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Acute effects of muscle fatigue on the knee joint-position sense of trained and non-trained individuals

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ABSTRACT

Introduction: The acute effects of muscle fatigue on the knee joint-position sense are not consensual. Although it is known that peripheral fatigue affects the muscle spindle function by increasing its discharge threshold, reports of positive and negative impacts of muscle fatigue on the knee joint-position sense of both trained and non-trained individuals can be found in the literature.
Objectives: To assess the acute effects of muscle fatigue on the knee joint-position sense of trained and non-trained individuals.
Methodology: Knee joint-position sense was tested in the dominant and non-dominant limb in a seated position, before and immediately after a repetitive sit-to-stand fatigue task. Target ranges of 20° and 45° of knee flexion were used, describing an active repositioning method, and using an inertial measurement unit system. Absolute and relative angular errors were calculated and intra- and intergroup comparisons were conducted.
Results: Sixty participants (29 female; 31 male), 29 semi-professional soccer players and 31 non-trained individuals, aged 18-30 years, participated in this quasi-experimental study. After fatigue, a significant increase was seen regarding the absolute ($p=0.034$) and relative ($p=0.017$) angular errors only in the non-trained individuals during the 45° repositioning of the dominant limb.
Conclusion: The proposed fatigue protocol appears to have no acute effects on the knee joint-position sense of soccer players, while it appears to be harmful in non-trained individuals.

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RESUMO

Introdução: Os efeitos agudos da fadiga muscular na sensação de posição articular do joelho não são consensuais. Embora se saiba que a fadiga periférica afeta a função do fuso muscular aumentando o seu limiar de descarga, relatos de impactos positivos e negativos da fadiga muscular na sensação de posição articular do joelho de indivíduos treinados e não-treinados podem ser encontrados na literatura.
Objetivos: Avaliar os efeitos agudos da fadiga muscular na sensação de posição articular do joelho de indivíduos treinados e não-treinados.
Metodologia: A sensação de posição articular do joelho foi testada no membro dominante e não-dominante na posição de sentado, antes e imediatamente após uma tarefa de fadiga repetitiva de sentar e levantar. Foram utilizadas amplitudes-alvo de 20° e 45° de flexão do joelho, descrevendo um método de reposicionamento ativo e utilizando um sistema de centrais inerciais. Foram calculados os erros angulares absolutos e relativos, e realizadas comparações intra- e intergrupos.
Resultados: Sessenta participantes (29 do sexo feminino; 31 do sexo masculino), 29 jogadores de futebol semiprofissionais e 31 indivíduos não-treinados, com idades entre os 18-30 anos, participaram neste estudo quase-experimental. Após a fadiga, observou-se um aumento significativo nos erros angulares absolutos (p=0,034) e relativos (p=0,017) apenas nos indivíduos não-treinados durante o reposicionamento de 45° do membro dominante.
Conclusões: O protocolo de fadiga proposto parece não ter efeitos agudos na sensação de posição articular do joelho de jogadores de futebol, enquanto parece ser prejudicial em indivíduos não-treinados.

Introduction

Joint-position sense is a submodality of proprioception that can be defined as an individual's ability to understand a joint angle and to reproduce it, actively or passively, without the aid of sight.[1] The muscle mechanoreceptors responsible for mediating knee joint-position sense (KJPS), and especially muscle spindles, are described as the ones providing more proprioceptive input,[2] being particularly active in intermediate ranges of the range of motion (ROM)[3] between 40° and 80°,[4] while joint mechanoreceptors signal proprioceptive information in extreme ranges near to the limit of the knee ROM.[1,2]

Different factors have been proposed to positively or negatively influence the KJPS. Regarding factors with proven positive effects, it can be highlighted performing a warm-up,[5] and practicing sports.[6-8] On the contrary, aging is pointed as a factor that causes a decline in KJPS.[9]

Regarding muscle fatigue, its acute effects on the KJPS appear to be not consensual in the available literature. Muscle fatigue is defined as the reduction of a muscle's ability to generate strength and power.[10] Currently, it is known that peripheral muscle fatigue, as it occurs within the muscle, leads to metabolic changes that impair the muscle spindle function, increasing its discharge threshold and disturbing the proprioceptive input coming from this muscle mechanoreceptor.[11,12] Fatigue exercise can also induce an increase in knee ligament laxity,[13] which may also disturb the input from joint mechanoreceptors.

