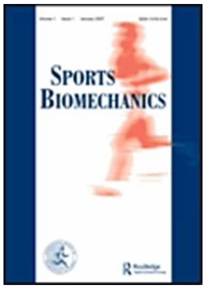

Muscle activation and local muscular fatigue during a twelve minute rotational bridge

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use of two brackets for (i), (ii)…
'Methods' instead of 'Methods and Materials'
BMI has been explained and standard units applied (under Participants in the methods section)
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Muscle activation and local muscular fatigue during a twelve minute rotational bridge

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Muscle activation and local muscular fatigue during a twelve-minute rotational bridge

Abstract

Due to anecdotal reports of back pain during a 12-minute rotational bridge test by uniformed services the level of fatigue leading to possible back pain and or injury was investigated. We hypothesised a high level of fatigue due to diminishing core muscle activation. Nineteen highly trained uniformed service members were measured by surface electromyography of the rectus abdominis, external oblique, internal oblique, lumbar erector spinae, thoracic erector spinae and latissimus dorsi. Average rectified electromyography amplitude (AEMG) and median power frequency were analysed to determine activation and fatigue. All AEMG was normalised and expressed as a percentage of maximal voluntary isometric contraction (%MVIC). Significant increases in AEMG were observed over the test duration for the rectus abdominis (+ 19.5 %MVIC), external oblique (+ 18.0 %MVIC) and internal oblique (+ 23.2 %MVIC) during the prone position; and for the external oblique (+ 21.8 %MVIC) when bracing on the measurement side (all, $p < 0.05$). No significant changes in median power frequency were observed (all, $p > 0.05$). Combining prone and side bridge positions is a reasonable measure of anterior, posterior and lateral trunk musculature. Muscular fatigue remained low throughout making this a safe assessment in trained individuals.

Keywords**:** core; neuromuscular; electromyography

Word count: 195

Introduction

Core stability is an important component of physical performance as it may reduce the risk of injury during activities of daily living, sports, and periods of prolonged, heavy physical work (Borghuis, Hof, & Lemmink, 2008). Core stability relies on passive, active and neural subsystems to ensure appropriate force is developed, and to maintain neutral spine alignment during various physical activities (Panjabi, 1992). Success of these processes is dependent on musuclar strength and endurance and, as such, monitoring and training core strength and/or endurance is often prioritised in sporting and uniformed service settings (McGill, Childs, & Liebenson, 1999; Willardson, 2007).

Uniformed services (especially the military) are frequently required to perform physical activity while carrying heavy loads for prolonged durations (Jones & Knapik, 1999). In order to maintain the spine in neutral alignment during such tasks, an advanced degree of core stability is required (Borghuis et al., 2008). Given the importance of adequate core stability, uniformed services often utilise core endurance tests to assess the ability of individuals to partake in periods of heavy physical work (Jones & Knapik, 1999; McGill, Grenier, Kavcic, & Cholewicki, 2003). The most commonly used assessment is a sit-up or trunk curl test (Cuddy, Slivka, Hailes, & Ruby, 2011); however, these tests may not adequately assess posterior core muscles (Burden & Redmond, 2013; Escamilla et al., 2006). Additionally, the safety of such tests may be questioned as *in vitro* studies have shown that modest compressive forces, combined with repetitive flexion/extension motions, significantly increases the risk of intervertebral disc herniation (Callaghan & McGill, 2001). Consequently, isometric core endurance tests, such as the prone or side bridge, have been recommended due to the neutral spine position eliciting lower compressive forces (Marshall, Desai, & Robbins, 2011; McGill, 2001).

The prone and side bridge are core endurance exercises that improve/test core stability by challenging an individual to maintain a neutral spine position, against gravity, over a period of time (Garcia-Vaquero, Moreside, Brontons-Gil, Peco-Gonzalez, & Vera-Garcia, 2012; Marshall et al., 2011). The prone bridge appears a suitable assessment and training tool for the anterior and lateral core musculature (Ekstrom, Donatelli, & Carp, 2007; Garcia-Vaquero et al., 2012; Lehman, Hoda, & Oliver, 2005), whilst the side bridge appears more suitable for the posterior and lateral core musculature (Hibbs, Thompson, French, Hodgson, & Spears, 2011; Juker, McGill, Kropf, & Steffen, 1998; Marshall et al., 2011).

