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Effect of Quadriceps Femoris Muscle Fatigue after Closed Kinetic Chain Exercise on Knee Joint Proprioception

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ABSTRACT
Background: Players in table tennis must adopt the semi-flexed knee position for extended periods of time, which wears down the knee joint. This fatigue adversely affects joint proprioception, which triggers sporting injuries.
Objective: This study aimed to investigate the effect of quadriceps fatigue after closed kinetic chain exercises on knee joint proprioception in table tennis players.
Materials and methods: An observational study that was conducted on 26 healthy male subjects with mean age of 23 ± 1.6 years. Fatigue protocol (FP) was induced by double legged squat until it could not be accomplished more. At 50 degrees of knee flexion, subjects were put through a weight-bearing joint position sense test. The measurements were done four times: before the FP, after the FP immediately, after 5 minutes of FP and after 10 minutes of FP by smartphone goniometer attached to the upper one third lateral section of the dominant leg.
Results: Multiple pairwise comparison tests (Post-hoc tests) showed statistically significant lower knee position sense values immediately after fatigue in comparison with before fatigue values (p-value = 0.002), while there was non-significant difference between before fatigue in comparison with after 5 min and after 10 min of fatigue (p-values = 0.263 and 0.117 respectively).
Conclusion: A study revealed that quadriceps fatigue after closed kinetic chain exercises had affected knee joint proprioception in table tennis players and 5 minute recovery was enough for proprioceptive recovery.
Keywords: Fatigue, Goniometer, Proprioception, Smart phone, Table tennis.

INTRODUCTION

Exercise-induced reduction in the muscles' capacity to generate force or power is known as muscle fatigue, and it is an often noticed phenomenon that impairs sports performance and other intense or prolonged activity **[1]**.

Additionally, it can come from many points along the motor route and is typically split into central and peripheral components. Peripheral tiredness is brought on by changes at or distal to the neuromuscular junction, whereas central weariness is brought on by changes at the central nervous system (CNS), which decreases the neural drive to the muscle**[2]**.

Activity-related injuries have become more frequent as a result of increased participation in sports and leisure activities **[3]**. Sports performance fatigue has long been a topic of practical attention **[4]**. The ability to detect how different body parts move and are positioned in space is known as proprioception **[5]**.

It contributes significantly to neuromuscular performance **[6]**. It is also the fundamental component of spontaneous movement regulation, balance, joint stability, and injury prevention **[7]**.

Additionally, it includes both the feeling of joint location and the experience of joint movement (kinesthesia). Joint position sensing (JPS) refers to a person's ability to perceive a target and actively or passively recreate it without the use of sight, it is a proprioception submodality **[8]**. Even more so than for routine motions, proprioception is essential for skill-demanding activities **[9]**.

Table tennis is a racket sport in which players must maintain a semi-flexed knee position of up to 90^o or more for extended periods of time while performing abrupt asymmetrical torsional trunk movements, subjecting the knee to excessive rotational torques due to the lower limb being fixed in place on the ground **[10]**. The possibility for chronic overuse injury in racket sports has been demonstrated due to the high repetition of activity required to develop and perfect abilities **[11]**.

Further data suggests that fatigue from exercise might affect our perception of limb position, it might be relevant since misplacing our limbs during exercise or sport due to fatigue's effect on position awareness raises the chance of sustaining a sports injury **[12]**.

Since the knee joint is the most sensitive for proprioception, fatigue typically affects it **[13]**. Therefore, practising executive table tennis may exhaust the knee musculatures, impair knee proprioception, and result in knee injury.

Smartphone technology is one of the no-cost and simpler to utilise than certain digital procedures, which may increase the measurement's precision and accuracy **[14]**. Additionally, it was proven to be a legitimate and trustworthy instrument for assessing joint position sensation and range of motion (ROM) **[5]**.

Therefore, the goal of the study was to find out how table tennis players' knee joint proprioception is affected by quadriceps fatigue following closed kinetic chain exercises.

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MATERIALS AND METHODS

An observational study that included 26 healthy male table tennis players in age group of 18-25 yrs.

Inclusion criteria:

1. The subject was between the ages of 18 and 25 years old.
2. All subjects were in good health and have no diseases or injuries that could compromise the outcome of the experiment.
3. All subjects were table tennis players.

