



The influence of gender on neuromuscular pre-activity during side-cutting

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ABSTRACT

It is well established that female athletes are at increased risk for sustaining ACL injuries in sports, where sudden changes of direction are a frequent movement pattern. The underlying neuromuscular mechanisms related to the elevated ACL injury rate in female athletes has yet to be fully investigated. This cross-sectional study aimed to examine gender differences in neuromuscular pre-activity during a maneuver that mimics a movement associated with the incidence of ACL injuries. Twenty-four team handball players (12 male and 12 female) with no history of ACL injury were tested for EMG pre-activity of vastus lateralis, vastus medialis, semitendinosus, and biceps femoris during a side-cutting maneuver. Mean EMG amplitude 50 ms prior to toe down was normalized to maximal EMG obtained during maximal isometric contraction.

The results showed that females had significantly lower hamstring EMG pre-activity 50 ms prior to toe-down than males ($P < 0.01$). No gender difference was present in quadriceps EMG pre-activity during side-cutting.

Lower hamstring activation prior to toe-down may result in lower hamstring contraction force during the initial part of the ground contact, and thus lesser knee joint stability compared to males. Specific training should be employed to alter the neuromuscular coordination towards a more stabilizing motor pattern.

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1. Introduction

Identification of risk factors that predispose female athletes for ACL injury has high clinical relevance. Epidemiological studies have shown that females – participating in sports – are 2–8 times more prone to ACL injuries than males (Arendt and Dick, 1995; Roos et al., 1995; Myklebust et al., 1997; Bjordal et al., 1997; Micheli et al., 1999). Approximately 70% of all ACL injuries occur in so called non-contact situations where physical contact with another player or direct blow to the knee is absent (Noyes et al., 1983; Strand et al., 1990). This indicates that assessment of biomechanics and neuromuscular strategies during high-risk situations between genders is important in identifying risk factors that predispose the female athlete for non-contact ACL injury. Thus, the role of gender – and gender-related neuromuscular strategy – in non-contact ACL injury has been the focus of extensive research in the past years.

The injury mechanism of an ACL injury in side-cutting movements appears to be a forceful valgus collapse with the knee close to full extension combined with external or internal rotation of the tibia (Olsen et al., 2004). Co-contraction of the hamstring muscles potentially lower the stress on the ACL imposed by strong quadri-

ceps contraction (Solomonow et al., 1987; Baratta et al., 1988), as the hamstrings works as antagonists to the anterior pull of the tibia, and to the external and internal rotation (Li et al., 1999). Thus, adequate co-contraction of the hamstring muscles during explosive and forceful movements is extremely important for dynamic knee joint stabilization.

Dynamic assessment for neuromuscular control by electromyography (EMG) has been shown to be an important indicator in determining joint stability during functional tasks (McKinley and Pedotti, 1992; Ebige et al., 1997). Both preparatory and reactive muscle activity assist in regulating muscular stiffness (Grillner, 1972), and increased muscular stiffness provides greater joint stability and protection against joint injury (Riemann and Lephart, 2002). A recent study showed that the timing of non-contact ACL injury ranges from 17 to 50 ms after initial ground contact (Krosshaug et al., 2007), leaving no time for mechanosensory feedback mechanisms to prevent injury. The extremely short periods of time that individuals have to react to forces during functional activity, indicates that preparatory muscle activity – i.e. EMG pre-activity – plays a much larger role in maintaining dynamic joint stability than the reactive activity (Dyhre-Poulsen and Laursen, 1984; Gollhofer and Kyrolainen, 1991; Wikstrom et al., 2006). Thus, during fast movements like the side-cutting maneuver, substantial neural preactivation of the knee flexor muscles just before ground contact seems essential (Zebis et al., 2009).

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Studies on gender differences in muscular activation during jumping or cutting activities have shown a tendency to higher activation of quadriceps and lower activation of hamstrings in females compared to males (Malinzak et al., 2001; Urabe et al., 2005; Sigward and Powers, 2006; Chappell et al., 2007). These studies did not report pre-activity patterns for the examined muscles. However, in a study by Hanson et al. (2008) more quadriceps pre-activity and a larger quadriceps-to-hamstring activation were found in female than male soccer players during a standardized side-cutting maneuver (Hanson et al., 2008).