Muscle activation during core stabilty exercises can provide information on the efficacy of such tasks to maintain neutral spine alignment. McGill and Karpowicz (2009) identified that starting in a side bridge position and rolling to a prone bridge, pausing, and continuing to a side bridge on the opposite arm significantly increases activation of the anterior, lateral and posterior core musculature. As muscle endurance of both the trunk flexors and lumbar extensors is essential for core stability, an assessment/test which suitably challenges anterior, lateral and posterior core musculature would be advantageous (Hibbs, Thompson, French, Wrigley, & Spears, 2008). A test similar to that described by (McGill & Karpowicz, 2009; Tong, Wu, & Nie, 2013) has been adapted by some uniformed services in attempt to allow a functional muscular endurance assessment of the entire core. However, it is unkown whether the prolonged 12 minute duration of the uniformed services assessment could predispose an individual to injury through local muscular fatigue of the core stabilisers. There was anecdotal reports of low back pain when the test was performed. Hence, this research was required to determine if the level of fatigue was a contributing factor to the low back pain by examining the core muscle activation during a 12 minute rotational bridge.

The task involved rotating between isometric prone and side bridge positions, every 30 seconds for a total duration of 12 minutes. It was hypothesised that (i) each position (prone and side) would activate the anterior, lateral and posterior core musculature to differing sub-maximal levels of muscle activation, and (ii) the prolonged duration would result in local muscular fatigue of the assessed muscles.

Methods

Participants

Nineteen highly trained men (40 ± 5 y, 1.84 ± 0.05 m, 93.6 ± 7.4 kg) who had normal body mass index (25.4 ± 1.9 kg/m²) volunteered for this research. Participants were all current uniformed service personnel and engaged in regular resistance and cardiovascular exercise (> 3 days per week) for a minimum of six months prior to testing. All participants were free from any musculoskeletal injury. Ethical approval was provided by the Massey University Human Ethics Committee (application HEC 13/71), and all participants received verbal and written information prior to giving written consent.

Procedures

Electromyography (EMG) recording: Twelve disposable Ag-AgCl electrodes (Ambu®, BlueSensor, Denmark) were placed in pairs over the skin and parallel to the fibres of the rectus abdominis; external oblique; internal oblique; lumbar and thoracic portions of the erector spinae, and latissimus dorsi; with an inter-electrode spacing of 2 cm. Detailed electrode locations for each muscle are reported below. To minimise the risk of skin artefact, rigorous skin preparation methods were applied (Disselhorst-Klug, Schmitz-Rode, & Rau, 2009). Prior to electrode placement each participant's skin was shaved of any hair with a disposable single use razor, and vigorously cleansed with alcohol wipes. Raw EMG signals were collected with TeleMyo® DTS wireless surface EMG sensors (Noraxon, Arizona, USA) at a sampling rate of 1000 Hz. Raw EMG signals were processed and analysed using

MyoResearch® XP (Noraxon, Arizona, USA). The raw EMG data was amplified by a gain of 1000, filtered using a Lancosh FIR digital bandpass filter set at 10-500 Hz, and smoothed to a 50 ms root mean square (RMS) algorithm.

The rectus abdominis electrodes were placed 3 cm lateral and 2 cm superior of the umbilicus (Hibbs et al., 2011). The external oblique electrodes were positioned midway between the anterior superior iliac spine and the rib cage (Youdas et al., 2008). The internal oblique electrodes were placed in the centre of a triangle formed by the inguinal ligament, outer edge of the rectus sheath and a line from the anterior superior iliac spine to the umbilicus (Garcia-Vaquero et al., 2012; Youdas et al., 2008). The lumbar erector spinae electrodes were positioned 3 cm lateral to the posterior spinous process at the level of the third lumbar vertebrae (Garcia-Vaquero et al., 2012; Lehman et al., 2005), while the thoracic erector spinae electrodes were positioned 4 cm lateral to the spinous process at the level of the ninth thoracic vertebrae (Potvin, Norman, & McGill, 1996; Vera-Garcia, Moreside, & McGill, 2010). Finally, the latissimus dorsi electrodes were placed 4 cm below the inferior tip of the scapula and midway between the spine and lateral edge of the torso (Hibbs et al., 2011). All electrode pairs were placed on the participant's hand dominant side, as motor control symmetry was assumed between both sides of the body (McGill, Cannon, & Andersen, 2014). It is acknowledged that some muscle cross-talk is likely to have occurred, however, this effect was minimised through precise land marks and guidelines for electrode placement of each muscle (Ekstrom et al., 2007; Hislop, Avers, Brown, & Daniels, 2014, pp. 1-203).