Exclusion criteria:

1. Pathological conditions that affect any intra-articular structure
2. A recent lower limb fracture in past times
3. Previous knee, ankle, or hip joint surgery.
4. Knee, ankle, and hip joints with osteoarthritis.
5. Subjects who engage in any form of physical training or exercise that could influence the outcome of the exam.

Instrumentations:

1. **Handheld Dynamometry (HHD):** The Lafayette Manual Muscle Tester, model number 01163 was utilised. In comparison to isokinetic devices, hand-held dynamometry could be regarded as a reliable and valid instrument for assessing muscle strength because of its portability, affordability, and compact size. Additionally, its maximum angle isometric force serves as a clinical indicator of fatigue [15].
2. **Smartphone goniometer:** Android smartphone goniometer application [android app Clinometer – version 2.4 (16052510)] was used to gauge the sensation of the knee joint.

Testing procedures:

Before the test, the subject's age, sex, height, weight, and BMI were documented. All subjects were assessed on four occasions, first at the beginning of test, second after the selected exercise (double limb squat) that would cause quadriceps fatigue, third after five minutes of exercise and fourth after ten minutes of exercise.

Following a 5-minute warm-up and test demonstration, the subjects were instructed to complete the test before fatiguing protocol to record their proprioception immediately. Following a 3-minute break, the fatigue protocol (FP) was initiated by execution double-legged squats with arms parallel to the floor until their knees were flexed 90 degrees. Operationally, exhaustion was defined as the moment at which participants were unable to complete the FP [16].

Laffayate HHD was used to measure muscle force in Newtons, which was then converted to torque [force (N) moment arm (m) (distance between the dynamometer's axis of rotation, which was positioned two cm proximal to the lateral malleolus and coaxial to the lateral femoral epicondyle, measured from the point of maximum protrusion] [17]. **Figure (1)** to measure quadriceps muscle fatigue. The therapist would be in a squatting position with both arms extended to the subject's dominant leg for stabilisation and the back against the wall for support, minimising the results dependence on subject or therapist strength **(figure 2).**

The subjects had to exert their strongest knee extension for five seconds. Results shown on HHD have been recorded [18]. The goniometer was attached to the top third of the lateral side of the dominant leg along the joint line to measure.

Fig. (1): Measuring moment arm.

Fig. (2): Measuring quadriceps muscle strength by Lafayette HHD.

Position sense in the knee joint. The test began with the knee extended **(figure 3)** and the subjects were instructed to squat until they achieved the objective (predefined) angle of 50°, which is equivalent to the middle range of knee flexion shown in (**figure 4).** The individuals were blindfolded and instructed to hold the goal angle for 5 seconds before returning to the beginning position (full knee extension). The patients were instructed to replicate this angle three times in order to calculate an average and record the angles [19].

Proprioceptive error from the JPS test (from the dominant leg) was recorded as absolute angular error, which measures accuracy without directional bias (AAE - JPS). The absolute angular error is defined as the absolute difference between the goal position and the position replicated by the subject bias and may be calculated as follows: [(Target – Trial 1) + (Target – Trial 2) + |(Target – Trial 3)]/3 (in degrees) [20].

Fig. (3): Starting position**.**

Fig. (4): Target position.

Ethical approval:

Cairo Physical Therapy Ethics Committee of Faculty of Physical Therapy, Cairo University gave its approval to this study. Following receipt of all information, all participants provided written consent. The Helsinki Declaration was followed throughout the study's conduct. All participants signed informed consents for participation in the study.

Statistical analysis

SPSS computer program, V. 20 for Windows was used. Data were expressed as mean ± SD. Descriptive statistic was used to show subjects characteristics of the study group. Kolmogorov-smirnov test was used for testing normality of data distribution. Repeated measures ANOVA was performed to compare between the repeated measures of (Quadriceps peak torque, knee flexion proprioception measure and proprioception error). P ≤ 0.05 was considered significant.

RESULTS

General characteristics of the subjects:

In this study, twenty-six healthy male subjects participated in this study. The means of their age, weight, height and BMI were 23 ± 1.6 years, 62.7± 9.6 kg, 167± 9.5 cm and 22.3± 1.4 kg/m^2 respectively (Table 1).

