ARE THIGH MUSCLE ACTIVATION PATTERNS DURING DROP JUMPS DEPENDENT ON SEX AND FATIGUE? A PILOT STUDY IN COMPETITIVE SOCCER PLAYERS

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The purpose of this study was to identify whether sex- and fatigue-dependent effects occur in the muscle activation patterns during drop jump. Therefore 12 (5 female, 7 male) competitive soccer players performed five drop jumps (DJs) in rested and fatigued state. Lactate, maximum knee flexion angle and the quadriceps to hamstring muscle activation ratio (QH_{GRF} ratio) were compared via a repeated- measures MANOVA and effect sizes were used for interpretation. In the fatigued state jump height and maximum knee flexion angles were reduced (large effect) and the left limb showed an non-significant medium effect towards an increased QH_{GRF} ratio. Additionally, a sex-specific medium effect of the QH_{GRF} ratio of the left limb indicates a higher QH_{GRF} ratio for males than. The indicates a tendency towards a quadriceps-dominant landing strategy at least in one limb

KEYWORDS: knee injury, injury prevention, screening test, biomechanics, football.

INTRODUCTION: The muscle activation patterns of the quadriceps and hamstring muscles play an important role in leg stabilization and anterior cruciate ligament (ACL) stress (Bencke & Zebis, 2011). In this context, assessing the quadriceps-to-hamstring-activation ratio at the maximum vertical ground reaction force (QH_{GRF}) under high and dynamic loading, such as during a drop jump (DJ) has been suggested to provide information about a predisposition to knee overuse complaints (Ellenberger et al., 2021). The authors found a significantly higher QH_{GRF} in male athletes than in female athletes. Ford, Myer, and Hewett (2003) assumed that women might choose a ligament-dominated landing strategy, whereas men might use a more active landing strategy using quadriceps dominance. If this is the case, it should also be visible in the QH_{GRF} ratio. In ligament dominance, muscles of the posterior kinetic chain are not sufficiently activated to absorb the GRFs; therefore, passive structures such as the ligaments are required for further absorption. In quadriceps dominance, knee stability is reached by knee extension and stiffening, which increases quadriceps muscle activation. This activation of the quadriceps muscles causes an anterior displacement of the tibia relative to the femur, which results in elevated stress on the ACL (Hewett, Ford, Hoogenboom, & Myer, 2010; Urabe et al., 2005).
Muscular fatigue has been shown to alter neuromuscular control patterns, which may increase the risk of noncontact ACL injury in soccer players (Alentorn-Geli et al., 2009). Under fatigued conditions, a stiffer landing position is adopted, resulting in a reduced knee and trunk flexion angle. Consequently, less energy is absorbed by knee flexion during landing, and the vertical GRF is increased (Wong, Huang, & Chen, 2020); both aspects are associated with a higher risk of ACL injury (Leppanen et al., 2017). Additionally, decreased trunk flexion during landing has been shown to result in increased quadriceps muscle activation and landing forces, which

again elevate ACL loading (Blackburn & Padua, 2009). Additionally, such fatigue dependent effects should theoretically be reflected in an increased QH_{GRF} ratio.
Although injuries typically occur later in e.g a soccer game, screening test, such as the DJ, are usually performed in rested states, and little is known about sex-specific and fatigue-dependent muscle activation patterns.
Therefore, the purpose of this study was to investigate the QH_{GRF} ratio in female and male soccer players in rested and fatigued states. This may provide further insight into whether including fatigue in DJ testing provides further information about potential risks for ACL injury.

