study is the first to use TMS of the motor cortex to simultaneously assess voluntary contraction of trunk flexor and extensor muscles.

The motor cortex provides a critical contribution to postural control (Deliagina, Beloozerova, Zelenin, & Orlovsky, 2008). It has been shown that inhibition of the motor cortex can reduce postural activity of the trunk muscles associated with voluntary limb movements (Hodges, et al., 2003). As cortical regions contribute to postural control, it could be speculated that deficits in postural activation, such as observed in people with low back pain, may be associated with changes in the excitability and organisation of the motor cortex. These parameters have previously been reported as altered in patients with low back pain (Strutton, et al., 2005).

The results of this study demonstrate the co-activation and close synchrony of ES and RA during both postural and respiratory tasks, with increased activity in both muscle groups arising from voluntary contraction of just one muscle group. Clinically this suggests that a targeted training program addressing one muscle group (e.g. RA) may have a facilitatory effect on motor function in the opposing muscle group (e.g. erector spinae). The plateau effect in MEPs (cortical facilitation) observed at higher levels of voluntary contraction in the FEBH task suggests that maximum voluntary effort may be unnecessary to achieve maximum cortical facilitation in this task. However, for the postural task examined in this study (BLBE), no plateau effect was observed. The varied response of both ES and RA across the two tasks examined in this study reinforces the importance of including training across a range of tasks within a rehabilitation program, and identifying relevant task specificity for function.

5. Conclusion

This study has shown that the synchronous recording of MEPs in trunk muscles of healthy individuals provides valuable information on changes occurring at the level of the central nervous system, such as threshold to TMS, facilitation patterns and task specificity of a muscle's activity. Investigations such as this offer further insight into the neurophysiology underlying trunk motor control and could be used to explore efficacy of rehabilitation strategies addressing postural control dysfunction.

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