Table (1): General characteristics of subjects in the study

Subjects' characteristics	Age (years) Mean ± SD	Weight (kg) Mean ± SD	Height (cm) Mean ± SD	BMI (kg/m^2) Mean ± SD
	23 ± 1.6	62.7± 9.6	167± 9.5	22.3± 1.4

The effect of quadriceps fatigue on knee peak torque of quadriceps:

The means of quadriceps peak torques for four measurements; pre, post (immediate) , after 5 min and after 10 min of quadriceps fatigue were 14.4 ± 3, 10.2 ± 2.3, 11.3 ± 2.6 and 12.6 ± 2.8 Newton meter (NM) respectively. There was statistical significant difference in quadriceps peak torque between the four measurements (P=0.001) (Table 2).

Table (2): Mean values and % of change of knee flexion proprioception, proprioception error and peak torque for the four measurements

Measured variables / **Time**	**Peak torque**	**Proprioception (degree)**	**Proprioception error (degrees)**
Pre fatigue	14.4± 3	55± 6	7.5± 2.3
Post fatigue (immediate) % of change	10.2± 2.3 -29%	61± 9.3 11%	14± 4.6 92.8%
5 min after fatigue % of change from pre	11.3± 2.6 -21.5%	57.3± 4.7 4.2%	8.4± 2.7 12%
10 min after fatigue % of change from pre	12.6± 2.8 -12.5%	51.8± 1.4 -6%	2.8± 0.9 -62.7%
F- value	11.55	11.76	63.34
P- value	0.001*	0.001*	0.001*

P-value: level of significance, *: significant

Post-hoc test between the four measurements of peak torque of quadriceps: As observed in table (3), post hoc test (Bonferroni test) for changes in the mean values of quadriceps peak torques revealed that there was a significant decrease in post fatigue (immediate) quadriceps peak torque than pre fatigue measure {the mean difference was 4.2 in favor of post fatigue and (p=0.001)}. There was a significant decrease in 5 min after fatigue than pre fatigue measures {the mean difference was 3.1 in favor of 5 min after fatigue (p=0.001)}. There was no significant difference between pre fatigue and 10 min after fatigue measures {the mean difference was 1.8 in favor of 10 min (p=0.106)}. There was no significant difference between post fatigue (immediate) and 5 min after fatigue measures {the mean difference was -1.1 (p=0.768)}. Also, there was no significant difference between 5 min and 10 min after fatigue measures {the mean difference was -1.2 and (p=0.594)}. While there was a significant increase in 10 min after fatigue than post (immediate) fatigue measures {the mean difference was – 2.4 in favor of 10 min after fatigue and (p=0.001)}.

Table (3): Post-hoc test between the four measurements

		Peak torque	Proprioception	Proprioception error
pre vs. post	difference	4.2	-6	-6.5
	P-value	0.001*	0.001*	0.001*
Pre vs. 5 min after fatigue	difference	3.1	-2.3	-0.9
	P-value	0.001*	1	1
Pre vs. 10 min after fatigue	difference	1.8	3.2	4.7
	P-value	0.106	0.333	0.001*
Post vs. 5 min after fatigue	difference	-1.1	3.7	5.6
	P-value	0.768	0.082	0.001*
Post vs. 10 min after fatigue	difference	-2.4	9.2	11.2
	P-value	0.001*	0.001*	0.001*
5 min vs. 10 min after fatigue	difference	-1.2	5.5	5.6
	P-value	0.594	0.009*	0.001*

Vs: versus, *: significant

The effect of quadriceps fatigue on knee proprioception measures: As demonstrated in figure (5), the means of knee flexion proprioception for four measurements; pre, post (immediate) , after 5 min and after 10 min of quadriceps fatigue were 55 ± 6), 61 ± 9.3, 57.3 ± 4.7 and 51.8 ± 1.4 degrees respectively. There was statistical significant difference between the four measurements (P=0.001).