METHODS: Twelve female and male soccer players competing at the regional and national levels (♀: n=5, 22±1.1 years, 178±6.5 cm; ♂: n=7, 21.9±3.7 years, 182 ±6.9 cm) performed five DJs before and after a fatigue protocol (Fidai et al., 2020). Prior a warm-up and maximal voluntary contraction (MVC) trials were performed. For the DJs the athletes were instructed to keep hands akimbo, drop off a 32.6-cm-high box onto in the floor embedded force plates and jump as high as possible with minimal ground contact time. The fatigue protocol was slightly adapted to that of an earlier study (Fidai et al., 2020). It consisted of repeated circuits, where each circuit included 5 exercises (jumping jacks (60 s), jump squats with 180° jump turn (30 s), alternating lunges (60 s), side lunges (60 s), sumo squats (30 s)) with 60 s rest between each circuit round. The circuit was repeated until participants reported after the 4th circuit the same perceived exertion (VAS) as for the previous circuit or a value of 8. The level of fatigue was controlled by lactate measurements (Lactate Scout 4, EKF Diagnostics, SensLab GmbH, Leipzig, Germany) at rest and immediately after performing the fatigue protocol.
A motion capture system (Vicon, Oxford, UK) using 14 infrared cameras synchronously collected the data of reflective markers, EMG sensors (Myon AG, Schwarzenberg, Switzerland) and GRF via two force plates (40x60 cm, Kistler 9260AA6, Kistler Holding AG). The maximal knee flexion angle for the contact phase of the DJ was calculated using the Cleveland Clinical Marker set and the respective calculation routines implemented in Vicon Nexus 2.12. Jump height was determined by the vertical difference of the sacrum marker between take-off and maximum vertical marker position. Based on the measured GRFs, the ground contact phases (threshold: 20 N) and the timepoint of maximal vertical force were determined. Thigh muscular activation patterns were assessed by the use of 8 EMG sensors attached to the left and right m. vastus lateralis (vl), m. vastus medialis (vm), m. semitendinosus (st), and m. biceps femoris (bf) muscles. Kinematic data were collected at 200 Hz, and EMG and GRF data were collected at 2000 Hz.
EMG data processing was performed in MATLAB (MATLAB R2020b, The MathWorks, Inc., Natrick, MA). The raw EMG signals were filtered with a 4th order bandpass filter (20 - 500 Hz) and smoothed by a root mean square approach with a time period of 30 ms. EMG activation was normalized to the respective MVC trial. The QH_{GRF} was calculated for each limb as the sum of vl and vm divided by the sum of bf and st at the timepoint of maximal GRF. For each trial, the identified parameters were computed and averaged for the rested and fatigued conditions.
The statistical analysis was performed using SPSS. For the parameters lactate, jump height, maximal knee flexion angle, and QH_{GRF} ratio, a repeated-measures multivariate analysis of variance (MANOVA) with within-subject factors (rested vs. fatigued) and between-subject factors (female vs. male) was calculated ($p<0.05$). Due to the small sample size, the effect size (partial eta (η^2)) was also used for data interpretation (small: $\eta^2 = 0.01$; medium: $\eta^2 = 0.06$; large: $\eta^2 = 0.14$).

RESULTS: On a multivariate level a significant effect of fatigue ($p=0.017$) and interaction between fatigue and sex (0.026) was calculated. On a univariate level fatigue showed a significant increase in lactate values to 11.1±2.3 mmol/l (males) and 10.3±1.4 mmol/l (females) ($p<0.001$) and jump height. ($p=0.002$) (Table 1). As expected, male athletes jumped on average 85 mm (rested) and 69 mm (fatigued) significantly higher than female athletes (large effect), For all other parameters no statistical significance was reached, however, fatigue- and sex- dependent medium effect sizes occurred on the left limb QH_{GRF} ratio, which increased

due to fatigue by 2% (males) and 4% (females) and was lower for the females than males by 8% (rested) and by 6% (fatigued). Additionally, a large fatigue-dependent effect was observed for the maximal knee flexion angle, which decreased in both sexes in both limbs by approx. 2° after the fatigue protocol (Table 1).

