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Effects of gender and fatigue on strength and activity of gluteus medius muscle during a controlled cutting maneuver in preadolescent athletes

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A R T I C L E I N F O

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A B S T R A C T

The present study aimed to investigate the effects of gender on hip muscle strength and activity during a controlled cutting maneuver in preadolescent athletes. Fifty-six football and handball preadolescent players participated (35 females and 21 males). Normalized mean activity of the gluteus medius (GM) muscle was measured using surface electromyography during cutting maneuvers in pre-activation and eccentric phases. The stance duration and the strength of hip abductors and external rotators were recorded with a force plate and a handheld dynamometer, respectively. Descriptive statistics and mixed model analysis were used to assess statistical difference ($\alpha = 0.05$). The results showed that boys activate the GM muscle significantly more than girls during the pre-activation phase ($P = 0.022$). Boys also demonstrated greater normalized strength of hip external rotation than girls ($P = 0.038$), but not for hip abduction or duration of stance ($P > 0.05$). When adjusted for abduction strength, however, boys had significantly shorter stance duration than girls ($P = 0.006$). It seems that sex-dependent differences are present in preadolescent athletes as observed in the strength of hip external rotator muscles and neuromuscular activity of the GM muscle during a cutting maneuver. Future studies are needed to investigate whether these changes influence risk of lower limb/ACL injury during sport activities.

1. Introduction

An anterior cruciate ligament (ACL) tear is one of the most important injuries that occurs in open-skill sports (Michaelidis and Koumantakis 2014) with the highest incidence found in younger individuals (Nicholls et al. 2018). Due to the complex and severe nature of the injury and the essential need for stability of the knee joint, ACL injuries usually cause numerous financial (e.g., surgery and rehabilitation) and non-financial costs (e.g., staying away from exercises and competitions) (Mather et al. 2013), as well as future clinical problems (e.g., joint degeneration and early onset of osteoarthritis) (Lohmander et al. 2007). Therefore, awareness of risk factors and efforts to prevent or reduce the occurrence of ACL injury is essential.

Most ACL injuries occur in a non-contact manner, where there is neither body-to-body contact nor a direct blow to the knee joint (Chia et al. 2022). This type of injury commonly happens in landing, jumping, and cutting tasks, where a rapid change occurs in the acceleration and direction of movement (Koga et al. 2010), commonly found in sports such as football and basketball (Hart et al. 2007). For these situations, the following mechanism has been introduced: the hip is medially rotated, the knee is near full extension, the foot is planted with most of the weight on it, and the body is decelerating while the trunk is tilted laterally over the stance leg, causing the body center of mass to shift laterally and induce a valgus collapse of the knee joint (Hewett, Torg, and Boden 2009). More specifically, side-step maneuver is a common movement pattern of ACL injury (Koga et al. 2010). In addition to anterior shear forces of the tibia, hip abduction, knee joint valgus and internal rotation moments are strong contributors of this injury (Kiapour et al. 2016; McLean et al. 2004). Hip abductor muscles control frontal plane joint motion during the performance of a cutting maneuver task (Maniar et al. 2019). During this task, gluteus medius (GM) and piriformis, an external rotator of the hip, are the key muscles opposing the knee valgus moment, as reported in a recent musculoskeletal modeling study (Maniar et al. 2018). Weakness of these muscles can therefore

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cause greater hip adduction or internal rotation movements (Patrek et al. 2011), which may be related with greater knee valgus moment during a side-step task (McLean, Huang, and Van Den Bogert 2005) and contribute to a higher risk of ACL rupture (Khayambashi et al. 2016; Kim et al. 2021). Fatigue of the lower limb muscle groups can induce multiplanar biomechanical changes during functional movements, which may make the knee joint more susceptible to injury (Briem et al. 2017). As ACL rupture mostly occur in a short time-frame after foot–ground (Koga et al. 2015), investigating activities of these muscles in this time-frame seems most relevant for the ACL injury mechanism.

