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Earlier onsets in internal oblique and gluteus maximus muscles during leg raising in Functional Movement Screen score 3 than score 1

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Active straight leg raising (ASLR) is a fundamental test and used in the Functional Movement Screen (FMS). In the ASLR of the FMS, one subgroup performs the movement correctly without any compensation (ASLR-3), whereas another subgroup has limitations in ASLR but not the passive straight leg raising (ASLR-1-SMCD). We aimed to investigate whether abdominal muscle activities in ASLR are different between individuals with ASLR-1-SMCD and ASLR-3. The relative latency of the onset of the following muscles to the right rectus femoris muscle during the right ASLR and the amplitude of activity in the following muscles for 50 msec after the onset of rectus femoris muscle activity were compared: left rectus abdominal, bilateral external oblique, bilateral internal oblique, and left gluteus maximus muscles. Data of 17 participants with ASLR-3 and 34 participants with ASLR-1-SMCD, whose sex ratio was matched to the ASLR-3 group, were analyzed. Those with ASLR-1-SMCD had statistically significant delays in the relative latency of the right internal oblique muscle (46.32±70.83 msec) and left gluteus maximus muscle (100.36±75.40 msec) muscles compared with those with ASLR-3 (right internal oblique muscle=9.75±23.07 msec, left gluteus maximus muscle=57.50±36.89 msec). However, the difference in the amplitude of activity in any muscles was not significant. The ASLR-1-SMCD group had greater relative latency of the onset of right internal oblique muscle and left gluteus maximus muscle to the onset of the right rectus femoris muscle during the right ASLR compared with the ASLR-3 group.

Keywords: Abdominal, Onset, Muscle activity, Trunk

INTRODUCTION

Active straight leg raising (ASLR) is a common test for the evaluation of multisegmental control in trunks and hips (Bennett et al., 2017). It is included in a valid and reliable system for grading movement competency (Moran et al., 2016; Warren et al., 2018), the Functional Movement Screen (FMS) (Cook, 2010), most commonly used in professional sports (McCall et al., 2014). The ASLR of the FMS has four grades (score 0 for individuals with pain during movements and scores 1–3). Specific criteria for scoring are described in a previous study (Cook et al., 2006). In general, score 3 (ASLR-3) indicates correct execution of movement patterns without any compensation (i.e., good movement competency) (Cook, 2010). Score 1 indicates incomplete execution of the movement patterns (i.e., impaired movement competency) (Cook, 2010). Majority of participants had score 2 (Abraham et al., 2015; Schneiders et al., 2011) (i.e., between score 1 and score 3). Regarding ASLR, scores are decided according to the location of a vertical line through the malleolus of the elevated lower limbs on the remaining lower limb (score 1, below the knee joint line of the remaining lower limb; score 3, above the mid-thigh of the remaining lower limb). Further, score 1 in FMS ASLR is further divided into two subgroups: (a) limitations in both ASLR and passive straight leg raising and (b) limitation in ASLR but not in passive straight leg raising. In the latter case, an underlying mechanism of such limited ASLR is considered to include stability or motor control dysfunction (SMCD) of the trunk and hip muscles (Cook, 2010), known as the ASLR-1-SMCD subgroup.

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Evidences of the common occurrence of motor reorganization in the trunk muscles with a nociceptive input over the back muscle have been increasing (Hodges and Tucker, 2011; Hodges et al., 2013). Further, the onset of relative latency in the abdominal muscles, particularly the transverse abdominal muscle, internal oblique muscle, and rectus abdominal muscle, to the onset of rectus femoris muscle is more delayed in people with low back pain than healthy individuals during a hip flexion task (Hodges and Richardson, 1998). Therefore, the onset of relative latency in the abdominal muscles to the onset in the rectus femoris muscle during ASLR was hypothesized to be different between those with ASLR-1-SMCD and ASLR-3.

