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Journal of Science and Medicine in Sport 15 (2012) 164–168

Journal of Science and Medicine in Sport

www.elsevier.com/locate/jsams

Original research

Neural conduction and excitability following a simple warm up

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Received 13 May 2011; received in revised form 18 August 2011; accepted 17 September 2011

Abstract

Objective: This study examined the effect of a generic, active warm up on neural and muscular conduction time.
Design: Single group, pre-post design.
Methods: Central and peripheral neuromuscular conduction time was quantified in the abductor pollicis brevis (APB) and gastrocnemius muscles of 18 healthy participants (mean age 25.9 ± 5.8 years, 12 males) using transcranial magnetic stimulation (TMS) and M-wave techniques, prior to and immediately following an active warm up consisting of 5 min running at 65% of maximum heart rate. Neural conduction time, for both TMS and M-wave, was quantified as the time between stimulus artefact and deflection of the wave form, whilst muscle conduction time for TMS and M-wave, was quantified from the stimulus artefact to the absolute peak twitch response.
Results: Following the warm up protocol, a significant reduction in muscle conduction time was found in both TMS and M-wave of 0.43 ms ($P = 0.02$) and 0.30 ms ($P = 0.001$) for the APB; and 0.29 ms ($P < 0.001$) and 0.87 ms ($P = 0.003$) for the gastrocnemius, respectively. No change was found in neural conduction using either TMS or M-wave techniques.
Conclusions: These findings support previous data which demonstrate an improvement in muscular conduction time and subsequent improvement in athletic performance post warm up. The data also make evident that changes in muscular conduction time are a global response to warm up and are not directly related to muscular activity. In contrast, neural conduction time did not change and should not be confused with changes in muscular conduction time in the literature.

Keywords: Warm up; Transcranial magnetic stimulation; M wave; Neural conduction

1. Introduction

Defined as a brief period of general preparatory activity incorporating low-intensity aerobic exercise,[1] prior to competition or training, the ‘warm up’ is a commonly observed practice in sport and physical activity. In a recent systematic review,[2] 79% of the studies examined demonstrated an improvement in performance was achieved after the completion of warm-up activities lasting between 3 and 10 min. Further, these authors concluded there is little evidence to suggest that warming-up is detrimental to sports performance.

There are a number of mechanisms through which warm up is thought to modulate subsequent performance.[3,4] These include temperature related effects, such as decreased resistance of muscles and joints, release of oxygen into the working muscles, and improvement in chemical reactions in the muscle; as well as non-temperature related effects, such as increased blood flow to the muscles, improvement in oxygen consumption and increased preparedness for activity.

Another area also frequently discussed as being positively affected by the warm up is an improvement in nerve conduction time (see reviews by Bishop[3,4] and Knudson[5]). However, the most cited primary reference to support this assertion,[6] which continues to be perpetuated in the sports science literature, is not based on evidence but rather a series of lectures presented by Archibald Hill.[7] In contrast, there is good evidence describing an improvement in muscle fibre conduction time (via a reduced time to peak twitch) following active exercise.[8,9] The type of activity does not appear to affect muscle fibre conduction time with Girard et al.[10] showing a reduction in time to peak twitch in vastus medialis and lateralis muscles following either running or back squat strength

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doi:10.1016/j.jsams.2011.09.001