In team handball, the highest frequency of ACL-injuries is seen during non-contact side-cutting movements (Strand et al., 1990; Myklebust et al., 1998; Olsen et al., 2004). The side-cutting maneuver in handball is usually very abrupt and explosive with a high angle of change of direction, and is a technical movement acquired through many hours of practise. The side-cut in handball may therefore be different from side-cutting maneuvers seen in other sports, and it is a movement with a high degree of biomechanical and neuromuscular reproducibility (Bencke et al., 2000; Zebis et al., 2008). Unlike side-cutting movements performed in laboratories, where the movement is restricted to specific pre-defined degrees of cutting angle, a side-cut movement with no restrictions – performed as the player would do during real match play – may to a greater extent resemble the specific motor program developed through years of practice.

The purpose of the present study is to examine potential gender differences in muscular preactivation pattern in team handball players during the execution of a subject-specific handball side-cutting maneuver. We hypothesize that females display lower hamstring pre-activity compared to male handball players. Further, we hypothesize that females display higher quadriceps pre-activity compared to male handball players.

2. Methods

2.1. Subjects

A cross-sectional study was performed in Copenhagen, Denmark. Twelve female and twelve male team handball players, with no previous history of knee injury, were recruited from the second best division of Danish National Team Handball League. Subject demographics are detailed in Table 1. The players were fully informed of all experimental procedures and risks before giving their written informed consent to participate. The study conforms to the code of ethics of the Declaration of Helsinki and was approved by the Local Ethics Committee. Informed consent was obtained from all players before testing.

2.2. Electromyography

Bipolar surface electrodes (Medicotest A-10-N, Ag/AgCl electrodes) were placed 2 cm apart over the following four leg muscles all acting over the knee joint: m. vastus medialis (VM), m. vastus lateralis (VL), m. biceps femoris caput longum (BF), and m. semitendinosus (ST). The electrodes were placed over the middle part

of the muscle belly according to standardized procedures (Hermens et al., 2000).

The EMG signals were recorded by use of telemetric equipment with a frequency response of 10 Hz–1.5 kHz (Medinic IC-600-C). To permit the subjects to move freely and to prevent movement artifacts, transmitters and wires were tightly strapped to the skin with tape and elastic bandage.

2.3. Sampling procedure

An analogue-to-digital converter (Data translation DT2801-A) operating at 1000 Hz sampling rate was used to collect the EMG and force plate data (AMTI LG6-4). A pre-trigger function with a sensitivity of 28 N was used to initiate the sampling 500 ms before toe-down on the force platform. The total sweep duration was one second.

Additionally maximal EMG for each of the four muscles was measured during a maximal voluntary contraction (MVC) in a Darcus dynamometer (Darcus, 1953). Each subject performed three consecutive MVCs for each muscle group with 2 min pause between trials.

2.4. Test procedure

To standardize the test procedure the subjects were instructed to take only one step forward on the preferred cutting leg before they performed the handball specific side-cutting on the force platform. Ten consecutive trials were recorded for each subject with a 45 s pause between the trials. The subjects were allowed to perform a number of warm-up trials to get accustomed to the experimental conditions.

2.5. Side-cutting maneuver

The purpose of the side-cutting maneuver is to fake the defense player in one direction, and then cut in the other direction. The efficiency is not judged by the speed of the movement but rather on the translation of the body from the starting position and to the side over the planted leg and then explosively in the opposite direction. The movement could thus be considered a qualitative movement, rather than a quantitative movement, however with an explosive push off phase. The EMG activity during a side-cutting maneuver has been shown to be highly reproducible in athletes (Zebis et al., 2008), implying a highly consistent motor program.

2.6. Data treatment

All EMG-recordings were highpass filtered at 20 Hz, and rectified and lowpass filtered at 10 Hz (fourth order Butterworth digital filters with zero phase lag). The EMG-signals from 10 trials of each subject recorded during the side-step cutting were normalized to the MVC EMGs. The highest mean amplitude during an interval of 500 ms of the rectified and filtered MVC EMGs was selected for normalization. The mean EMG amplitude during the last 50 ms prior to toe-down was calculated for all muscles – i.e. VL, VM, BF and ST – and normalized to the MVC EMG of the respective muscles examined. *Neuromuscular pre-activity* refers to the normalized EMG 50 ms prior to toe-down. A hamstring-to-quadriceps pre-activity ratio was calculated by dividing the sum of the medial and lateral hamstring pre-activity by the sum of the medial and lateral quadriceps activity.