When controlling for exposure, ACL injuries occur more often in women than men (Gornitzky et al. 2016), likely due to risk factors such as environmental, anatomical, hormonal, and biomechanical factors (Harmon and Ireland 2000). In terms of biomechanical differences, numerous studies have shown that there are significant differences between men and women in kinematics (Bruton, O'Dwyer, and Adams 2013; Decker et al. 2003; Jacobs and Mattacola 2005), kinetics (Decker et al. 2003), muscle strength (Jacobs and Mattacola 2005), muscle activity (Hart et al. 2007; Otsuki, Del Bel, and Benoit 2021), and neuromuscular control (Bruton, O'Dwyer, and Adams 2013) of cutting and landing movements. There are, however, some studies where no significant sex-dependent differences were found in muscle activity (Carcia and Martin 2007; Zazulak et al. 2005). Although the prevalence of ACL injury in children and teenagers has gradually increased in the last two decades (Zacharias et al. 2021), sex-dependent differences in children are not well studied. In this regard, Otsuki et al. (2021) in a review study stated that although the prevention of ACL injury in children and adolescents is essential, no sufficient results exist on sex-dependent differences in muscle activity to provide a meaningful conclusion for this population (Otsuki, Del Bel, and Benoit 2021). Furthermore, during and after puberty, the coordination and motor control between the sexes are different (Quatman et al. 2006), and boys increase their muscle strength more than girls (Barber-Westin, Noyes, and Galloway 2006).

In order to elucidate potential differences in neuromuscular mechanisms in childhood, including responses to factors such as fatigue, the present study aimed to investigate the effects of gender and fatigue on strength and activity of GM during a controlled cutting maneuver in preadolescent athletes. If neuromuscular differences between boys and girls are identified, appropriate exercise programs (influencing strength and activation of hip abductor muscles) can be designed to prevent serious knee injuries like ACL rupture.

2. Methods

2.1. Subjects

To calculate proper sample size, power analysis software (G*power) was used and showed that at least 20 subjects for each group are necessary (statistical power = 0.90, effect size = 0.40, and alpha level = 0.05). A total of 56 children (10–12 years old; 21 boys and 35 girls) were recruited to participate in this cross-sectional study. All participants were active players in team sports (handball, soccer, or both) at the time of participation. The subjects had no history of tearing knee ligaments or lower extremity muscles, intra-articular corticosteroid injection in the last three months before testing, neurological or balance impairments, or any orthopedic problems of the lower extremities. The written informed consent was given from the subjects and their guardians before participating in the test procedure. Also, the study was approved by the review board of the National Bioethics Committee (VSNb20112020011/03.7).

2.2. Task procedure

After the subjects came to the laboratory and their physical characteristics (age, height, weight, and length of lower limb) were measured, the warm-up was performed with 5 min of cycling at a moderate intensity on a stationary bicycle (Keiser Power Pacer) (Ghasemi et al. 2023). After skin preparation, surface EMG electrodes were placed over the mid-belly of GM bilaterally according to Seniam guidelines (Hermens et al. 1999). EMG signals were recorded by a wireless 12-channel EMG system (Kine, Hafnarfjörður, Iceland) with the sampling frequency of 1600 Hz. After electrode placement, strength of hip abductors and external rotators was measured during three maximum voluntary isometric contractions (MVIC) for each muscle group (Lafayette Manual Muscle Tester, Model 01163). EMG data were collected for the GM during each hip abductor strength test, for normalization purposes.

A standardized set-up was used for strength testing of hip abductor and external rotator muscles (Martins et al. 2017). Hip abductors were tested in a side-lying position, completing three 5 s tests with 1 min rest between repetitions. After a 5-minute rest period, hip external rotators were tested in the same manner but in a seated position. During the trials, the participants were instructed to use maximal voluntary effort, giving them verbal encouragement (Martins et al. 2017). After MVIC and strength measurement tests, participants performed five successive cutting maneuver tests to each side according to standardized verbal instructions so that they made a game-like cut past a defensive player (a camera tripod with a face on it) placed on the ground behind a force plate (AMTI, Watertown, sampling rate of 2000 Hz). To obtain a valid measurement, the participants had to plant the foot entirely on the force plate before pushing past the defender.

A fatigue protocol for the lower extremities was implemented with the goal of targeting the muscle groups most relevant for the cutting maneuver task, i.e. ankle, knee, and hip joint extensors, and hip abductors (Briem et al. 2017). The task used was deemed likely to achieve exertion for those muscle groups and thereby influence the task performance if fatigue was achieved. A slide board with a slippery and polished surface was used (length: 2.0 m and width: 0.6 m). The distance between two bumpers, located at each end of the board, was adjusted for each participant (1.5 times the total leg length). The participants were asked to maintain a semi-squat position while pushing off the bumpers with the lateral part of the foot and gliding to the other side for five consecutive minutes, while the intensity was increased every minute and ended with an all-out effort for the last minute. The squat position ensured constant lower limb extensor activity while pushing off the bumpers emphasized exertion of the GM. Then, they were asked to rate their fatigue level on a 0–10 numerical rating scale (NRS), where 0 indicated no exertion and 10 to maximum fatigue. After performing the fatigue protocol, the cutting maneuver task was repeated in the same way as before fatigue.