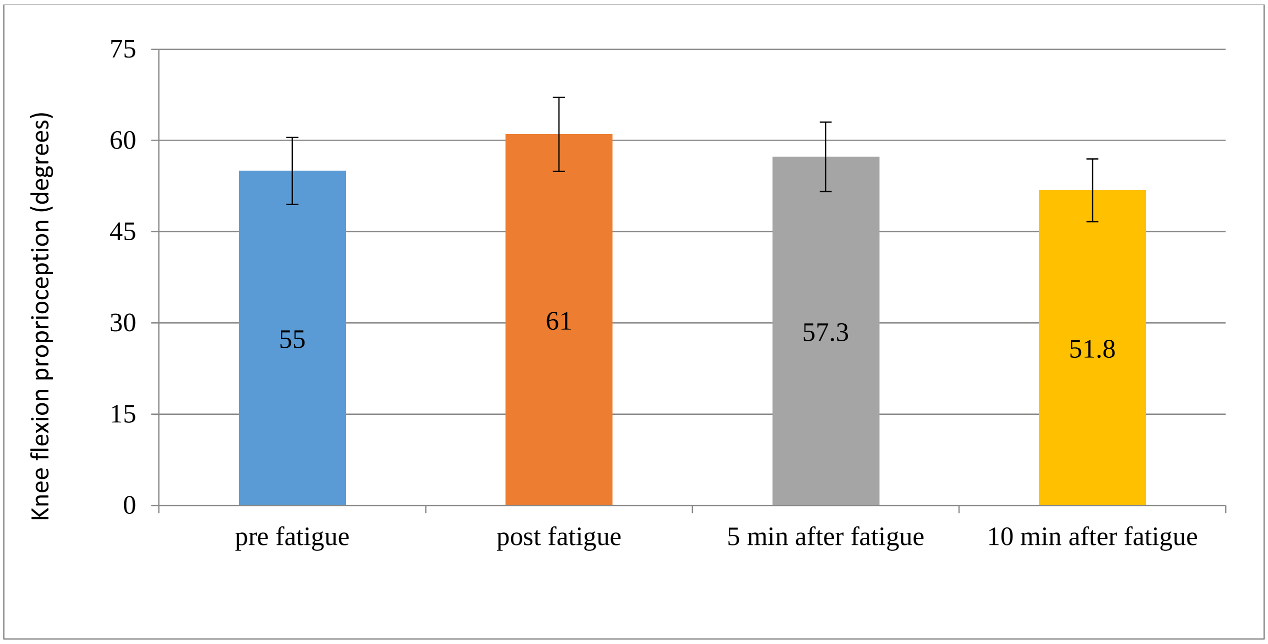

Fig. (5): Mean values and of knee flexion proprioception of the four measures.

Post-hoc test between the four measurements of proprioception:

As observed in table (3), post hoc test (Bonferroni test) for changes in the mean values of knee flexion proprioception measures revealed that there was a significant increase in post fatigue (immediate) proprioception measure than in pre fatigue measure {the mean difference was -6 in favor of post fatigue (immediate) (p=0.001)}. There was no significant difference between pre fatigue and 5 min after fatigue measures {the mean difference was – 2.3 (p=1)}. There was no significant difference between pre fatigue and 10 min after fatigue measures {the mean difference was 3.2 (p=0.333)}.

Also, there was no significant difference between post fatigue (immediate) and 5 min after fatigue measures {the mean difference was 3.7 (p=0.082)}. There was a significant decrease in 10 min after fatigue than post fatigue (immediate) measures {the mean difference was 9.2 in favor of 10 min after fatigue (p=0.001)}. Also, there was a significant decrease in 10 min after fatigue than 5 min after fatigue measures {the mean difference was 5.5 in favor of 10 min after fatigue (p=0.001)}.

The effect of quadriceps fatigue on knee proprioception error: As demonstrated in figure (6), the means of knee flexion proprioception error for four measurements; pre, post (immediate), after 5 min and after 10 min of quadriceps fatigue were 7.5 ± 2.3, 14 ± 4.6, 8.4 ± 2.7 and 2.8 ± 0.9 degrees respectively. There was statistical significant difference between the four measurements (P=0.001).