Normalisation: Familiarisation of all movements with visual EMG feedback was conducted, followed by a five-minute rest period prior to maximal voluntary isometric contraction (MVIC) performed against manual resistance for each movement. This was in accordance with previously published best practice (Ekstrom et al., 2007; Lehman et al., 2005; Vera-Garcia et al., 2010). The detailed movements for MVIC are outlined below. For rectus abdominis, the participant lay supine on an examination table with the feet secured. They then performed a partial curl up with manual resistance applied at the shoulders (Ekstrom et al., 2007). For the external oblique, participants remained in the same position with resistance applied diagonally while the participant attempted to move the shoulder toward the opposite knee (Ekstrom et al., 2007). For the internal oblique, the participant performed a side bridge while maximally resisting downward pressure applied at the pelvis (Vera-Garcia et al., 2010). The MVIC for the lumbar erector spinae was performed in the prone position with participant's torso secured at the thoracic level, and legs cantilevered over the end of the table. With flexed knees the participant attempted to maximally extend the lower trunk and hips against resistance (Vera-Garcia et al., 2010). The MVIC for the upper thoracic spine was also performed in the prone position but with their legs secured and torso horizontally cantilevered over the end of the table; they maintained a horizontal position while extending their upper torso against resistance (Vera-Garcia et al., 2010). Finally, MVIC of the latissimus dorsi was obtained with the participant lying prone and forearm pronated, they then raised an arm off the table as high as possible, while keeping a straight elbow, they maintained position against downward resistance (Hislop et al., 2014, pp. 1-203).

Participants performed three MVIC's per muscle group, maintaining each contraction for 5 s (Hibbs et al., 2011; Youdas et al., 2008). All muscles were tested in a randomised order. Sixty seconds rest was provided between each repetition (Hibbs et al., 2011; Youdas et al., 2008). Average rectified EMG amplitude (AEMG) was recorded during the MVIC trials. The average of three, 3 s timestamps (occurring in the middle of each MVIC) was calculated to represent 100 %MVIC. All subsequent data collected during the bridge test was normalised to this 100 % value.

Test protocol

All testing sessions took place within 24 hours of familiarisation; participants were instructed not to perform any other exercise 48 hours prior to testing. Following a standardised warm up consisting of light aerobic exercise and dynamic stretches, the test was started in the prone bridge position with the elbows braced on the floor directly beneath the shoulders, and the feet together. The pelvis was raised off the ground to form a straight line through the shoulder, hip, knee and ankle. This position was maintained for 30 s before rotating on to their hand-dominant side (bracing arm measured) to assume a side bridge position. The side position required the participant to brace one elbow directly beneath the shoulder with the lateral aspect of the ipsilateral foot resting on the ground. The pelvis remained raised to maintain a straight midline of the body. The side bridge was held for 30 s before rotating back to the prone position for another 30 s, then rotating to the non-dominant side (non-bracing arm measured) and maintaining for 30 s. This process was continued for a total duration of 12 minutes, allowing three minutes in each side position and six minutes in the prone position. Synchronised video was recorded throughout the 12-minute test using a high definition camera (Logitech, HD C615, Switzerland) sampling at 30 Hz.