Effectively, there are studies reporting negative impacts of muscle fatigue induced by sports practice on the KJPS of trained individuals such as soccer players.[5,14] Indeed, it has been suggested that muscle fatigue is related to the high prevalence of injuries especially in the last 15 minutes of soccer practices or matches and even in the last phases of seasons, as it can impair the neuromuscular control by inducing proprioceptive changes.[15-17] Regarding non-trained individuals, conflicting results are found, with negative impacts[18,19] or no significant effects[20,21] of muscle fatigue being reported.

Considering the lack of consensus in the literature, the purpose of this investigation is to determine the acute effects of muscle fatigue on the KJPS of trained and non-trained individuals. We hypothesize that the muscle fatigue protocol will negatively affect the KJPS of both groups.

Methodology

Study Design and Participants

This quasi-experimental study was reported according to the TREND Statement Checklist.[22] A convenience sample of trained and non-trained individuals were invited to participate in the study. The non-trained individuals were students recruited from the university and the soccer players from two Portuguese semi-professional male and female soccer teams. Data collections of the non-trained individuals occurred in the university premises, and regarding the soccer players, collections were conducted in the medical departments of the soccer teams. Inclusion criteria were: male or female; age between 18-30 years; and without history of knee injuries within the past six months. Participants were excluded according to the following criteria: history of knee surgery; cardiorespiratory, vestibular or neuromuscular disorders; positive knee integrity tests (Lachman test; anterior and posterior drawer test; valgus and varus stress tests); taking medication with an influence on motor control (analgesics, non-steroidal anti-inflammatory drugs; muscle relaxants; antibiotics); and pregnant or breast-feeding participants.

Determination of the dominant limb was performed by questioning participants which lower limb was their preferred to kick a ball.[23]

Age of the participants was self-reported and the weight and height of participants was measured with a weighing scale and a stadiometer, respectively. Body mass index (BMI) was then calculated using the following formula: weight / (height).[2]

The study was approved by the Ethics Committee of the Sciences of Health Faculty of Fernando Pessoa University, and every participant signed the informed consent form, declaring their willingness to participate in the study. All procedures were according to the Declaration of Helsinki.

Assessment of joint position sense

KJPS was assessed in both the dominant and non-dominant limb in open kinetic chain and describing an active repositioning method. To eliminate visual input, all participants were blindfolded during the procedures.

The assessment of the KJPS was conducted in the seated position, with the participants' knee flexed at 90° (starting position). From this position, passively and slowly, the investigator moved the leg of the subject to extension to one of the target ranges, defined by a goniometer. Participants were instructed to actively keep the test position for 5 seconds in order to memorize it, and after that period they were asked to return to the starting position, and immediately after, to actively reposition the knee to the target range, holding it for 5 seconds.[5] Participants were tested for two distinct target ranges: 20° of flexion,[24] a position near the end range of the knee ROM, where joint mechanoreceptors are more active[4]; and 45° of flexion,[21] an intermediate range of the knee ROM, where the muscle mechanoreceptors are more active.[2,4] Three repositionings were performed for each target range.

Knee angles were assessed using a Xsens MTx Inertial Measurement Unit (IMU) System (Xsens, Enschede, Netherlands). One inertial sensor was placed in each limb, positioned medially and immediately below the anterior tibial tuberosity.[25]

Repositioning errors were reported as: the Absolute Angular Error (AAE) defined as the absolute value of the difference between the value of the target range and the range reproduced by the participant[26]; and the Relative Angular Error (RAE) defined as the arithmetic difference between the value of the target range and the range reached by the subject[26] (negative RAE's indicate a directional bias into the extension movement or an overestimation, and positive RAE's into the flexion movement or underestimation of the target range).