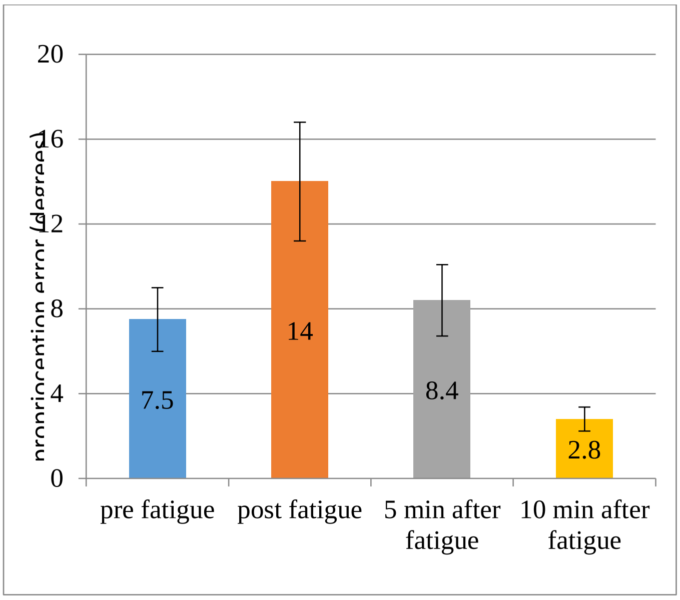

Fig. (6): Mean values of knee flexion proprioception error of the four measures.

Post-hoc test between the four measurements of proprioception error: As observed in table (3), post hoc test, (Bonferroni test), for changes in the mean values of proprioception error measures revealed that there was a significant increase in post fatigue (immediate) proprioception error measure than pre-fatigue measure {the mean difference was -6.5 in favor of post-fatigue (immediate) (p=0.001)}. There was no significant difference between pre-fatigue and 5 min after fatigue measures {the mean difference was – 0.9 (p=1)}. There was significant decrease of 10 min after fatigue than pre-fatigue {the mean difference was 4.7 in favor of 10 min after fatigue and (p=0.001)}. There was significant decrease of 5 min after fatigue than post-fatigue (immediate) {the mean difference was 5.6 in favor of 5 min after fatigue (p=0.001)}. There was significant decrease of 10 min after fatigue than post-fatigue (immediate) {the mean difference was 11.2 in favor of 10 min after fatigue (p=0.001)}. Also, there was significant decrease in 10 min after fatigue than 5 min after fatigue {the mean difference was 5.6 in favor of 10 min after fatigue (p=0.001)}.

DISCUSSION

Quadriceps muscle fatigue after closed kinetic chain exercises had negative impact on knee joint position sense in table tennis players. It has long been hypothesised that fatigue contributes to diminished proprioceptive abilities, which in turn contributes to joint injury. The current study's findings suggested that knee joint proprioception in table tennis players is decreased by tiredness from closed-chain activities, as seen by the increased reproduction error for joint position perception. Furthermore, the high frequency of injuries that develop after a period of athletic or recreational activity showed that tiredness may play a role in altered neuromuscular regulation of the lower limb and, as a result, in decreased capacity for dynamic knee stabilization **[3].**

Our study is the first to examine the effects of a semi-flexed knee position (up to 90° or more) on the position sense of the knee joint and to calculate the time needed for proprioceptive recovery. The fatigue protocol employed for this study was also distinctive since it replicated the demands of playing table tennis and may have the benefit of more precisely duplicating the alterations in neuromuscular control and proprioception seen in sporting contexts. The moment at which the patients were unable to complete the FP was used to operationally characterise fatigue **[16].** Additionally, it was defined a 20% drop in force production as "fatigued" and this definition had been validated by a previous study that statistically support our findings [21].

After fatigue, there was a statistically significant reduction in quadriceps torque (P-value < 0.001) with percentage of change 29 %. In earlier research assessing the effects of tiredness brought on by athletic exercise on proprioception, it was shown that during an overhead throw, functional exhaustion induced a considerable drop in three-dimensional multi-joint position reproduction acuity [22]. Additionally, there was a significant decline in knee joint position awareness in older subjects following maximal knee isokinetic contractions at 120°/s. They came to the conclusion that the local exhaustion regimen would confuse the muscle spindle sensitivity, leading to inaccuracies in joint position perception [23].

The findings of **Mohammadi *et al.*** [24] also demonstrated that quadriceps muscle fatigue reduced the precision of young men's reconstructions of joint angles. Muscle tiredness may directly impact this process and increase the risk of injury, especially in light of the importance of proprioception in the reconstruction of joint angles. In addition, the knee JPS was assessed following quadriceps eccentric activities till exhaustion, and proprioceptive degradation was discovered up to 48 hrs after the fatigue protocol [25]. Additionally, the results of **Changela and Selvamani** [4], which used data on young, healthy individuals to determine the threshold for movement perception before and after exhaustion, revealed a statistically significant variation in the threshold value following the induction of fatigue, supporting the findings of the investigation. Additionally, the results of **Kamrani and Khaleghi** [26] on healthy young women demonstrated that the hamstring and quadriceps muscles can become fatigued and can decrease proprioception at the knee joint.