Data analysis

The EMG data used for analysis was collected from the 25th to the 27th second of each stage of the test. This time window was chosen as local muscular fatigue is likely highest during the latter portion of each position, and also to ensure the analysed portion of each position was purely isometric (before any postural shift to new position). Visual recordings were used to ensure that participants were not initiating a postural shift within this period of EMG recording. Analysis utilised two EMG signal parameters including: AEMG data (amplitude); and median power frequency. Average rectified EMG amplitude was utilised to give an indication of level of muscle activity involved with the test, and was obtained by calculating the mean area under the processed EMG curve, and dividing by the 3 s recording window. Under constant load, median power frequency often represents changes occurring in the muscle fibre conduction characteristics of active motor units (Medved & Cifrek, 2011, pp. 349-366; Talebinejad, Chan, Miri, & Dansereau, 2009; Yoshitake, Ue, Miyazaki, & Moritani, 2001), which are important for determining muscular fatigue; and was chosen for analysis as it is less variable than mean frequency (Basmajian & De Luca, 1985, pp. 201-222; De Luca, 1997; Roman-Liu, Tokarski, & Wojcik, 2004).

Statistical analysis

Normalised AEMG, and the group average median power frequency for each muscle was analysed using a series of repeated measures analysis of variance (ANOVA) to determine any statistical differences between different stages of the test. Where appropriate, post hoc testing using Bonferroni multiple comparison analysis was performed to identify the location of any statistical differences between stages (duration of test), for each prone and side position. Alpha was set to $p \leq 0.05$. Cohen's d effect sizes (Cohen, 2013, pp. 274-288) were calculated for relevant stages and positions of the test. Effect sizes *(ES)* were classified as *small* (*ES* = 0.20-0.49), *moderate* (*ES* = 0.50-0.79), and *large* (*ES* ≥ 0.80). All statistical analysis was performed using SPSS version 22.0 (SPSS Inc., Chicago, IL, USA).

Results

Muscle activation for the majority of muscles across the 12 minutes was significantly different between prone, dominant side and non-dominant side positions (all, $p < 0.01$); the exceptions being the internal oblique during prone and dominant side positions, and latissimus dorsi during dominant and non-dominant side positions (both, $p > 0.05$). The prone position produced the highest muscle activation in the rectus abdominis (25.6 ± 10.5 %MVIC), internal oblique (28.6 ± 13.8 %MVIC) and latissimus dorsi (22.8 ± 8.8 %MVIC); while the dominant side position produced the highest muscle activation of the external oblique (46.6 ± 19.8 %MVIC), lumbar erector spinae (26.3 ± 11.1 %MVIC) and thoracic erector spinae (19 ± 12.6 %MVIC).

The amplitude (AEMG) of rectus abdominis, external oblique, internal oblique and lumbar erector spinae was significantly different ($p < 0.05$) between the first and at least one of the last two stages, 11 and 12 in the prone position (Table 1). The associated calculated effect sizes were all large $ES > 1$.

Insert Table 1 & 2 about here

All muscles on the same side as the brace arm (dominant side) during the side bridge position, displayed a small but non-significant increase in activation across the duration of the test ($p > 0.05$). The exception was the external oblique (Table 2) which displayed significantly greater muscle activation between the first and last stage of the test ($ES = 1.10$; $p < 0.05$). When bracing on the non-dominant side, muscle activation remained relatively constant in all muscles contralateral to the brace arm, with no significant changes in AEMG across the duration of the test ($p > 0.05$).

No significant changes in median power frequency were observed across each stage, for all muscles, during prone (Figure 1) and side (Figure 2) bridge positions ($p > 0.05$). However, large effect sizes were revealed for the rectus abdominis ($ES = 1.06$) and internal oblique ($ES = 1.18$) between the first and last stages of the test in the prone position.

Insert Figure 1 & 2 about here

Discussion and Implications

Our first hypothesis was supported in that there were significant differences in the level of trunk muscle activation observed between prone and side bridge positions. The prone position elicited more activation of the rectus abdominis, internal oblique and latissimus dorsi; while the dominant side bridge position elicited more activation of the external oblique, lumbar erector spinae and thoracic erector spinae. Previous research advises that muscle activity less than 40 %MVIC is optimal when training for muscle endurance (Baker & Newton, 2004; Escamilla et al., 2010; Youdas et al., 2010). Hence, the level of trunk muscle activation present in this study demonstrates that a rotational bridge exercise, which combines both prone and side bridge positions, may be a suitable means of assessing the endurance capabilities of the trunk musculature. Our second hypothesis was not supported because despite significant differences in AEMG in certain muscles, over the duration of the test, there were no significant changes in median power frequency, indicating minimal muscular fatigue.