2.3. Data processing

Strength data for hip abductor and external rotator muscles were normalized to body mass for each subject. The EMG signal of GM during the cutting maneuver task was considered from 50 ms before foot–-ground contact or T_0 time, which was identified with the force plate data, to 50 ms after foot–ground contact, representing respectively the pre-activation (-50 ms to T_0) and eccentric (T_0 to + 50 ms) phases (Zebis et al. 2008). For both cutting maneuver and MVIC tests, EMG signals were band-pass filtered (16–500 Hz) using KinePro software, and then filtered with a seventh-order high-pass filter of Butterworth with a cut-off frequency 30 Hz. Then, the signals were processed with the root mean square (RMS) method with a 50 ms time constant. These data were normalized to the highest RMS peak value obtained during the MVIC test and then multiplied by 100, thereby showing muscle activity as a percentage of its highest level (Carcia and Martin 2007). The EMG data were analyzed with an algorithm written in MATLAB software version 2015 and then exported to Microsoft Excel files. The mean activation levels during the pre-activation and eccentric phases were used for statistical analysis.

2.4. Statistical analysis

For statistical analysis, the EMG data were transformed by taking the 4th root of RMS values to adjust for skewness in the data. Parameters were then back transformed for presentations. At first, data normality and variance homogeneity were approved with Shapiro-Wilk and Levene's tests, respectively ($P < 0.05$). Independent t-tests were used to compare demographic data between genders. In addition, mixed-model analysis of variance (ANOVA) for repeated measurements was used to analyze the EMG outcome variables, where time (before and after fatigue) was considered as a within-subject and sex as a between-subject factor, as well as strength as a covariate. Tukey post hoc tests were used to further analyze significant interactions. Pearson correlation coefficient was used to assess the relationship between independent and dependent variables. All statistical tests were completed at the significance level of 0.05 with SAS software.

3. Results

Girls were generally taller and heavier and had a higher body mass index (BMI) than boys ($P < 0.05$), while no significant difference was observed for level of post-exertion fatigue as per NSR values ($P > 0.05$) (Table 1). The results of the present study showed that during the pre-activation phase boys had significantly greater normalized mean activity of GM than girls ($P = 0.022$), while there was no effect of fatigue ($P = 0.699$) or side ($P = 0.630$). No significant interactions were found between gender and fatigue ($P = 0.377$) (Fig. 1). Compared to girls, boys also had greater activity of GM in the eccentric phase, although this did not reach statistical significance ($P = 0.229$). There was no effect of fatigue ($P = 0.852$) or side ($P = 0.187$) and no significant interactions were found between gender and fatigue ($P = 0.565$) (Fig. 1). Normalized strength of hip abductor and external rotator muscles had no significant correlation with normalized mean activity of the GM muscle in the pre-activation and eccentric phases ($P > 0.05$).

No significant difference was observed for normalized strength of hip abductor muscles ($P = 0.980$), while boys demonstrated significantly greater normalized strength of hip external rotator muscles compared to girls ($P = 0.038$) (Fig. 2).

Stance duration was not significantly different between the sexes ($P = 0.109$) or between before and after fatigue ($P = 0.125$), and the interaction between sex and fatigue was nonsignificant ($P = 0.990$). However, when adjusted by adding weight as a covariant in the statistical models, strength of hip abductor and external rotator muscles had a significant negative correlation with stance duration ($P = 0.022$ and $P = 0.001$, respectively). When adjusted for weight and strength of hip abductor (but not for hip external rotator) muscles, boys showed significantly shorter stance duration than girls ($P = 0.006$) (Fig. 3).

4. Discussion

The aim of the present study was to investigate the effects of gender and fatigue on strength and activity of the GM muscle during a controlled cutting maneuver in preadolescent athletes.