2.7. Statistics

Before the main analyses Shapiro–Wilk testing for normality was performed. All parameters were normally distributed and with

Table 1
Mean (SD) of baseline characteristics.

	Males	Females	P-value
Age (years)	23.1 (3.4)	22.7 (3.1)	0.755
Height (cm)	183.1 (4.8)	172.4 (5.4)	0.000
Weight (kg)	80.9 (7.1)	66.6 (7.5)	0.000
Experience (years)	13.8 (4.2)	14.7 (3.6)	0.572
MVC hamstring (Nm/kg)	1.5 (0.2)	1.5 (0.2)	0.382
MVC quadriceps (Nm/kg)	3.1 (0.4)	2.9 (0.6)	0.336

equal variance, and thus all data were investigated for differences between gender with student's *t*-tests for independent samples.

A priori power analysis showed that 24 subjects in a cross-sectional study design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 15% with an alpha level of 5% (Zebis et al., 2008).

To guard against mass-significance, we used a Bonferroni correction. We wanted the overall probability of a false positive finding to be less than 5%. Each of the two hypotheses – i.e. “lower hamstring pre-activity in female players” and “higher quadriceps pre-activity in female players” was therefore tested at the significance level 2.5%. Results are reported as group means $\pm$ SD.

3. Results

3.1. Hamstring pre-activity

Females displayed lower neuromuscular pre-activity of the ST ($33 \pm 12\%$ vs. $46 \pm 14\%$; $P < .01$) and BF ($30 \pm 10\%$ vs. $52 \pm 22\%$; $P < .01$) during side-cutting compared with males (Fig. 1A and B).

3.2. Quadriceps pre-activity

No significant difference between male and female players was observed for any of the quadriceps muscles examined. In average, neuromuscular pre-activity of the VM and VL was $61 \pm 25\%$ and

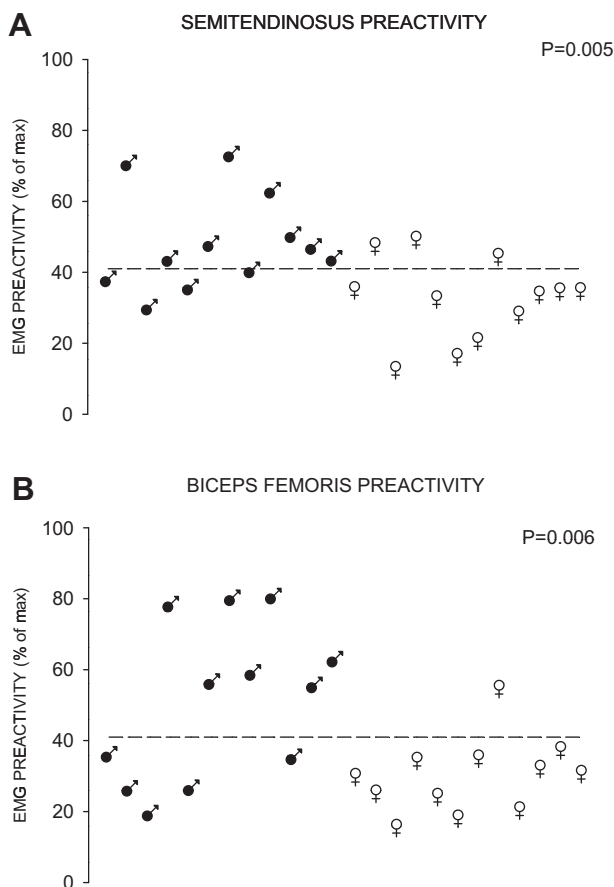


Fig. 1. Electromyography (EMG) pre-activity during side-cutting recorded for the semitendinosus (A) and biceps femoris (B). ♂: Male players. ♀: Female players. Dashed line indicates overall mean. The *P* value shows the significant difference level between the 2 groups.