The KJPS of the participants was assessed in one session before and immediately after the muscle fatigue protocol, not allowing the recovery from the fatigue state. The same investigator conducted all the procedures and the order of assessment for the limbs and target ranges was randomized.

Fatigue Protocol

Quadriceps fatigue protocol consisted of a repetitive sit-to-stand task from an adjustable height bench so that the thigh and knee joints were flexed at 90°, with participants holding their arms folded across the chest. The cadence of the movement was controlled with a metronome at 30-beats per minute, meaning that between each beat, the participants had to stand up, sit and stand up again in a two second-interval. The fatigue protocol was terminated according to the following criteria: when the subject was no longer able to perform the task; when the rhythm at which the task should be performed was not the default rhythm (2s); or after 30 minutes of protocol.[27] The duration of the fatigue protocol was recorded.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences Software v. 26 for Windows. A new variable was calculated (Variation), through the difference in the absolute and relative errors between the assessment after and before fatigue (assessment after - assessment before), where positive values indicate worsening in the errors, and negative values an improvement. Normality of data distribution was tested using the Shapiro-Wilk Test, and considering that data was not normally distributed, descriptive statistics were reported as median and interquartile range (Mdn; IQR), and non-parametric tests were used in the analysis. The Wilcoxon test was used for intragroup comparisons of the AAE and RAE between before and after fatigue. The Mann-Whitney test was used for intergroup comparisons of the variables: age, body mass index (BMI), fatigue protocol duration, AAE and RAE between the soccer players and the non-trained individuals' groups. The level of significance was set at 0.05.

Results

Sixty subjects participated in the study, where 29 were soccer players (14 female; 15 male) and 31 were non-trained individuals (15 female; 16 male). The right lower limb was the dominant limb in 88% of the participants.

Table 1 presents the comparison between groups regarding age, BMI and fatigue protocol duration. No significant differences between groups were found regarding age, BMI or duration of the fatigue protocol (p>0.05) (Table 1).

Table 1. Comparison of age, BMI and fatigue protocol duration between the soccer players and the non-trained individuals.

	Soccer Players n=29	Non-trained individuals n=31	*p*
	Mdn; IQR	Mdn; IQR	
Age (years)	21.00; 8.00	22.00; 3.00	0.109
BMI (kg/m2)	21.50; 3.80	23.10; 6.0	0.077
Fatigue Protocol Duration (min)	4.17; 12.73	7.14; 13.13	0.211

Table 2 and 3 shows the intra- and intergroup comparisons of the repositioning errors before and after the fatigue protocol in the soccer players and in the non-trained individuals, respectively. Repositioning errors did not significantly change after the fatigue protocol in the soccer players, but in the non-trained individuals, a significant increase of the AAE (p=0.034) and RAE (p=0.017) was found only in the dominant limb and for the 45° test range.

Table 2. Comparison of the AAE and RAE before and after the fatigue protocol, of the soccer players.

		Soccer Players (n=29)			
		Before fatigue	After fatigue	*p*	Variation
		Mdn; IQR	Mdn; IQR		Mdn; IQR
AAE	**DL 20°**	3.15; 5.85	3.71; 3.98	0.812	0.46; 6.73
	DL 45°	2.63; 4.46	4.42; 3.90	0.061	0.54; 4.28
	NDL 20°	1.99; 2.89	2.61; 3.41	0.309	0.25; 4.24
	NDL 45°	5.34; 4.98	4.64; 5.19	0.456	-0.41; 6.99
RAE	**DL 20°**	-2.76; 7.25	-2.94; 4.17	0.738	-0.31; 7.96
	DL 45°	-2.63; 4.78	-4.42; 4.31	0.078	2.52; 8.59
	NDL 20°	-1.48; 4.47	-1.54; 4.90	0.820	-0.66; 6.94
	NDL 45°	-5.34; 5.84	-4.64; 5.19	0.689	0.36; 7.31

*p≤0.05 (AAE: absolute angular errors; RAE: relative angular errors; DL: dominant limb; NDL: non-dominant limb; Mdn: Median; IQR: Interquartile Rage)

Table 3. Comparison of the AAE and RAE before and after the fatigue protocol, of the non-trained individuals.