The result of the present study showed that boys have significantly greater normalized mean activity of GM in the pre-activation phase than girls ($P < 0.05$). These results are consistent with the study of Zazulak et al. (2005), who reported lower but non-significant GM activation in collegiate females than males in the pre-activation phase of single-leg landing (Zazulak et al. 2005). In contrast, Carcia and Martin (2007) and Hanson et al. (2008), both reported no significant difference in GM activity between genders during the pre-activation phase of drop-jump or side-step cutting tasks (Carcia and Martin 2007; Hanson et al. 2008). These controversial results are probably related to the task protocol (drop-jump and side-step cutting vs. cutting maneuver), conducting the method of task (e.g., standardized approach speed and cutting angle), the duration of pre-activation phase (200 ms vs. 50 ms), and the difference in sample size (16 and 32 vs. 56 subjects), subjects' age (young versus pre-puberty), and various EMG signal processing methods. Generally, a cutting maneuver in game-like situations is often performed in a short time and is sometimes unanticipated, leaving athletes little time for posture correction and the control of excessive movements and loads. During such tasks, proper muscle pre-activation may be effective for ACL injury prevention (de Britto et al. 2014; McLean, Huang, and Van Den Bogert 2005). Therefore, it seems that the higher activity level of GM in the pre-activation phase seen in boys can play a role in lowering risk of ACL injury during a cutting maneuver movement.

Although not statistically significant, the present study showed a slightly greater normalized mean activity of GM muscle during the eccentric phase in boys compared to girls (47% vs. 42% for overall conditions). These results are consistent with the study of Hart et al. (2007), who showed significantly higher activation levels of GM for males compared to females during a forward single-leg jump landing (Hart et al. 2007). In contrast, Carcia and Martin (2007), found no significant difference in GM activity between genders in the eccentric phase of the drop-jump task (Carcia and Martin 2007). These controversial results are probably related to the task protocol (drop-jump vs. cutting maneuver), the duration of the eccentric phase (250 ms vs. 50 ms), and the difference in sample size (20 vs. 56 subjects) and subjects' age (young versus pre-puberty). The GM muscle has an important role in creating internal rotation and abduction moments of the hip joint (Patrek et al. 2011), thereby having opposing effects on the mechanics related to ACL injury (Kim et al. 2021; Lessi et al. 2017). Also, the GM has the highest capacity to oppose the knee valgus moment during the eccentric phase of a cutting maneuver task (Maniar et al. 2018). Therefore, it is assumed that the higher contraction level of GM in the eccentric phase in boys can prevent excessive hip adduction movement and decrease the risk of ACL injury, although future studies with kinematic data are needed to prove this hypothesis.

Greater normalized strength of hip external rotator muscles, but not hip abductor muscles, was found in boys compared to girls ($P < 0.05$). The significance of this is unclear as well as the implications for dynamic movements such as cutting, especially as the test position of external rotators (seated with hip close to 90° flexion) is very different from the more extended position during cutting. McKay et al. (2017) applied the same tests and observed that teenage boys had greater isometric strength of hip external rotator and abductor muscles than girls (McKay et al. 2017). Furthermore, decreased muscle strength of hip external rotators and abductors has been implicated in ACL injuries in both boys and girls (Khayambashi et al. 2016). Therefore, it seems that strengthening the hip muscles during pre-puberty can be beneficial and reduce the risk of ACL injury.

In addition, increased strength and decreased body weight resulted shorter stance duration; thus, boys had shorter stance duration than girls when stance duration was adjusted to weight and hip abduction muscle strength ($P < 0.05$). Shorter stance duration can also represent higher velocity of performance (Kimura and Sakurai 2013). This data correlates well with the results of this study as hip strength had a significant effect on the stance duration, showing that stronger individuals can receive higher loads during cutting maneuvers and can therefore perform the activity faster. However, the optimal balance between performance and

Table 1
Mean (SD) values of demographic characteristics and NSR values between girls and boys.

Variable	Girls	Boys	P-value
Height (cm)	151.7 ± 7.1*	146.7 ± 7.3*	0.014
Weight (kg)	45.2 ± 12.8*	36.8 ± 6.9*	0.008
BMI (kg.m^2)	19.4 ± 4.2*	17.0 ± 2.0*	0.017
NRS (0–10)	6.8 ± 1.7	7.3 ± 1.9	0.419

The sign * shows the significant difference between genders ($P < 0.05$).

