EXERCISE PHYSIOLOGY

Muscle activity of the upper and lower rectus abdominis during exercises performed on and off a Swiss ball

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Summary This study sought to examine any differences in upper rectus abdominis (URA) and lower rectus abdominis (LRA) muscle activity during four abdominal exercises, the curl-up, Swiss ball curl-up, Swiss ball jackknife and Swiss ball rollout. Fourteen healthy adults (7 males, 7 females, mean age ± S.D. = 21.8 ± 3.8 years) performed abdominal exercises in a randomised order following maximal voluntary isometric contraction. Muscle activity of the URA and LRA was assessed using surface electromyography. Results indicated that activity of the URA was significantly greater than muscle activity of the LRA for the curl-up, Swiss ball curl-up and Swiss ball rollout. LRA muscle activity was greater than URA during the jacknife exercise. Muscle activity during the curl-up was significantly lower than muscle activity during the other exercises. To conclude, muscle activity was greater when exercises were performed on a Swiss ball in comparison to a stable surface and LRA muscle activity was maximized during the Swiss ball jacknife.

Introduction

The Swiss ball has become a widely used mode of abdominal training in both recreational and clinical settings. Its use has been justified on the basis that increased muscular recruitment and co-ordination is required to maintain postural stability although evidence supporting this is lacking (Marshall and Murphy, 2006). However, a number of research studies have examined muscle activity using electromyography (EMG) on stable and unstable surfaces. Andersen and Behm (2004) reported no difference in EMG activity of the pectorals, triceps, latissimus dorsi or rectus abdominis (RA) when performing maximal isometric chest presses under stable and unstable conditions and Lehman et al. (2005) reported no significant differences in rectus abdominis, activity when an exercise bench was replaced with a Swiss ball for shoulder press, shoulder raise and tricep extension exercises. Similar findings have been reported for abdominal muscle activity during curl-up exercises when performed on unstable surfaces (Vera-Garcia et al., 2000; Rodd et al., 2002).
Examining abdominal muscle activity during exercise performed on stable and unstable surfaces is clearly important for conditioning of athletic groups and in rehabilitation from injury. However, results from previous studies are contradictory and although the rectus abdominis is one muscle, it is common practice within strength and conditioning and rehabilitation settings to prescribe abdominal exercises that work the ‘upper or lower abs’ (Clark et al., 2003). As a result, many individuals believe they are recruiting more motor units from one area of the RA than another or that the upper fibers of the RA are separate muscles to the muscle fibers in the lower RA. Moreover, the majority of studies that have examined muscle activity of the RA on stable and unstable surfaces have not examined both the upper rectus abdominis (URA) and the lower rectus abdominis (LRA) (Beim et al., 1997; Whiting et al., 1999). One study by Clark et al. (2003) reported no significant differences in EMG activity of the URA and LRA across a range of abdominal exercises although significantly higher activity of the URA and LRA was evident during a Swiss ball curl-up compared with the other exercises used in this study. Therefore, the aim of this study was to compare muscle activity of the URA and LRA during four commonly used abdominal exercises (curl-up, Swiss ball curl-up, Swiss ball rollout and Swiss ball jackknife).

Method

Following ethical approval and informed consent, 14 subjects (7 males, 7 females) volunteered to participate in this study (mean age ± SD = 21.8 ± 3.8 years). Subjects were all regular exercisers, did not have any musculoskeletal pain or disorders and were asked to refrain from vigorous exercise in the 24 h prior to testing. All testing took place within the institution’s human performance laboratory.

Experimental design

This study employed a within subjects repeated measures experiment whereby participants were asked to perform four abdominal exercises (curl-up, Swiss ball curl-up, Swiss ball rollout and jackknife) in a randomised order. Muscle activity was assessed using surface electromyography. Collected signals were expressed as a relative percentage of the maximal voluntary isometric contraction (MVIC) performed for each muscle.

Measurement of muscle activity

Muscle activity of the URA and LRA muscles was measured using surface EMG. Passive bipolar surface electrodes of 30 mm diameter (Blue Sensor, Ltd., Denmark, Ag/AgCl) were placed on the belly of each of the muscles, in line with the muscle fiber direction, with an interelectrode distance of 1.5 cm. Electrode placement for the URA and LRA followed guidelines reported by Ng et al. (1998). Before electrode placement, the area was cleaned with isopropyl alcohol, shaved and abraded in order to reduce skin impedance. All electrodes remained in place until data collection was completed in the four exercises. EMG activity was differentiated by pre-amplifiers and recorded via an on-line ME6000 system (MEGA Electronics, Ltd., Finland), with an input impedance of less than $10^{15}/0.2 \Omega/pF$, a common mode rejection ratio at 60 Hz of greater than 110 dB, a noise level of 1.2 $\mu$V, a gain of 10±2% and a bandwidth range to 500 Hz. Muscle activity was sampled at 1000 Hz using MegaWin software, version 1.2 (MEGA Electronics, Ltd., Finland). The raw EMG data were filtered using a Butterworth high- and low-pass filter (5–500 Hz) and visually checked for artefacts, which were excluded from subsequent analysis. On completion of the experimental protocol, the raw EMG signal was then full wave rectified and the root mean square (RMS) calculated.