Individuals with ASLR-1-SMCD require effective exercises to improve their movement competency. Understanding differences in motor parameters between individuals with ASLR-1-SMCD and ASLR-3 facilitates the identification of important factors for the prescription of optimal exercises to improve ASLR movement competency. The aim of the study was to investigate the differences in motor parameters in the abdominal and hip muscles between those with ASLR-1-SMCD and ASLR-3.

MATERIALS AND METHODS

Design

This cross-sectional study using the surface electromyography (EMG) was approved by the human research ethics committee in the Saitama Prefectural University (No. 30089). Written informed consent was obtained from each participant prior to data collection.

Participants

Using convenience sampling, participants were recruited via advertisements in the Saitama Prefectural University. Inclusion criteria were (a) age of >17 years, (b) no pain in the spine or lower extremities during the previous month, (c) no history of diagnosed spinal deformities or central nervous system disorders, (d) similar ASLR scores of the FMS in both sides of ASLR, and (e) ASLR-1-SMCD or ASLR-3. The ASLR-1-SMCD criteria are as follows: (a) during ASLR, the vertical line at the malleolus of an elevated lower limb resided below the knee joint line of the nonmoving lower limb while the nonmoving lower limb remained in the neutral position, and (b) during passive straight leg raising, the vertical line at the malleolus of an elevated lower limb resided above the knee joint line of the nonmoving lower limb while the nonmoving lower limb remained in the neutral position. Authors certified for FMS level 1 (SK, TW, and HT) selected the participants.

Procedures

Procedures published in a previous study (Takasaki and Okubo, 2020) were used. Participants elevated their right lower limb to their end-range of hip flexion from the relaxed supine lying position while keeping the knee straight when they placed their arms beside the trunk with palms facing up. They were also instructed to elevate the right lower limb to the end-range for 1 sec immediately after they saw the lighting placed in front of their face. The timing of lighting was randomized, ranging from 10–15 sec. They repeated ASLR 17–20 times until at least 10 clear EMG datasets were obtained.

Motion data of the hip were measured using a myoMOTION system (EM-M07, Noraxon, Scottsdale, AZ, USA) with a sampling frequency of 100 Hz, which was synchronized in the EMG system and externally triggered by a light. Inertial Measurement Unit sensors were attached on the pelvis and lateral side of the right thigh. After the EMG data collection during ASLR, the maximum voluntary contraction for each muscle was performed as per standard procedures (Takaki et al., 2016).

Measurements

As per a previous study (Takasaki and Okubo, 2020), primary measures were; (a) relative delay of the onset of following muscles to the onset of the right rectus femoris muscle (relative latency) and (b) amplitude of activity of the following muscles at an early phase of ASLR: left rectus abdominal, bilateral external oblique, bilateral internal oblique, and left gluteus maximus muscles. A reason for the selection of the left side in the rectus abdominal and gluteus maximus muscles was due to the limited number of sensors. The visual detection method with raw EMG data was used to identify the EMG onset of each muscle, with high intersession reliability (Hodges and Bui, 1996). A research assistant randomized the order of EMG data presentation and masked the labels of EMG data during analyses for assessor blinding. An assessor identified the EMG onset using the following criteria: (a) increased EMG amplitude above baseline levels, (b) recruitment of additional motor units, or (c) increased firing rate of active motor units. When the timing of onset was unclear because of overlap with other noises (e.g., electrocardiographic complex) or earlier onsets of muscle activity than a light trigger, all EMG analyses for this trial were not carried out. For the amplitude of muscle activity, the amplitude data during 50 msec after the onset of rectus femoris muscle activity were calculated, considering the potential differences in our pilot testing. The mean of the first 10–15 datasets was used for statistical analyses of both primary measures. Second-

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ary measures included (a) demographics (age, sex, and body mass index) and (b) the time required to reach 95% hip flexion range.