As core stability is a product of muscular endurance and strength, it was purported that determining the level of muscle activation over the test duration would inform whether the 12-minute duration is a relevant assessment of core stability. Furthermore, analysis of median power frequency in conjunction with amplitude was performed to determine whether fatigue may be occurring over the duration of the test which could lead to injury. Increases in EMG signal amplitude for the same force development would indicate that local muscular fatigue may be occurring if coupled with a decrease in median power frequency. Results showed no significant differences in median power frequency in all positions, across the duration of the test. The median power frequency was measured during a three second window from seconds 25-27 s of each position over the 12-minute test duration. This measurement window was chosen as it was believed the highest amount of local muscular fatigue may be occurring during this sampling window, and to mitigate the influence of movement artefact as the participants had not yet initiated a postural shift to a new position. As shown in Figure 1, the median power frequency of the rectus abdominis decreased from 60.1 Hz to 48.6 Hz over the duration of the test performed in the prone position; however, the decrease was non-significant.

During low level contraction, as observed in this study, high threshold motor units are newly recruited, and as the action potential of the newly recruited motor units have a high conduction velocity it can lead to an increased median power frequency of surface EMG (Merletti, Rainoldi, & Farina, 2004, pp. 233-258). This may explain the non-significant reduction of median power frequency. However, despite this, it appears that regular (every 30 s) changes in isometric bridge position mitigated the level of local muscular fatigue due to low muscle activation in certain positions. It has been previously shown that sustained contractions at intensities greater than 20 %MVIC restricts blood flow to the muscle, and may contribute to local muscular fatigue through accumulation of metabolic by products (Barnes, 1980; Yoshitake et al., 2001). In this research, the non-bracing arm in the side-bridge position elicited < 15 %MVIC, which is much lower than the intensity shown to induce ischemia (Barnes, 1980; Yoshitake et al., 2001). Similarly, in the prone position, activity of the erector spinae was low, thus allowing this muscle to recover; likewise for the rectus abdominis when in the dominant side position.

Rotation between prone and side bridge positions during a core endurance test allows the assessment of all major core muscles involved in stability during bridging tasks (McGill & Karpowicz, 2009). Indeed, McGill and Karpowicz (2009) have shown that rolling from a side bridge to a side bridge on the opposite arm significantly challenges the internal and external obliques, rectus abdominis, latissimus dorsi and erector spinae. For this reason, the rotational bridge may not be suitable for untrained individuals, or individuals lacking appropriate core stability. However, in well trained individuals (such as military, police etc.), the rotational bridge serves as a practical assessment of all major muscles involved in core stability. Furthermore, alternating between prone and side positions, at regular intervals, may mitigate local muscular fatigue through low levels of muscle activation in differing positions. Although, no significant fatigue was shown to manifest throughout the test, it is important to acknowledge that the participants were highly trained and familiar with the testing protocol. Furthermore, fatigue of low threshold motor units may have been occurring, but did not result in local muscular fatigue. From these results the authors could only assume the reason for anecdotal reported back pain with the test was due to a lack of trained status and/or incorrect technique at the time.

Limitations

Although the present study has shown a favourable degree of muscle activation of the anterior, lateral and posterior core musculature with each position of the rotational bridge test, it is pertinent to recognise the potential limitations of the study. The method to obtain MVIC is likely one of the major factors associated with differences in muscle activity between studies when similar electrode placement is used. To mitigate the influence of variability between studies, previously validated manual muscle testing techniques were employed (Ekstrom, Soderberg, & Donatelli, 2005; Hibbs et al., 2011), and precise guidelines were followed to reduce inter-individual variability (Ekstrom et al., 2007; Hislop et al., 2014, pp. 1-203). The recording of the internal oblique muscle is particularly difficult due to the deep orientation of the muscle. Without the use of invasive intramuscular electrodes, muscle crosstalk contamination was minimised through precise placement of the surface electrodes (Garcia-Vaquero et al., 2012; Youdas et al., 2008). While no significant fatigue was reported, the sample population was restricted to uniformed service personnel familiar with the 12-minute rotational bridge test, which may not be the case in individuals untrained or unfamiliar with this protocol. However, the sample was representative of the cohort likely to perform this type of core assessment. Future research should utilise general healthy populations to determine whether muscular fatigue might be greater in individuals not accustomed to this exercise.