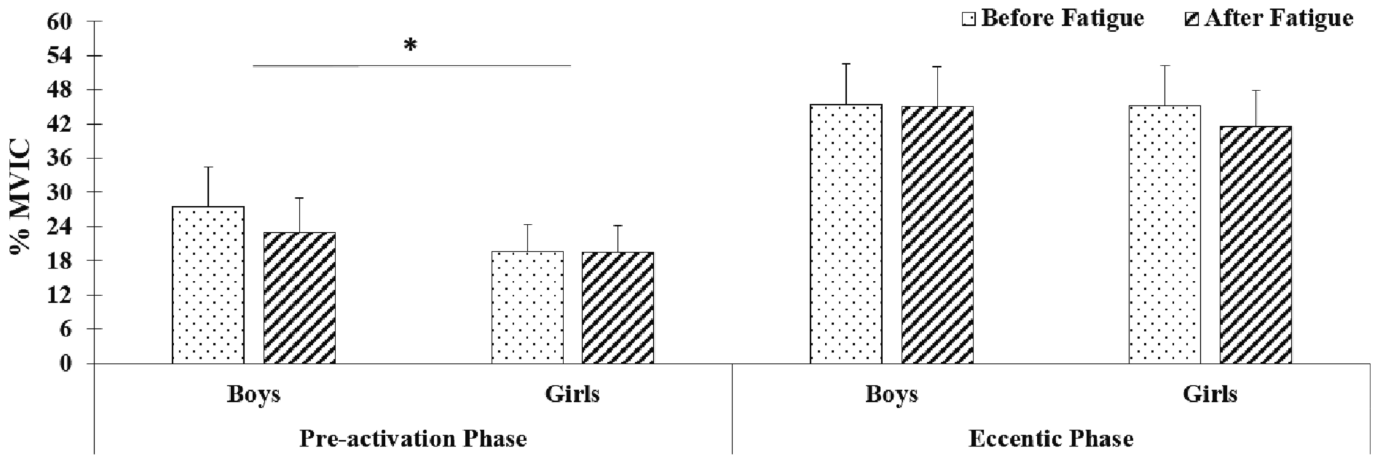

Fig. 1. Normalized mean activity of the gluteus medius muscle in the pre-activation and eccentric phases for both genders before and after fatigue protocol during a cutting maneuver (the sign * shows the significant difference between genders).

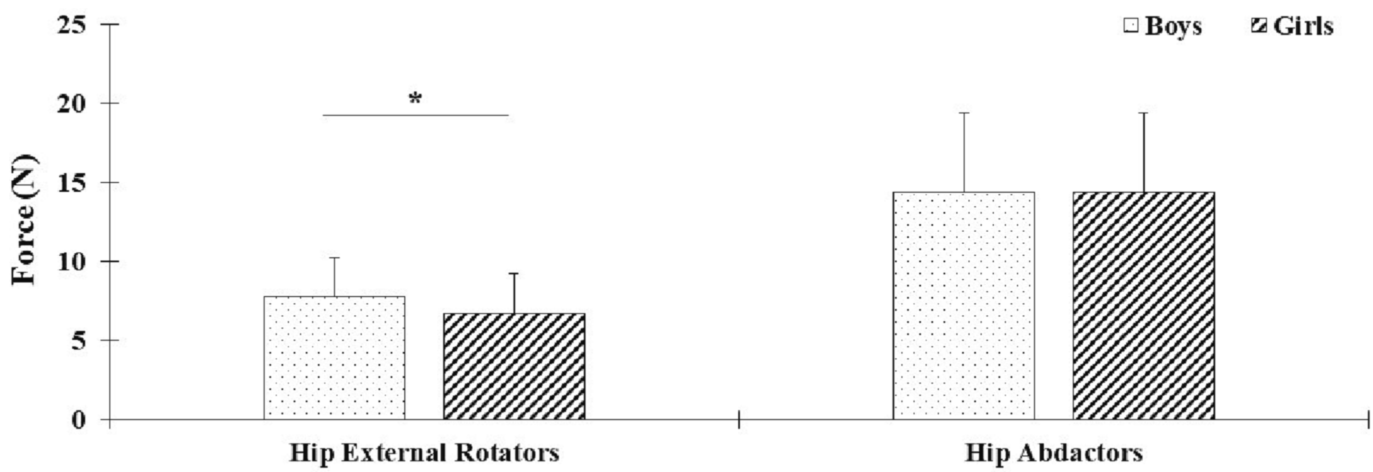

Fig. 2. Normalized strength of hip external rotator and abductor muscles for both genders (the sign * shows the significant difference between genders).