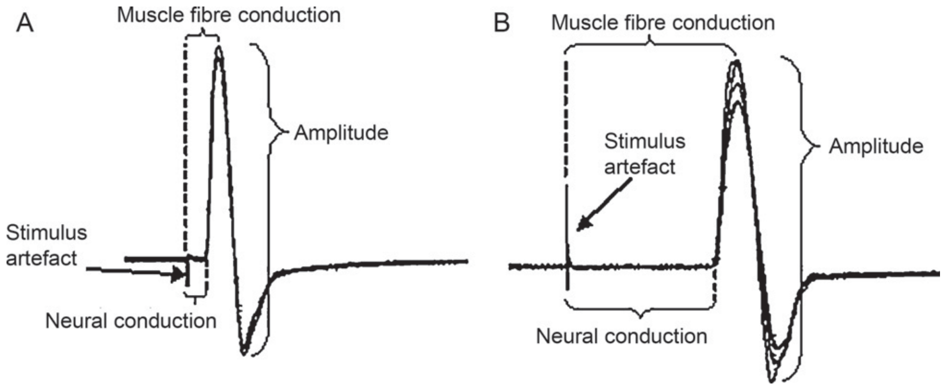

Fig. 1. Examples of overlaid M-waves (A) and motor evoked potentials (B) as recorded by EMG placed over the target muscle. Neural conduction for both waveforms is measured from the stimulus artefact to the initial onset of the waveform. Muscle fibre conduction is measured from the stimulus artefact to absolute peak twitch. Image taken from author's own collection.

exercise. The improvement in muscle conduction time may be due to a combination of factors influencing the propagation of the action potential across the sarcolemma, including muscle fibre swelling, temperature increases, and altered membrane properties.[11] However, studies in muscle fibre contraction time should not be confused with nerve conduction time. Also described as central motor conduction or latency,[12] this measure, taken from the stimulus artefact to the onset of an evoked potential,[13] reflects the speed of neural transmission prior to muscular contraction and can be measured at the peripheral (via M-wave technique), spinal (H-reflex) and supraspinal (central) levels.[12,14]

Studies investigating supraspinal latency can be undertaken using the technique of transcranial magnetic stimulation (TMS). TMS is a non-invasive method to quantify the excitability of the human corticospinal system.[12] Since 1985 this technique has been widely used to study aspects of human brain and nervous system (corticospinal) physiology.[15] Among a number of parameters TMS can quantify the speed of conduction from the primary motor cortex (M1) to the target muscle by measuring the latency of the time between stimulation to onset of the evoked response (see Fig. 1 for an example). Testing of motor conduction, using TMS, is used regularly in people with neurodegenerative or neurological conditions.[12] Conversely, in healthy humans, TMS latency is a reliable measure and, as a result, is now rarely reported. Simply measured from the time of stimulation to the onset of the evoked potential, TMS latency includes both central (time from M1 to activation of spinal motor neurons) and peripheral components (time from activation of the spinal motor neurons to the muscle).[13] It is also well known that voluntary muscular activation can reduce the central motor conduction time by an average of 2–3 ms,[16] due to facilitation of spinal motor neurons. However, to date, latency has not been used to quantify central motor conduction time following warm-up activities.

The aim of this study was to re-examine the discussion regarding neural conduction time and warm up. Using TMS, as well as incorporating peripheral neural stimulation (M-wave) to measure central and peripheral conduction time, we hypothesized that central and peripheral measures of neural conduction would improve (reduce in time) following an active warm up.

2. Methods

Participants for this study were 18 healthy males and females (25.9 ± 5.8 years, 12 males), free of musculo-skeletal injury, and/or neurological condition. All methods, conformed to the Declaration of Helsinki and were approved by the Victoria University Human Research Ethics committee. The a priori predicted sample size was calculated by using muscle fibre conduction time data from previous research[11] which corresponded to a standardized effect size of 0.6. Based on this effect size, an alpha set at 0.05 for a directional hypothesis and a desired power of 0.80, 24 participants were calculated to be required for the study.

Participants completed two studies to investigate changes in neural and muscle conduction time in muscles either passively (abductor pollicis brevis [APB]) or actively (gastrocnemius) involved in a generic warm up. Both studies used a single group, pre-post design to quantify the neural measures prior to and immediately following warm up. Participants were familiarised with all testing protocols prior to the data collection sessions. Once the participant was familiarised with all study procedures, pre-measures of central (time of stimulation artefact to onset of twitch,[12] Fig. 1) and peripheral (time of stimulation artefact to absolute peak twitch,[8,9] Fig. 1) nerve latency were taken (10 sweeps of 100 ms durations for each technique) for the APB and gastrocnemius muscles. Nervous system conduction time was measured centrally, using TMS (Magstim 200,[2] UK), and peripherally, using M-wave techniques (Nihon Koden, Japan). TMS is a non-invasive and safe[17] technique used to assess the physiology of the central nervous system.[12] If the stimulus depolarises neural tissue it elicits a response, known as the motor evoked potential (MEP), which can be recorded

Table 1
Mean (±SD) for peripheral and central motor latency before and after the general warm up.