EMG processing

Following the standardized skin preparation as per the SENIAM recommendations, self-adhesive Ag/AgCl electrodes (electrocardiographic electrodes 2009111-150, CareFusion, San Diego, CA, USA) were attached on standardized positions of the left rectus abdominal, bilateral external oblique, bilateral internal oblique, right rectus femoris, and left gluteus maximus muscles with a 20-mm interelectrode distance. For the rectus abdominal muscle, the electrode was placed 4 cm lateral to the navel and vertically with the lower border of the caudal electrode at the navel level (Huebner et al., 2015). For the external oblique muscle, the electrodes were placed over a line extending from the most inferior point of the costal margin to the opposite pubic tubercle, where a lateral electrode was placed 14 cm lateral to the median line and lower than 1-cm level above the umbilicus (Boccia and Rainoldi, 2014). For the internal oblique muscle, a lateral electrode was placed at 2 cm lower than the most prominent point of the anterior spina iliaca superior, and a medical electrode was inclined 6° inferomedially to the horizontal line (Boccia and Rainoldi, 2014). For the rectus femoris muscle, the electrodes were placed at 50% on the line between the anterior spina iliaca superior and superior part of the patella as per the SENIAM recommendations. For the gluteus maximus muscle, the electrodes were placed at 50% on the line between the sacral vertebrae and greater trochanter as per the SENIAM recommendations.

EMG data were measured using a myoMUSCLE system (TELEmyo DTS 580-8M, Noraxon) with a sampling frequency of 1,500 Hz. The amplitude of muscle activity was calculated by reducing the electrocardiographic complex, filtering the EMG data using a 20- to 500-Hz band pass filter (Bennell et al., 2010), and calculating the root mean square using a 100-ms sliding window.

Statistics

IBM SPSS Statistics ver. 21.0 (IBM Co., Armonk, NY, USA) was used for statistical analyses. Descriptive statistics were used to summarize the participants' characteristics. Group differences were compared using the Mann–Whitney *U*-test. The level of α was set at 5%. For primary measures, the effect size *r* was calculated, which was interpreted as small at 0.10, medium at 0.30, and large at 0.50 (Cohen, 1988).

Our pilot testing on 12 individuals with ASLR-1-SMCD and six with ASLR-3 showed potential differences in the relative latency of the right internal oblique muscle. Recruitment of those with ASLR-3 was more difficult than those with ASLR-1-SMCD, and the ratio of recruitment was estimated at 2:1 (ASLR-1-SMCD: ASLR-3). G*Power 3 (Faul et al., 2007) estimated that 34 participants with ASLR-1-SMCD and 17 with ASLR-3 were required to detect a statistical significance in the relative latency of the right internal oblique muscle using two-tailed Mann–Whitney *U*-test, with a normal distribution of $\alpha = 0.05$, $\beta = 0.8$, and effect size of 0.88. No changes in measurement methods were observed from the pilot testing, and thereby, 11 participants with ASLR-3 were added. Subsequently, 22 additional participants with ASLR-1-SMCD, whose sex and age were matched to those in the ASLR-3 group, were recruited.

RESULTS

There were no missing data in the current study. Table 1 presents demographics in each group, showing no statistically significant difference. Table 2 presents the relative latency, where the ASLR-1-SMCD group had statistically significantly greater relative latency than the ASLR-3 group in the right internal oblique muscle and left gluteus maximus muscle. Table 3 presents the amplitude of muscular activity at an early phase of ASLR, where no statistically significant difference ($P > 0.05$) was observed between the two groups.