		Non-trained Individuals (n=31)			
		Before fatigue	After fatigue	*p*	Variation
		Mdn; IQR	Mdn; IQR		Mdn; IQR
AAE	**DL 20°**	3.30; 4.38	4.62; 4.53	0.357	-0.01; 4.04
	DL 45°	4.89; 4.70	6.09; 7.78	0.034*	1.78; 8.54
	NDL 20°	3.83; 5.03	4.57; 4.92	0.906	0.51; 4.13
	NDL 45°	5.54; 7.83	4.76: 6.10	0.248	0.33; 5.90
RAE	**DL 20°**	2.44; 6.90	3.51; 7.66	0.891	1.05; 4.85
	DL 45°	4.82; 6.73	6.09; 8.71	0.017*	0.02; 5.27
	NDL 20°	3.83; 5.46	3.68; 7.04	0.367	0.65; 6.95
	NDL 45°	5.54; 7.91	4.76; 6.43	0.240	-0.20; 6.85

*p≤0.05 (AAE: absolute angular errors; RAE: relative angular errors; DL: dominant limb; NDL: non-dominant limb; Mdn: Median; IQR: Interquartile Rage)

Discussion

The main findings of this study were that a repetitive sit-to-stand fatigue task did not affect the KJPS of soccer players, but significantly increased the repositioning errors of the non-trained individuals' group in the dominant limb and in intermediate ranges of the knee ROM.

Regarding the soccer players' group, results are not in agreement with prior research such as the one of Salgado, Ribeiro and Oliveira[5] who also assessed the effect of fatigue on the KJPS of these athletes, but contrary to our results, the authors reported a significant increase of the repositioning errors. However, although the KJPS assessment method employed in this study was similar (open kinetic chain technique and active repositioning method from a passive positioning), two aspects should be recognized. First, the fatigue protocol was distinct. In the study of Salgado, Ribeiro and Oliveira[5] fatigue was induced by a 90 minutes soccer game, which might suggest that the protocol of the present study was not enough to effectively cause fatigue in the soccer players. Second, the repetitive sit to stand task induced muscle fatigue locally in the knee joint while a soccer game may induce a more general fatigue. Indeed, previous studies compared the effect of local and general fatigue protocols on the KJPS, and reported a significant increase of the repositioning errors only after the induced general fatigue, without even reporting a significant decrease of muscle strength.[28] Although local fatigue can cause a disfunction of the muscle mechanoreceptors, these authors hypothesized that the general fatigue protocol could have affected other mechanisms of the proprioceptive pathway that gave origin to a central fatigue, which might have led to a deficit of the central processing of the proprioceptive input, which may explain the distinct results from the present investigation and the one of Salgado, Ribeiro and Oliveira.[5]

Regarding the non-trained individuals, the hypothesis was confirmed as the results showed that muscle fatigue negatively affected the KJPS, but only in the dominant limb when repositioning to the target range of 45°, which denotes two important aspects. First, the dominant limb seems to be more affected by muscle fatigue than the non-dominant limb. However, to the best of our knowledge, no previous studies compared the proprioceptive acuity between lower limbs after a fatigue protocol, so we hypothesize that during the repetitive sit-to-stand fatigue task, these participants possibly did not symmetrically distribute the load by both lower limbs, which might have overloaded the dominant one, leading to proprioceptive differences between limbs. Second, as significant changes in the repositioning errors were only reported in the intermediate range of 45° and not for the extreme range of 20°, this suggests that muscle fatigue had a greater impact on muscle mechanoreceptors. Similar results to the ones presented here were also previously reported by Ali, Farzaneh and Homayoon[24] that have assessed the effect of the Functional Fatigue Protocol on the knee repositioning errors for the same ranges of this study (20° and 45° of knee flexion), and have also described a significant increase of the repositioning errors only for the range of 45°. Similarly, Da Silva, Monjo, Zghal, Chorin, Guérin and Colson[18] found significantly increased errors after an eccentric fatigue protocol when KJPS was assessed in an intermediate range of 70°, while no significant effect was seen at the extreme range of 30°.