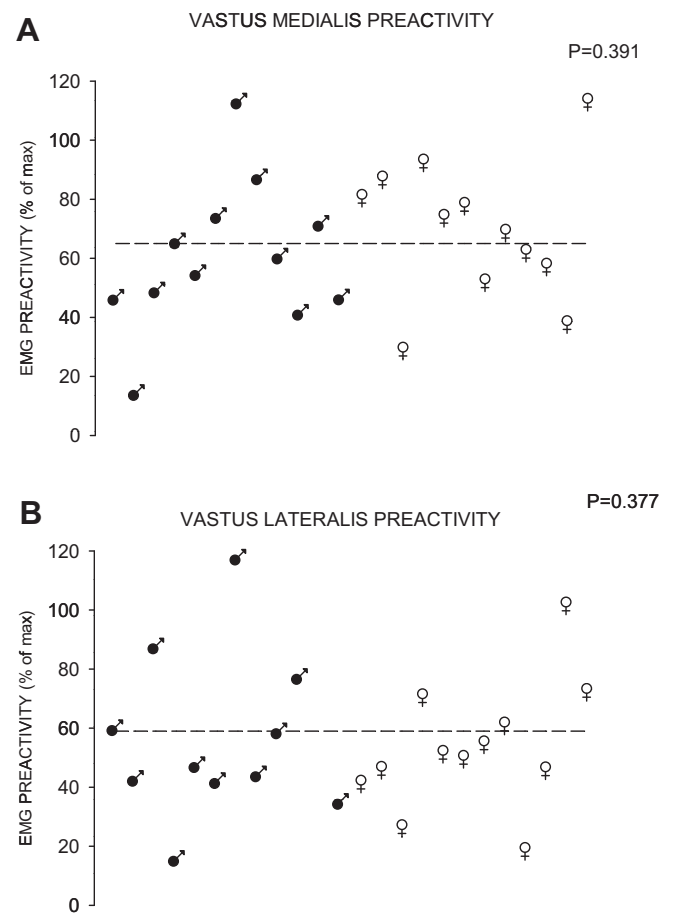


Fig. 2. Electromyography (EMG) pre-activity during side-cutting recorded for the vastus medialis (A) and vastus lateralis (B). ♂: Male players. ♀: Female players. Dashed line indicates overall mean. The *P* value shows the significant difference level between the 2 groups.

$64 \pm 36\%$, respectively, for the males and $69 \pm 24\%$ and $53 \pm 22\%$, respectively, for the females, (Fig. 2A and B).

3.3. Hamstring/quadriceps pre-activity ratio

Females displayed lower hamstring-to-quadriceps pre-activity ratio (0.52 ± 0.13 vs. 0.91 ± 0.42 ; $P < .01$) during side-cutting compared with males (Fig. 3).

4. Discussion

The main finding of the present study is that female team handball players display significantly lower hamstring EMG activity in the preactivation period during side-cutting than their male counterparts. On the other hand we did not observe any gender differences in neuromuscular pre-activity of the quadriceps.

The lower neuromuscular pre-activity of the hamstrings among females in the present study, support the notion that female athletes display different neuromuscular strategy in situations where ACL injuries occur. If the knee is subjected to rotational moments and in valgus position during side-step cutting, as studies indicate (Cross et al., 1989; Ebstrup and Bojsen-Moller, 2000; Besier et al., 2001a,b), then hamstring activation may be crucial for preventing a damaging strain of the ACL. It is not known if knee joint angles are different between genders in the handball side-step maneuver. In contrast to the running side-cutting maneuver seen in most studies, the technique of the handball side-step maneuver is

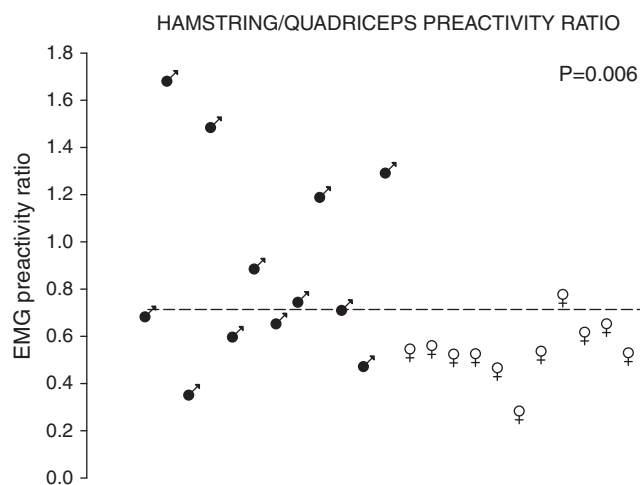


Fig. 3. Electromyography (EMG) hamstring-to-quadriceps pre-activity ratio during side-cutting. ♂: Male players. ♀: Female players. Dashed line indicates overall mean. The *P* value shows the significant difference level between the 2 groups.