As *post hoc* analyses, the primary measures of the internal and external oblique muscles were compared between left and right in the ASLR-3 group using the Wilcoxon signed-rank test. Consequently, there were statistically significant differences in all primary measures in the internal oblique muscles (relative latency, $P = 0.013$, $r = 0.60$; amplitude, $P = 0.002$, $r = 0.74$) but there was no difference in any measures in the external oblique muscles (rel-

Table 1. Demographics and secondary outcome measures in the two groups

Variable	ASLR-1-SMCD (n = 34)	ASLR-3 (n = 17)	*P*-value
Age (yr)	20.38 ± 1.78	20.76 ± 0.73	0.856*
Women gender	26 (76.47)	13 (76.47)	-
Body mass index (kg/m^2)	20.92 ± 2.26	20.84 ± 1.19	0.135*
Time for reaching to 95% of the hip flexion range (second)	0.77 ± 0.22	0.77 ± 0.13	0.617*

Values are presented as mean ± standard deviation or number (%).
ASLR-1-SMCD, individuals with score of 1 in the active straight leg raising (ASLR) of the Functional Movement Screen (FMS) who satisfied the criteria of the hip flexion range in the FMS for score 2 during passive straight leg raising; ASLR-3, individuals with score 3 in the ASLR of the FMS.
*The Mann–Whitney *U*-test.

Table 2. Relative latency of the onset of muscles to the onset of rectus femoris muscle during right active straight leg raising

Muscle	ASLR-1-SMCD (n=34)	ASLR-3 (n=17)	*P*-value*	Effect size (*r*)
Left RA	80.75±53.31	77.62±37.80	0.920	0.01
Left EO	50.71±51.78	37.56±30.18	0.603	0.07
Right EO	67.41±48.65	51.01±45.89	0.484	0.10
Left IO	59.70±41.32	43.46±42.77	0.124	0.22
Right IO	46.32±70.83	9.75±23.07	0.044	0.28
Left GM	100.36±75.40	57.50±36.89	0.017	0.33

Values are presented as mean±standard deviation (msec).
ASLR-1-SMCD, individuals with score of 1 in the active straight leg raising (ASLR) of the functional movement screen (FMS) who satisfied the criteria of the hip flexion range in the FMS for score 2 during passive straight leg raising; ASLR-3, individuals with score 3 in the ASLR of the FMS; RA, rectus abdominis; EO, external oblique; IO, internal oblique; GM, gluteus maximus.
*The Mann–Whitney *U*-test.
Positive values indicate delayed onset from the onset of rectus femoris muscle.

Table 3. Amplitude of activity in abdominal and hip muscles for 50 msec after the onset of right rectus femoris muscle activity during right active strait leg raising

Muscle	ASLR-1-SMCD (n=34)	ASLR-3 (n=17)	*P*-value*	Effect size (*r*)
Left RA	3.06±3.31	1.57±1.30	0.055	0.27
Left EO	4.02±3.59	2.57±1.80	0.168	0.19
Right EO	3.18±2.69	3.23±2.01	0.460	0.10
Left IO	2.98±2.08	2.14±0.98	0.101	0.23
Right IO	9.20±16.47	6.18±6.54	0.460	0.10
Left GM	2.82±2.01	4.33±6.59	0.984	0.00

Values are presented as mean±standard deviation (% maximum voluntary contraction).
ASLR-1-SMCD, individuals with score of 1 in the active straight leg raising (ASLR) of the functional movement screen (FMS) who satisfied the criteria of the hip flexion range in the FMS for score 2 during passive straight leg raising; ASLR-3, individuals with score 3 in the ASLR of the FMS; RA, rectus abdominis; EO, external oblique; IO, internal oblique; GM, gluteus maximus.
*The Mann–Whitney *U*-test.

ative latency, $P=0.113$, $r=0.39$; amplitude, $P=0.356$, $r=0.22$).