	Pre	Post
Heart rate (bpm)	67.11 ± 13.28	124.78 ± 8.26*
Abductor pollicis brevis muscle ($n = 18$)		
M-wave stimulation artefact to onset (ms)	3.54 ± 0.55	3.48 ± 0.54
M-wave stimulation artefact to absolute peak twitch (ms)	5.74 ± 0.68	5.44 ± 0.75*
Motor evoked potential stimulation artefact to onset (ms)	23.11 ± 1.68	23.70 ± 1.71
Motor evoked potential stimulation artefact to absolute peak twitch (ms)	27.06 ± 1.8	26.54 ± 1.92*
Gastrocnemius muscle ($n = 18$)		
M-wave stimulation artefact to onset (ms)	4.37 ± 0.24	4.34 ± 0.25
M-wave stimulation artefact to absolute peak twitch (ms)	10.39 ± 0.67	9.52 ± 0.82*
Motor evoked potential stimulation artefact to onset (ms)	28.30 ± 1.85	28.22 ± 1.67
Motor evoked potential stimulation artefact to absolute peak twitch (ms)	32.19 ± 1.42	31.90 ± 1.04*

* Significant difference to pre-intervention value ($P < 0.05$).

by surface electromyography (EMG) in targeted muscles. A reliable measure in healthy participants, latency provides a determination of the neural conduction time from the brain (motor cortex) to the muscle. At rest, latency does not change, however, it is not known if latency alters as a result of exercise in the peripheral musculature. Peripheral nerve conduction time, used generally to investigate neural and electrophysiological properties of muscle contraction,[8,9] as well as being used to normalise the MEP between individuals,[12,13] was tested using electrically evoked muscle contraction.[18] Applying a percutaneous stimulation to either the superficial median or tibial nerves resulted in a twitch response (M-wave) in the APB and gastrocnemius muscles, respectively. Measured wave latency was determined in the same manner as for MEP (see Fig. 1).

The intervention itself consisted of a general warm up in which participants ran for 5 min at moderate intensity[2] (65% of their predicted maximum heart rate [MHR], calculated using the formula [220 − age] × 0.65).[19] Central and peripheral nerve conduction times were reassessed within 30 s of warm up completion.

Data were first screened to ensure they were normally distributed. No variable's z-score of skew or kurtosis was observed to be excessive. Further, Shapiro–Wilk tests showed all data were normally distributed. Pre/post data were compared using paired t-Test, and effect size analyses were used to compare the magnitude of difference (trivial ≤ 0.20; small 0.21–0.59; moderate 0.60–1.19; and large ≤ 1.20).[20] Alpha was set at $P < 0.05$, and all results are displayed as means (±SD).

3. Results

Of the 24 participants who completed the APB component of the study, 18 participants returned and completed the gastrocnemius data collection. Data from those participants who completed both testing sessions have been included in the analyses. Table 1 reports pre and post warm up data for both APB and gastrocnemius muscles. The warm up intervention significantly increased heart rate ($P < 0.001$; ES = 4.2; power = 1.0). No changes were observed in MEP or M-wave latency for the APB (MEP: $P = 0.68$, ES = 0.07, power = 0.10; M-wave: $P = 0.63$, ES = 0.11, power = 0.13) or the gastrocnemius (MEP: $P = 0.63$, ES = 0.11, power = 0.07; M-wave: $P = 0.08$, ES = 0.40, power = 0.37). However, time to peak twitch for both MEP and M-wave in the APB showed a significant mean reduction of 0.52 ms ($P = 0.02$; ES = 0.61; power = 0.87) and 0.30 ms ($P = 0.002$; ES = 0.82; power = 0.89), respectively. Similar findings for MEP and M-wave were also observed in the gastrocnemius (MEP: 0.29 ms, $P = 0.003$, ES = 0.70, power = 0.80; M-wave: 0.87 ms, $P < 0.001$, ES = 0.92, power = 0.95).