Although most of the available literature seems to demonstrate that muscle fatigue decreases KJPS, some studies also contradict this evidence. Dieling, Van der Esch and Janssen [21] did not report a significant increase of the repositioning errors both in trained individuals such as ballet dancers as in non-trained individuals for three distinct target ranges (30°, 45° and 60° of knee flexion), after performing a fatigue protocol in an isokinetic dynamometer. However, it should be noted that the authors used a passive repositioning method, a method that leads to a lower activation of the muscle mechanoreceptors, which may justify the absence of significant differences in the repositioning errors before and after the fatigue protocol.[29]

The present study also included participants of both sexes. Even though it was previously described that KJPS suffers changes during a menstrual cycle in females,[30] the literature is not consensual regarding differences in the KJPS between female and male individuals,[6,31-33] although the majority of studies concludes that there are no differences between sexes.[6,31,32] Effectively, only Muaidi [33] reported significant differences between sexes, with males presenting better KJPS. However, the study also reported a significantly different level of physical activity between male and female participants, with males presenting a higher level of physical activity. Indeed, Relph and Herrington[34] demonstrated previously that physical activity improves KJPS, which may explain the differences found.

In order to avoid possible injuries both in normal daily tasks as well as in specific sports tasks, the central nervous system must rely on adequate proprioceptive information from mechanoreceptors. This gives the capacity to provide correct neuromuscular responses that will assure protection against excessive motions in the knee, and consequently, ensure the joint's stability. Muscle fatigue, as discussed, impairs the KJPS, which can have repercussions in the emitted responses, which may not ensure the stability of the joint. Thus, a compromised position sense may result in an increased risk of injury, for example due to an increased time until activation of the muscles that can stabilize the joint and resist to high impacts,[35,36] as seen in possible falls in daily life, as well as to prevent injuries when landing after jumping or changing directions, which are common in many soccer activities.

Some limitations of the study should be recognized. First, the necessary sample size was not calculated, so it is possible that with a more representative sample, other results could have arisen. Second, the demonstration of the target angle was made through a passive positioning, although according to Pickard, Sullivan, Allison and Singer[37] muscle contraction prior to the reposition induces a higher precision in position sense. Third, the maximal voluntary contraction was not assessed before the fatigue protocol, so there was no possibility of estimating the effective strength decrease after the sit-to-stand fatigue task. Fourth, we did not assess if the load was symmetrically distributed by the lower limbs during the sit-to-stand fatigue task. Future studies should address these limitations and test different fatigue protocols in trained individuals in order to understand which activities effectively cause fatigue in these athletes that can lead to proprioceptive deficits and consequently increase the risk of injury.

Conclusion

The proposed fatigue protocol appears to have no acute effects on the KJPS of soccer players, while it appears to be harmful in non-trained individuals. Muscle fatigue also seems to affect more the dominant limb and the muscle mechanoreceptors.

Conflicts of Interest: Authors state no conflict of interest.