Muscular exhaustion is known to change the peripheral proprioceptive system. Specifically, during local muscle exhaustion, nociceptors were activated by metabolic byproducts of muscular contraction, including bradykinin, arachidonic acid, and prostaglandin E2. In addition, these metabolites and inflammatory substances have a direct impact on the muscle spindle discharge pattern, which represents the exhaustion's peripheral component [27]. Additionally, fatigue modifies the peripheral proprioceptive system by increasing the threshold for muscle spindle discharge, which modifies alpha/gamma co-activation, or in alpha motoneuron activation, which modifies muscle spindle excitability through stretch, reducing the positional sensitivity of the knee [22].

The loss of muscle receptor input caused by damage to the intrafusal fibres of spindle muscles might possibly be seen as the secondary cause of the decline in JPS. Fatigue was generated by having the participant engage only the hamstring muscle, but **Gear** [28] provided contradicting results demonstrating that muscle stress had a minimal impact on knee JPS. Using isokinetic quadriceps contractions as a fatiguing protocol, the active reproduction of knee joint angles was investigated. The study found no discernible difference in joint position sense between the experimental and control groups at rest and right after exercise. It was determined, however, that weariness might not cause a deficit in knee joint position sensing. It was interestingly discovered that the sense's precision and with repeated testing, accuracy in both groups greatly increased [3]. Additionally, a prior study that investigated the effects of local and general fatigue on knee joint position sense revealed that isokinetic fatigue to the thigh muscles had no influence on absolute inaccuracy during joint reposition sense testing, despite joint position sense deteriorating after a general fatigue protocol that involved running for 5 minutes at 10 km/h while a 10% uphill grade [29].

Due to the fact that the knee flexors/extensors ratio would change as a result of the knee muscles' decreased strength during the study, it was anticipated that all subjects would be directed into flexion movement both before and after the protocol for muscle fatigue, which is the direction of non-fatigued muscle. Additionally, it would be expected that shifts in the peak torque ratio of the knee muscles towards the flexor muscles would lessen the extensor muscles' ability to stop the movement. Thus, this would result in an overestimation of the target position, which occurred in 22 subjects. However, 4 of these subjects produced more extended angles, which were explained by reproducing a greater extension to meet the reference angle [30]. It was also hypothesised that this might be due to an increase in passive tension as a result of the exercise. Furthermore, it was stated that female knee proprioception may not be significantly reduced under all types of fatigue intervention when compared to male proprioception, so we chose healthy men as our subjects to remove the gender difference effect and discuss the isolated effect of fatigue on knee proprioception [29].

The knee joint torque was negatively impacted by quadriceps fatigue. This is consistent with **Miura *et al.*** [29] results, who found that after a local load to the knee, the peak torque of the knee flexors and extensors significantly decreased. This is because muscle starts to feel fatigue as soon as its maximum force or power capacity begins to decline. The decrease in performance coincides with the rise in tiredness when the job requires maintaining a maximal contraction [31].

Determining how long it takes for a table tennis player's proprioception to recover and reach baseline levels was a crucial aspect of this study. The length of time needed for a table tennis player's proprioception to return to baseline levels after exhaustion has not been previously studied. The findings of our investigation showed that the post-fatigue proprioceptive decrease quickly restored to baseline levels. Additionally, the study's statistical analysis of knee joint proprioceptive error revealed statistically significant lower knee proprioceptive error values after 10 minutes of fatigue (p-value 0.001) in comparison with before fatigue values, which may be related to the learning. As a 5-minute break showed in the control group, there was a considerable improvement in joint position sense. This suggests that motor learning influences knee proprioception [29]. Athletes' fulfilment of their joints may be enhanced by post-exercise neurophysiological alterations in their ligaments and muscles, according to research [32].

CONCLUSION

According to the present study's findings, we concluded that quadriceps fatigue after closed kinetic chain exercises affects knee joint proprioception in tennis table players.

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