4. Discussion

The aim of this study was to quantify neural and muscle fibre conduction time following a generic warm up. We observed an improvement in muscle fibre conduction, in muscles both actively and passively involved in a generic warm up, via a reduced time to peak twitch force in the M-wave and MEP. However, we found no change in the latency from stimulation to onset of the M-wave and MEP, indicating neural conduction time was unaffected by warm up. To our knowledge this is the first study separating neural conduction time with muscle fibre conduction time following a warm up, and as a result provides clarity in discerning the difference between neural and muscle conduction time changes following an active warm up.

A raison d'être for this study was to address the confusion in the exercise science literature which suggests warm up improves (reduces) nerve conduction time.[3–5] Indeed, evidence has previously demonstrated an improvement in muscle conduction time, with a reduction in time to peak twitch. For example, Girard et al.[10] showed a reduction in peak twitch time of the vastus medialis and lateralis muscles of approximately 12% with both running and strength exercise warm ups; whilst Van der Hoeven and Lange[11] showed a change of approximately 5% following intermittent isometric exercise in the biceps brachii muscle. Similarly, our study found a reduction in M-wave peak twitch time of ∼5% in the hand and ∼8.5% in the leg, supporting these previous findings.[9,11]

The explanations for why warm up reduces the time to muscle peak twitch include membrane hyperpolarisation due to increased Na^+/K^+ pumping activity[21,22] and muscle fibre swelling.[23] Gray et al.[9] suggested a greater increase in adenosine triphosphate (ATP) turnover may lead to individual sarcomeres becoming more rapidly activated, and as a result increase the contractile speed of the whole fibre.[9] Whatever the mechanism, our data suggest that changes in muscle conduction time are not restricted to those muscles actively involved in the warm up, as the APB, M-wave peak twitch time was significantly reduced.

The functional relevance of a 5–8.5% change in muscle conduction velocity remains unclear and was beyond the scope of the current study. However, Farina et al. demonstrated, following low-force isometric contractions in tibialis anterior muscle, that velocity in single motor unit conduction positively correlates with an increase in motor unit twitch force and the rate of force development.[8] Our data support these previous findings,[8,9,11] which suggest post warm up improvements in neuromuscular performance are due to alterations in the efficacy of contractile and muscle conduction properties.

In explaining the unchanged neural conduction time, it is well known that corticospinal neurons have fixed neural conduction speeds which are related to the muscle fibre type innervated. Axons of motor neurones supplying slow twitch muscle fibres have lower conduction velocities than those supplying fast twitch muscle fibres.[24] Similarly, pyramidal (corticopsinal) tract fibres, the majority of which emanate from the cerebral cortex and continue to the spinal cord before innervating α-motoneurons, have a range of diameters which influence the velocity of impulses. Large diameter, fast corticospinal fibres (11–20 μm) conduct at velocities of $\sim 50\,m\,s^{-1}$, whereas slow corticospinal fibres are small in diameter (1–4 μm) and conduct at speeds of $\sim 14\,m\,s^{-1}$.[24] Alterations in neural conduction velocities can occur as a result of pathology, for example with neurological (stroke) and neurodegenerative conditions (multiple sclerosis), resulting in a reduction in neural conduction rate.[25,26] In healthy populations, however, nerve conduction velocities remain unchanged. It is, therefore, unlikely that performing warm up activities would significantly alter neural conduction speeds and the data from this study appear to support this notion.

5. Conclusion

In conclusion, a generic warm up at 65% of HR_{max} improves muscle but not neural conduction time in both passive and active muscles involved in the warm up. Although warm up was quantified by the use of heart rate, further clarification of neural versus muscular conduction time is required, particularly with regard to changes in core body temperature, as previous research has shown that increases in muscle temperature improve muscle conduction time.[9] Using a similar methodology, future research should investigate the effect of changes in muscular and core temperature on both neural and muscular conduction times.

6. Practical implications

- Studies investigating the neuromuscular excitability can differentiate between neural and muscular conduction.
- When educating exercise scientists, sports medicine practitioners, coaches and athletes on the benefits of warming up, changes in muscle conduction time should be discussed, rather than neural conduction time.
- Increases in muscle activity, rather than neural activity, should be the main aim of prescribed warm-up activities.

Acknowledgement

No financial assistance for this project was provided.

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