Table 1: Mean (±SD) of jump height, Q:H ratio and maximal knee flexion angle of the right (R) and left (L) limb during a drop jump in rested and fatigued condition

	rested		fatigued		Effect size partial eta		
	male	female	male	female	fatigue	sex	sex*fat.
Jump Height [mm]	369 ± 29	284 ± 37	339 ± 24 *#	270 ± 55 *#	0.52	0.59	0.14
Q:H Ratio R	4.6 ± 2.3	4.4 ± 1.3	4.4 ± 1.7	4.4 ± 0.9	0.01	0.00	0.03
Q:H Ratio L	4.5 ± 1.8	3.7 ± 1.1	4.7 ± 1.7	4.1 ± 1.3	0.06	0.08	0.00
Knee $Flex_{max}$ R [°]	64 ± 12.8	62 ± 9.8	62 ± 11.4	60 ± 7.0	0.16	0.01	0.02
Knee $Flex_{max}$ L [°]	64 ± 12.0	64 ± 10.2	61 ± 12.0	62 ± 8.8	0.26	0.00	0.00

note: *sign. fatigue effect, # sign. sex effect, Effect size: shaded dark grey: large, shaded light grey: medium

DISCUSSION: The obtained lactate values indicate game-representative exhaustion of the soccer players participating in our study (e.g. Krustrup et al., 2021). Similarly, a decrease in jump height further supports that the fatigue protocol induced substantial exhaustion in the lower extremities (Chappell et al., 2005).

With respect to thigh muscle activation patterns, soccer players showed in rested state a QH_{GRF} ratio of 0.8±0.5/0.6±0.3 (male/female) in the preparatory phase of a box-jump side-step cut and 1.5±0.6/1.1±0.5 (male/female) in the loading phase in a previous study (Hanson, Padua, Troy Blackburn, Prentice, & Hirth, 2008). These values are far below the values observed in this study, but it is worth noting that this may be due to a derivation from slightly different movement tasks and different phase definitions. To the best of our knowledge, comparative data to the methodological approach taken in this study, are available only for competitive U16 ski athletes, where male skiers showed QH_{GRF} ratios of 3.9 ± 2.0 during DJ, while female QH_{GRF} ratios were 2.9 ± 1.4 (Ellenberger et al., 2021). The authors of that study concluded that the higher ratio in male skiers might result from reduced hamstring activity rather than hyperactivity of the quadriceps. Another study, Urabe et al. (2005), however, found no significant difference in hamstring muscle activation between the sexes and they explained the increased anterior tibial translation in women by the hyperactivity of the quadriceps muscles.

In this pilot study, in both limbs, the fatigue protocol induced slightly more extended knees on average. An increase in the QH_{GRF} ratio, which would be related to a quadriceps dominance strategy, was, however, only visible with a medium effect in the left limb (both not reaching significance. However, as the QH_{GRF} ratio indicates the quotient between the quadriceps and hamstring muscles, it remains unclear whether a decreased QH_{GRF} ratio is due to a decrease in quadriceps activation or an increase in hamstring activation. Although there is some evidence from skiers with ACL ruptures performing squat jumps that fatigue leads to a decrease in quadriceps activity and an increase in hamstring activity (Jordan, Aagaard, & Herzog, 2017). However, whether this is the case for the healthy soccer population as in this study, and which strategy the female soccer players choose, still needs to be further investigated.

Finally, it is worth highlighting that due to the small sample size of this pilot study, the statistical differentiation between the sexes must be interpreted with caution.

CONCLUSION: This pilot study investigated the effect of fatigue and sex on thigh muscle activation patterns during DJ in competitive soccer players. The fatigue protocol was effective in demonstrating decreased jump heights and increased lactate levels. After fatigue, the knees were less flexed during the ground contact phase (i.e., representing stiffer landings); however, the hypothesized sex- and fatigue-dependent effects of a more ligament-dominant strategy in females and a more quadriceps-dominated strategy in males could not be conclusively verified.

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