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References

1. Riemann BL, Myers JB, Lephart SM. Sensorimotor system measurement techniques. *J Athl Train*. 2002;37(1):85-98.

2. Proske U. A reassessment of the role of joint receptors in human position sense. *Exp Brain Res*. 2023;241(4):943-949. doi:10.1007/s00221-023-06582-0
3. Docherty CL, Moore JH, Arnold BL. Effects of strength training on strength development and joint position sense in functionally unstable ankles. *J Athl Train*. 1998;33(4):310-314.
4. Olsson L, Lund H, Henriksen M, Rogind H, Bliddal H, Danneskiold-Samsøe B. Test–retest reliability of a knee joint position sense measurement method in sitting and prone position. *Adv Physiother*. 2004;6(1):37-47. doi:10.1080/14038190310009894
5. Salgado E, Ribeiro F, Oliveira J. Joint-position sense is altered by football pre-participation warm-up exercise and match induced fatigue. *The Knee*. 2015;22(3):243-248. doi:10.1016/j.knee.2014.10.002
6. Azevedo J, Rodrigues S, Seixas A. The influence of sports practice, dominance and gender on the knee joint position sense. *The Knee*. 2021;28:117-123. doi:10.1016/j.knee.2020.11.013
7. Venâncio J, Lopes D, Lourenço J, Ribeiro F. Knee joint position sense of roller hockey players: a comparative study. *Sports biomechanics*. 2016;15(2):162-168. doi:http://dx.doi.org/10.1080/14763141.2016.1159323
8. Şahin N, Bianco A, Patti A, Paoli A, Palma A, Ersöz G. Evaluation of knee joint proprioception and balance of young female volleyball players: a pilot study. *Journal of physical therapy science*. 2015;27(2):437-440. doi:10.1589/jpts.27.437
9. Ribeiro F, Oliveira J. Effect of physical exercise and age on knee joint position sense. *Archives of gerontology and geriatrics*. 2010;51(1):64-67. doi:10.1016/j.archger.2009.07.006
10. Grassi B, Rossiter HB, Zoladz JA. Skeletal muscle fatigue and decreased efficiency: two sides of the same coin? *Exercise and sport sciences reviews*. 2015;43(2):75-83. doi:10.1249/JES.0000000000000043
11. Pedersen J, Ljubisavljevic M, Bergenheim M, Johansson H. Alterations in information transmission in ensembles of primary muscle spindle afferents after muscle fatigue in heteronymous muscle. *Neurosci*. 1998/02/24/ 1998;84(3):953-959. doi:10.1016/S0306-4522(97)00403-X
12. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *J Orthop Sports Phys Ther*. 1996;23(6):348-352. doi:10.2519/jospt.1996.23.6.348
13. Johannsen H, Lind T, Jakobsen B, Krøner K. Exercise-induced knee joint laxity in distance runners. *Br J Sports Med*. 1989;23(3):165-168. doi:Exercise-induced knee joint laxity in distance runners
14. Carrasco L, Espinar J, Carbonell FJ, Martínez-Díaz IC. Local and general fatigue: Effects on knee proprioception in soccer players. Article. *Revintmedciencactfísdeporte*. 2021;21(84):683-698. doi:10.15366/rimcafd2021.84.004
15. Allison KF, Abt JP, Beals K, et al. Aerobic capacity and isometric knee flexion strength fatigability are related to knee kinesthesia in physically active women. *Isokinetics & Exercise Science*. 2016;24(4):357-365. doi:10.3233/IES-160638
16. Giza E, Mithöfer K, Farrell L, Zarins B, Gill T. Injuries in women's professional soccer. *Br J Sports Med*. 2005;39(4):212-216. doi:10.1136/bjsm.2004.011973
17. Pedrinelli A, da Cunha Filho GAR, Thiele ES, Kullak OP. Estudo epidemiológico das lesões no futebol profissional durante a Copa América de 2011, Argentina. *Rev Bras Ortop*. 2013;48(2):131-136. doi:10.1016/j.rbo.2012.09.001
18. Da Silva F, Monjo F, Zghal F, Chorin F, Guérin O, Colson SS. Altered Position Sense after Submaximal Eccentric Exercise–inducing Central Fatigue. *Med Sci Sports Exerc*. 2021;53(1):218-227. doi:10.1249/MSS.0000000000002444
19. Shokri P, Eslamian F, Shakouri SK, Ohanian S, Jahanjoo F. Fatigue Induced Effects after Concentric versus Eccentric Exercises on Sense of Force and Senses of Position among Young Normal Adults-A Controlled Single-Blinded Study. *J res med dent sci*. May 2018;6(3):258-267. doi:10.24896/jrmds.20186340