practiced for many years. This could result in less gender differences, but existing studies on side-cutting show, that women produce smaller knee flexion angles and greater valgus moments during jumping and side-cutting than males (Malinzak et al., 2001; Ford et al., 2003; McLean et al., 2004), and this may increase the importance of hamstring activation for women. Before explosive movements like jumping, landing, running, and cutting the involved lower limb muscles are innervated before ground contact in order to build up necessary force before the impact, and in consideration to the electromechanical delay (EMD) (Viitasalo and Bosco, 1982; Dyhre-Poulsen and Laursen, 1984; Aura and Komi, 1986; Gollhofer and Kyrolainen, 1991). Recent studies have shown hamstring EMDs of approximately 100 ms (Ristanis et al., 2009; Troy Blackburn et al., 2009), but no differences between males and females were observed (Troy Blackburn et al., 2009). Thus, lower hamstring activation found during 50 ms prior to initial ground contact in this study indicates lower hamstring force in the first part of ground contact for the female subjects. As ACL injuries are reported to occur during the initial phase of ground contact (Krosshaug et al., 2007), the lower hamstring activation may reduce the potential for protection of the ACL in the female athletes. Furthermore, the hamstrings have been shown to contract concentrically during the initial part of the ground contact during side-step cutting, and thus the hamstrings may not be able to produce the same force with the given neural activation as if they were contracting isometrically or eccentric during the initial ground contact (Simonsen et al., 2000). The results of the present study underline the necessity to perform specific training that induce better activation of the hamstrings during initial ground contact as seen in previous studies (Zebis et al., 2008; Wilderman et al., 2009).

As in the present study, several electromyographical studies have evaluated gender differences during movements associated with the incidence of ACL injuries (Malinzak et al., 2001; Myer et al., 2005; Sigward and Powers, 2006; Chappell et al., 2007; Landry et al., 2007, 2009; Nagano et al., 2007; Hanson et al., 2008). It has been found that females exhibit greater quadriceps EMG activity during vertical stop-jump tasks (Chappell et al., 2007) and side-cutting maneuvers (Sigward and Powers, 2006; Hanson et al., 2008). Thus, a generally accepted theory is that female athletes are 'quadriceps dominant' compared to male athletes in high ACL risk positions (Hewett et al., 2005). In the present study, we were not able to confirm this finding. However, it should be recognized that differences in EMG parameters examined and specific move-

ment tasks – as well as subjects – tested may explain the discrepancy observed.

Although EMG is a widely used screening tool, there are certain limitations associated with this method. Thus, the EMG amplitude varies between individuals because of differences in skin conductance, thickness of subcutaneous fat, muscle fiber pennation angle, and muscle fiber size. Nevertheless, the present method of normalized EMG mean pre-activity amplitude during side-cutting has previously been shown to result in a highly reproducible EMG pattern (Zebis et al., 2008) and to identify female athletes at increased risk for future ACL ruptures (Zebis et al., 2009). Another limitation may be that performing the movement in a laboratory may be different from performing in a match-situation, where more movements are expected to be unanticipated. It is not known to what extent the pre-programming of this movement may be altered if the movement is unanticipated. Previous studies have reported increased knee loading when performing unanticipated side-step cutting (Besier et al., 2001a,b). However, in this study males and females are compared under the same conditions, and inducing changes in the time to prepare the movement may induce similar changes in both genders.

In conclusion, the hamstring EMG pre-activity during side-cutting was lower in female compared to male team handball players. Lack of sufficient hamstring contraction force during the initial ground contact may increase the risk of ACL-injury during side-step cutting in female team handball.

5. Perspectives

The reduced hamstring pre-activity found in female team handball players in the present study emphasizes the importance of training programs – implemented in the traditional training sessions – that alter the neuromuscular control during high-risk situations (Myklebust et al., 2003; Zebis et al., 2008).

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