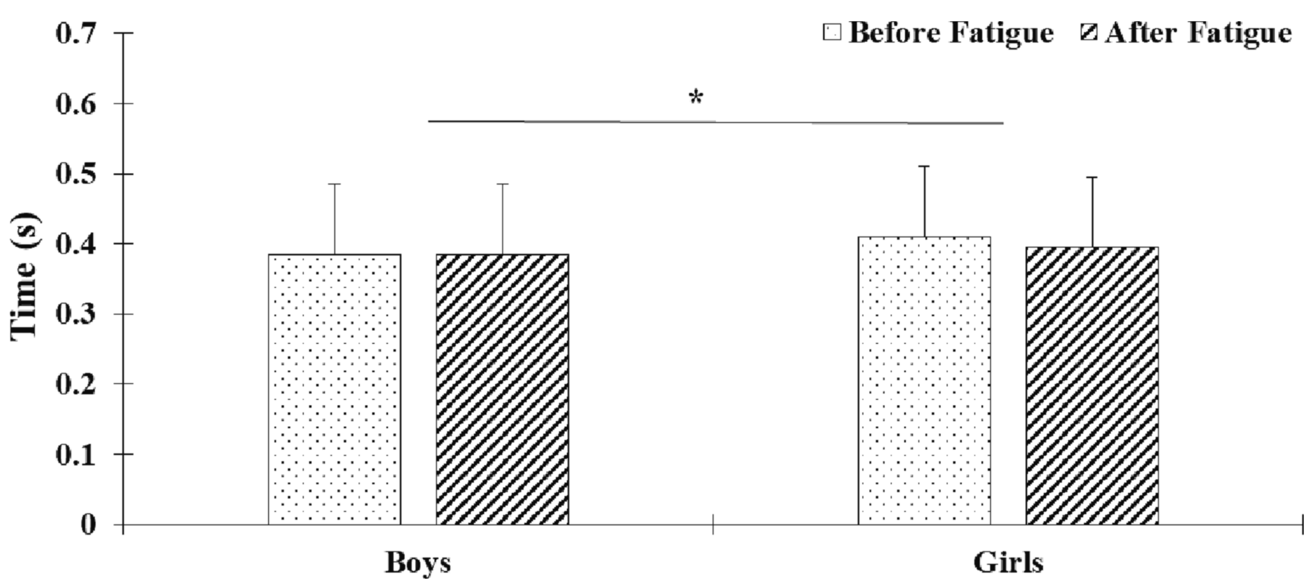

Fig. 3. Adjusted stance duration for both genders before and after fatigue (the sign * shows the significant difference between genders).

injury risk regarding velocity is unknown and is probably individualized based on neuromuscular ability and physical capacity. Future studies are needed to examine this issue more closely and its association with common knee injuries.

Interestingly, the fatigue protocol used in the current study had no effect on any GM variables, which may be related to the setup and execution of the fatigue protocol. During the sliding board performance, participants remained in a semi-squat position and pushed off the bumpers, which incorporates many lower extremity muscles other than hip abductors; thus, it is plausible that the movement was performed primarily by bigger and stronger muscles rather than hip abductors. As puberty involves physical, biomechanical, and neuromuscular changes (Barber-Westin, Noyes, and Galloway 2006; Quatman et al. 2006), it may be inferred from our results that sex-dependent differences, related to muscle strength and GM activation during the cutting maneuver task, start to develop in the pre-puberty age. Therefore, improving muscle strength and activation of hip muscles prior to puberty should be considered to lessen risk of injury.

5. Limitations

The fatigue protocol used in this study could be more specific to the GM and its intensity was subject-dependent. Also, future studies are needed to identify gender differences during pre-puberty ages on the kinematic and kinetic aspects of a cutting maneuver task. Additionally, prospective studies are needed to clarify the association of muscle strength and activation and incidence of later knee injury and better identify the mechanism and risk factors for preventing ACL injury.

Although SENIAM guidelines were followed some movement of the muscle under the skin is expected. However, it is unlikely that electrode placement would reach the innervation zone and any variability due to movement would occur in a random manner across all participants and therefore hardly affect the results. The cutting maneuver was performed from an ‘at-ready’ position and therefore does not replicate a running-based change of direction test.

Additionally, due to the nature of the measurements (involving markers, electromyography, force plates), the data may not represent that which occurs during real life sports competition, which is a limitation of all motion analysis research. The best we could do was to provide a dummy opponent and encourage the participants to use explosive movements as if they were cutting past the opponent during actual play.

6. Financial disclosure statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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