DISCUSSION

As far as the authors know, this is the first study that compared the motor parameters of the trunk and hip muscles by categorizing the FMS criteria. As we hypothesized, there were differences in the relative latency of the abdominal and hip muscles between individuals with ASLR-1-SMCD and ASLR-3. However, there was no statistically significant difference in the amplitude of the muscular activity at an early phase of ASLR. Theoretically the faster the onset, the greater the amplitude when apparent differences were observed in the motor control of the trunk and hip muscles. Therefore, these findings should be cautiously interpreted. Nevertheless, the delayed relative latency in the right internal oblique muscle and left gluteus maximus muscle in the ASLR-1-SMCD group indicates that exercises that facilitate movement of these muscles may improve ASLR competency in individuals with ASLR-1-SMCD and provide new exercise ideas to clinicians. Clinical trials will be required in the future to investigate effective exercises that reduce the relative latency in the right internal oblique muscle and left gluteus maximus muscle and improve ASLR competency.

The ASLR-3 group had statistically smaller relative latencies of the left gluteus maximus muscle and right internal oblique muscle than the ASLR-1-SMCD group. The gluteus maximus muscle is a monoarticular muscle, which tends to play a role of controlling/stabilizing a joint motion rather than producing a torque to generate a joint motion. Thus, the fast onset of the left gluteus maximus muscle would result in increase of the left hip stability, allowing increased right lower limb mobility. Regarding the group difference in the right internal oblique muscle, activation of the abdominal muscles increasing the intra-abdominal pressure, such as the transversus abdominis muscle, occurs prior to the activation of the rectus femoris muscle during a rapid hip flexion task (Hodges and Richardson, 1998). Onset of the internal oblique muscle using the surface EMG can be influenced by the onset of the transversus abdominis muscle due to the crosstalk between the two muscles (McGill et al., 1996). Therefore, the greater relative latency of the right internal oblique muscle in the ASLR-1-SMCD group than the ASLR-3 group during the right ASLR may indicate suboptimal trunk control in the ASLR-1-SMCD group and far larger difference may be detected in the transversus abdominis muscle using a fine wire EMG.

Interestingly, the *post hoc* analyses in the ASLR-3 group demonstrated that the relative latency was smaller and the amplitude of the muscular activity was greater in the right internal oblique muscle than the left internal oblique muscle. These findings indicate asymmetry in the relative latency of the internal oblique muscle during ASLR. Allison et al. (2008) reported that the feedforward response of the transversus abdominis muscle was specific to the direction of arm movement and not bilaterally symmetrical in a study using rapid arm movement tasks. The asymmetry of the internal oblique muscle found in the current study would correspond with the finding by Allison et al. (2008) by considering the crosstalk between the transversus abdominis and internal oblique muscles in the surface EMG (McGill et al., 1996).

Three limitations were identified in the current study. First, dis-

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criminant validity of the ASLR classification in the FMS cannot be guaranteed because of the lack of samples with score 2. Score 2 has the greatest proportion (43%–67%) (Abraham et al., 2015; Schneiders et al., 2011), and thus, large variability of motor performance is assumed in individuals with score 2. Further, effect sizes in differences between the ASLR-1-SMCD and ASLR-3 groups detected in this study were mostly small to medium. Considering these, a far larger cohort will be required to detect group differences in motor performances among the three ASLR competency levels in the FMS. Second, its generalizability is limited because of limited age variability and uneven sex balance in the study participants. Participants were recruited from a university where there were more female students than male students, and sex balance in the ASLR-3 group was uneven. Finally, the muscles evaluated in this study were limited and only surface EMG data were collected simply because of limited resources for measurements. Therefore, further studies that evaluate other trunk muscles are warranted.

It is necessary for individuals with ASLR-1-SMCD to improve their movement competency. This study demonstrated that one potential underlying mechanism why individuals with ASLR-1-SMCD cannot raise their leg includes motor control deficits in the ipsilateral internal oblique muscle and contralateral gluteus maximus muscle. To fully understand underlying mechanism why individuals with ASLR-1-SMCD cannot raise their leg, we need further studies on other trunk muscles such as extensor muscles and to fully build hypotheses and need to investigate cause-and-effect using randomized controlled trials. However, the current study would be a foundation for future studies to identify optimal exercises to improve ASLR movement competency.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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