Prior to data collection, MVICs were performed for each muscle prior to beginning the four abdominal exercises (DeLuca, 1997). The MVICs were performed over a 4 s period involving a gradual build-up to maximal muscle activity and were conducted according to protocols used by Marshall and Murphy (2006). Visual feedback was provided for each subject for the MVIC procedures. Maximum trunk flexor activation (for URA and LRA) was performed using a resisted sit-up task while lying supine in partial trunk rotation. Two MVICs were performed after familiarization with procedures (including performance of an unrecorded MVIC). The highest activity recorded based on the maximum value from the RMS of the EMG signal provided the reference MVIC (Farina et al., 2003). All EMG data collected were subsequently expressed as a percentage of this value and used in the analysis.

Abdominal exercises

The subjects were asked to perform 2 trials of each of the four abdominal exercises. The RMS EMG of each trial was taken and averaged. This value was then normalized as a % of the MVIC and used for all further analysis. Each trial was performed continuously over 6 s and was performed according to procedures outlined by Goldenberg and Twist (2002). Correct positioning at the start of each Swiss ball exercise was accomplished by subjective feedback from one of the experimenters. This ensured that for the curl-up and Swiss ball curl-up that there was concentric muscle action on the loading phase and eccentric muscle action on the unloading phase (isotonic action) and that isometric muscle actions were performed for the Swiss ball rollout and jackknife in accordance with recommended procedures (Goldenberg and Twist, 2002). A 65 cm Reebok Swiss ball (Reebok Ltd., Lancaster, United Kingdom) was used for the Swiss ball exercises and a 2 min rest was required between trials.

The curl-up was performed lying supine with an inclined knee angle of 90° and with arms placed across the chest. Participants were instructed to lift their head and shoulders towards the ceiling over 2 s, to hold the new position momentarily and then slowly return to the starting position over 2 s.

The Swiss ball curl-up was performed lying supine on the Swiss ball with arms placed across the chest. Participants were instructed to keep both feet flat on the floor and to position themselves so their lower back was supported by the ball with their torso parallel to the floor. Participants were instructed to lift their head and shoulders towards the ceiling over 2 s, to hold the new position momentarily and then slowly return to the starting position over 2 s.
The Swiss ball rollout was performed kneeling on the Swiss ball. The participants were instructed to roll the ball out over 2 s into a fully extended position (hips were fully extended and shoulders were in a flexed position next to the head), hold the position and then slowly return to the starting position.

The jackknife was performed with feet on the Swiss ball and hands on the ground in front of the ball (in a push-up position). With the torso square to the ground, the knees are brought towards the chest. The legs are then extended back into the start position.

**Statistical analysis**

Any differences in muscle activation between the URA and LRA across the four exercises were investigated using a 2 (URA vs. LRA) × 4 (exercise) ways, repeated measures analysis of variance, where any significant differences were found. Bonferroni’s multiple comparisons were used to determine where these differences lay. The level for statistical significance was set at p < 0.05.

**Results**

Results indicated a significant region by exercise interaction (F, 3.39 = 6.52, p = 0.001 and partial η² = 0.580). Muscle activity of the URA was greater than muscle activity of the LRA for the curl-up, Swiss ball curl-up and Swiss ball rollout. However, LRA muscle activity was greater than URA during the jackknife exercise. There was also a significant exercise main effect (F, 3.39 = 30.78, p = 0.0001 and partial η² = 0.861). Bonferroni multiple comparisons indicated that the muscle activity during the curl-up was significantly lower than muscle activity during the Swiss ball curl-up (mean diff. = −12.42, p < 0.02), the jackknife (mean diff. = −36.2, p < 0.001) and the Swiss ball rollout (mean diff. = −35.3, p < 0.0001). Furthermore, muscle activity during the Swiss ball curl-up was significantly lower than muscle activity during the jackknife (mean diff. = −23.7, p < 0.0001) and during the Swiss ball rollout (mean diff. = −22.9, p = 0.004). There was no significant difference in muscle activity between the jackknife and the Swiss ball rollout (mean diff. = 0.893, p > 0.05). In addition, no significant main effect according to region was evident (F, 1.13 = 0.064, p > 0.05). Mean ± S.D. of the muscle activity across the four abdominal exercises are presented in Table 1 and Figure 1.