Conclusions

In conclusion, core stability is an important physical requirement for uniformed personnel, ensuring adequate spine stabilisation during job specific tasks. The 12-minute bridge test serves as a trunk endurance assessment of the posterior and lateral core muscles (side position), and the anterior and lateral core muscles (prone position). The alternating positions may mitigate local muscular fatigue through low levels of muscle activation in differing positions. Therefore, the rotational bridge appears to be a suitable measure of trunk muscle endurance when assessing trunk stability in a well-trained population such as uniform personnel.

Conflict of interest

The authors declare no conflict of interest.

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Figure legends

Figure 1. Average median power frequency (Hz) during each stage of the 12-minute bridge test performed in the prone position. RA = rectus abdominis; EO = external oblique; IO = internal oblique.

Figure 2. Average median power frequency (Hz) during each stage of the 12-minute bridge test performed in the side position. EO = external oblique; IO = internal oblique; LUM ES = lumbar erector spinae; THOR ES = thoracic erector spinae.

Table 1. Normalised AEMG (± SD) during the prone position of a 12-minute rotational bridge to %MVIC

Time (min)	**RA**	**EO**	**IO**	**L ES**	**T ES**	**LD**
0.5	16.2 (6.7)	21.5 (10.2)	16.2 (6.8)	3.1 (1.2)	4.2 (2.1)	22.9 (6.8)
1.5	19.4 (7.3)	25.3 (17.0)	20.1 (10.0)	3.3 (1.2)	3.7 (1.8)	18.7 (5.8)
2.5	21.3 (9.6)	23.7 (13.1)	22.5 (12.1)	3.5 (1.3)	4.5 (3.0)	23.0 (7.7)
3.5	21.9 (10.2)	26.5 (15.0)	23.7 (11.7)	3.6 (1.3)	4.0 (1.9)	19.3 (6.7)
4.5	21.2 (9.3)	22.6 (10.1)	24.2 (11.9)	3.7 (1.3)	4.7 (3.4)	23.1 (9.1)
5.5	25.8 (11.9)	29.3 (15.7)	29.0 (13.2)	4.1 (1.4)	4.0 (1.6)	18.7 (8.3)
6.5	25.3 (10.9)	27.2 (11.5)	28.8 (12.4)	4.2 (1.4)	4.3 (2.2)	22.6 (9.6)
7.5	29.7 (13.2)	32.4 (16.3)	35.1 (18.2)	4.4 (1.7)	4.2 (1.9)	20.4 (8.3)
8.5	29.6 (9.2)	29.7 (14.1)	34.3 (15.8)	4.3 (1.5)	5.0 (2.6)	25.3 (11.9)
9.5	30.0 (12.8)	34.2 (15.3)	34.7 (18.2)	4.6 (1.4)	4.5 (2.0)	21.3 (9.2)
10.5	31.3** (11.1)	32.8 (14.7)	35.3* (16.5)	4.9* (1.9)	5.7 (3.6)	27.1 (13.6)
	ES 1.7		*ES* 1.64	*ES* 1.16		
11.5	35.6** (14.0)	39.2* (18.6)	39.4** (18.8)	5.0* (1.6)	4.8 (2.3)	22.5 (8.0)
	ES 1.87	*ES 1.23*	*ES 1.81*	*ES* 1.36		
Average	25.6 (10.5)	28.7 (14.3)	28.6 (13.8)	4.1 (1.4)	4.5 (2.4)	22.8 (8.8)

** Muscle activity is significantly higher than first stage of test – $P < 0.01$

* Muscle activity is significantly higher than first stage of test – $P < 0.05$

AEMG = average rectified variable electromyography;

ES = effect size in comparison to first stage where significant differences were identified;

%MVIC = % maximum voluntary isometric contraction; RA = rectus abdominis; EO = external oblique; IO = internal oblique; L ES = lumbar erector spinae; T ES = thoracic erector spinae; LD = latissimus dorsi

Table 2. Normalised AEMG (± SD) during the side bridge performed on the dominant [electrode] side (% MVIC).