20. Bersotti FM, De Melo TB, Rafael Skau J, Mochizuki L, Ervilha UF. Fatigue of knee extensor muscles does not alter knee joint position sense. *J Mech Med Biol*. 2022;22(2):2250012-1-2250012-9.
21. Dieling S, Van der Esch M, Janssen TW. Knee joint proprioception in ballet dancers and non-dancers. *Journal of Dance Medicine & Science*. 2014;18(4):143-148. doi:10.12678/1089-313X.18.4.143
22. Des Jarlais DC, Lyles C, Crepaz N, Group T. Improving the reporting quality of nonrandomized evaluations of behavioral and public health interventions: the TREND statement. *American journal of public health*. 2004;94(3):361-366.
23. McFadden C, Daniels KA, Strike S. Six methods for classifying lower-limb dominance are not associated with asymmetries during a change of direction task. *Scandinavian Journal of Medicine & Science in Sports*. 2022;32(1):106-115. doi:10.1111/sms.14054
24. Ali Y, Farzaneh G, Homayoon A. The Effect Of Fatigue On The Ankle And Knee Proprioception And Dynamic Control Of Posture. *International Journal of Sports Sciences & Fitness*. 2013;3(2):235-249.
25. Cloete T, Scheffer C. Repeatability of an off-the-shelf, full body inertial motion capture system during clinical gait analysis. IEEE; 2010:5125-5128.
26. Bennell K, Wee E, Crossley K, Stillman B, Hodges P. Effects of experimentally-induced anterior knee pain on knee joint position sense in healthy individuals. *J Orthop Res*. 2005;23(1):46-53. doi:10.1016/j.orthres.2004.06.008
27. Barbieri FA, Beretta SS, Pereira VA, et al. Recovery of gait after quadriceps muscle fatigue. *Gait & posture*. 2016;43:270-274. doi:10.1016/j.gaitpost.2015.10.015
28. Miura K, Ishibashi Y, Tsuda E, Okamura Y, Otsuka H, Toh S. The Effect of Local and General Fatigue on Knee Proprioception. Article. *Arthrosc - J Arthrosc Relat Surg*. 2004;20(4):414-418. doi:10.1016/j.arthro.2004.01.007
29. Proske U, Wise A, Gregory J. The role of muscle receptors in the detection of movements. *Prog Neurobiol*. 2000;60(1):85-96. doi:10.1016/S0301-0082(99)00022-2
30. Fouladi R, Rajabi R, Naseri N, Pourkazemi F, Geranmayeh M. Menstrual cycle and knee joint position sense in healthy female athletes. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2012;20(8):1647-1652. doi:10.1007/s00167-011-1811-7
31. Ghiasi F, Akbari A. Comparison of the effects of open and closed kinematic chain and different target position on the knee joint position sense. *J Med Sci*. 2007;7(6):969-976. doi:10.3923/jms.2007.969.976
32. Cug M, Wikstrom EA, Golshaei B, Kirazci S. The Effects of Sex, Limb Dominance, and Soccer Participation on Knee Proprioception and Dynamic Postural Control. *Journal of sport rehabilitation*. 2016;25(1):31-39. doi:10.1123/jsr.2014-0250

33. Muaidi QI. Does gender make a difference in knee rotation proprioception and range of motion in healthy subjects? *Journal of back and musculoskeletal rehabilitation*. 2017;30(6):1237-1243. doi:10.3233/BMR-169613
34. Relph N, Herrington L. The effects of knee direction, physical activity and age on knee joint position sense. *The Knee*. 2016;23(3):393-398. doi:http://dx.doi.org/10.1016/j.knee.2016.02.018
35. Maqsood M, Váczi M. Immediate Effects of Quadriceps Muscle Kinesiology Taping on Joint Position Sense and Force Sense in Healthy Individuals. Preprints: Preprints; 2023.
36. Nagai T, Schilaty ND, Strauss JD, Crowley EM, Hewett TE. Analysis of Lower Extremity Proprioception for Anterior Cruciate Ligament Injury Prevention: Current Opinion. *Sports Medicine*. 2018/06/01 2018;48(6):1303-1309. doi:10.1007/s40279-018-0889-1
37. Pickard CM, Sullivan PE, Allison GT, Singer KP. Is there a difference in hip joint position sense between young and older groups? *J Gerontol A Biol Sci Med Sci*. 2003;58(7):631-635. doi:10.1093/gerona/58.7.M631