**Discussion**

Results of the present study indicate that, in all cases, muscle activity was greater when exercises were performed on a Swiss ball in comparison to a stable surface. This supports the findings of a number of previous studies that also reported significantly greater muscle activity when exercises were performed on a labile as opposed to a stable surface (Marshall and Murphy, 2006; Vera-Garcia et al., 2000; Clark et al., 2003). Secondly, this study indicates that muscle activity of the URA was greater than that of the LRA during the curl-up, Swiss ball curl-up and Swiss ball rollout. This supports previous studies which also reported higher URA activity in curl-up exercises on both stable and labile surfaces (Clark et al., 2003; Whiting et al., 1999; Sarti et al., 1996). However, these findings contradict results from a study that reported minimal differences between URA and LRA activity across variations of curl-ups performed on stable and labile surfaces (Vera-Garcia et al., 2000). One explanation for this discrepancy may be the level of expertise of participants in the respective studies. If participants were familiar with exercising on labile surfaces it may be erroneous to assume that muscle activation will be different to exercise performed on a stable surface. Although there might be greater deviation in muscle activity due to participant’s adjusting their body, the mean activation levels may not be different. Indeed, recent work by Goodman et al. (2008) reported no difference in muscle activation of upper body and trunk muscles during performance of a one repetition maximum lift on a bench compared with a Swiss ball. The findings of Vera-Garcia et al. (2000) and Goodman et al. (2008) are not surprising given that the exercise tasks involved in their research were symmetrical. However, it is unclear whether using asymmetrical loads results in a different pattern of muscle activation on a labile compared with a stable surface. In addition, in the current study URA activity was lower than LRA activity during the jackknife exercise. This finding is not surprising as the jackknife exercise is purported to be an exercise that targets the lower abdominals to a greater extent (Goldenberg and Twist, 2002). One explanation for differing contribution of the URA and LRA across the abdominal exercises in the present study may be as a result of the segmental innervations of the antero-lateral abdominal musculature. The metameric nerve supply from the ventral rami of the lower 6 or 7 thoracic nerves imply the ability to selectively isolate different portions of the RA muscle (Sarti et al., 1996). Another explanation for the findings in the present study could be because the URA and LRA are embryologically distinct, forming from different parts of the embryonic plate (Rizk, 1980). Likewise, as a reflection of this embryological distinction the arrangement of the arterial, venous and lymphatic systems are completely distinct in the upper and lower abdominal walls and functionally the upper abdominal wall is far more involved in power generation and the

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<th>Curl-up</th>
<th>Swiss ball curl-up</th>
<th>Jackknife</th>
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<td>8.3</td>
<td>83.7</td>
<td>15.4</td>
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<tr>
<td>LRA</td>
<td>63.5</td>
<td>10.5</td>
<td>72.6</td>
<td>15.8</td>
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Table 1: EMG activity (% MVIC) recorded from the upper and lower rectus abdominis across abdominal exercises.

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sling mechanisms of the trunk, while the lower wall is more involved in stability of the lumbo-pelvic region.

There are possible limitations to the findings of the present study. The RA is primarily a phasic muscle and as such may have required more than 2 min rest between trials to ensure full recovery. However, the duration of the work completed for each trial was brief and as the objective was to compare URA and LRA it is unlikely that this markedly influenced results. Even so this should be considered by future researchers examining RA activity during various exercises. In addition, participants were instructed to maintain a neutral spinal position during the jackknife and rollout exercises in order to ensure an isometric contraction in the loading phase of the movement. However, in some cases, this may not have been achieved resulting in an eccentric contraction in the loading phase. As muscle recruitment tends to be greater during an eccentric compared with an isometric, this might explain the increased muscle activity values found for the jackknife and rollout compared with the curl-up and Swiss ball curl-up in the present study.

The RA plays a central role in movement and stabilization of the lumbar spine and examination of muscle activity across different exercises may be important in strength and conditioning, physical therapy and rehabilitation. In addition, strong abdominal musculature has been cited as contributing to low back health and improved sports performance (Johnson, 2002). In the current study, all abdominal exercises elicited a response greater than 60% MVIC from both the URA and LRA although muscle activation of the both the URA and LRA was greatest during the jackknife and Swiss ball rollout exercises. Therefore, if increased activation of the RA musculature is the goal of an exercise or rehabilitation programme these exercises may be particularly useful.

References