Time (min)	**RA**		**EO**		**IO**		**L ES**		**T ES**		**LD**	
1	10.8	(5.7)	37.0	(9.3)	16.9	(11.8)	24.3	(12.7)	15.3	(10.1)	8.4	(6.0)
3	12.4	(10.0)	42.4	(16.1)	21.5	(15.5)	26.0	(11.3)	16.6	(11.6)	9.8	(7.3)
5	13.8	(9.3)	48.4	(17.8)	26.1	(19.4)	26.5	(11.3)	19.4	(14.2)	11.0	(9.6)
7	15.7	(10.0)	55.2	(25.7)	27.4	(18.0)	26.6	(11.3)	18.6	(11.0)	10.5	(8.1)
9	15.3	(10.0)	50.2	(19.6)	29.1	(20.3)	26.9	(9.9)	21.7	(13.9)	11.4	(9.5)
11	17.5	(11.1)	58.8*	(30.2)	31.6	(20.9)	27.7	(10.2)	22.2	(14.7)	11.7	(8.5)
Average	14.3	(9.4)	46.6	(19.8)	25.4	(17.7)	26.3	(11.1)	19.0	(12.6)	10.5	(8.2)

* Muscle activity is significantly higher than first stage of test – $P < 0.05$
AEMG = average rectified variable electromyography;
%MVIC = % maximum voluntary isometric contraction; RA = rectus abdominis; EO = external oblique; IO = internal oblique; L ES = lumbar erector spinae;T ES = thoracic erector spinae; LD = latissimus dorsi

Figure 1

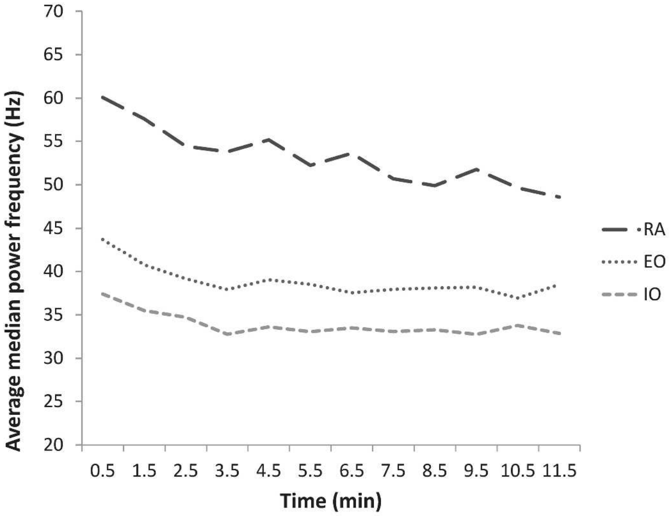

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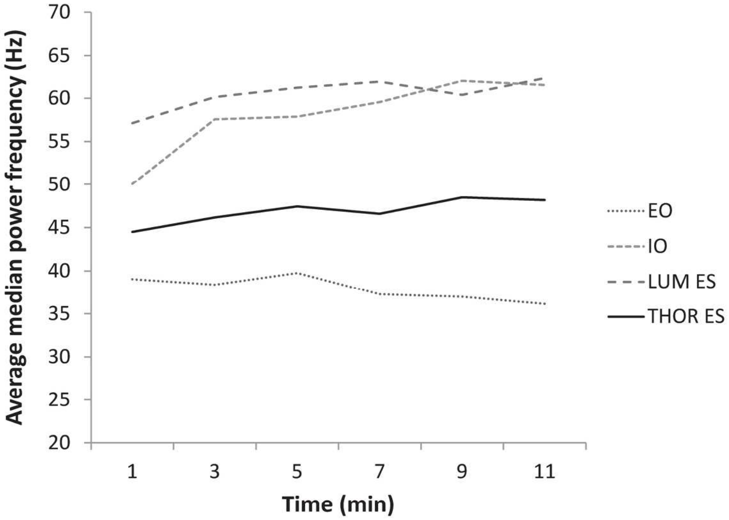
Figure 2



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