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MITIGATING WATERING HOLE ATTACKS A MULTI-LAYERED DEFENSE STRATEGY INTEGRATING MACHINE LEARNING AND BEHAVIORAL ANALYSIS

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ABSTRACT

To examine the effect of general muscle fatigue on knee joint-position sense and balance in healthy elderly men. Sixty-five healthy elderly men aged 60-70 years were recruited to participate in this study. They participated in a general fatigue protocol through running on a treadmill at a constant speed of 10 km/h. The joint position error of knee joint and balance indices were measured before and after the fatigue protocol by using an isokinetic dynamometer and Biodex stability system respectively. There was a significant increase in the repositioning error of knee joint, overall stability, anterior-posterior stability, and medial-lateral stability indices in the post-fatigue condition compared with that of the pre-fatigue condition ($p= 0.001$). This study revealed that induced general fatigue had a negative effect on proprioception of knee joint and balance of healthy elderly men

KEYWORDS Fatigue; Proprioception; Balance; Aging

1. INTRODUCTION

Fatigue is an important factor that induces changes within the neuromuscular function of the body. These fatigue-related alterations can, in turn, modify the proprioceptive and kinesthetic properties of joints by increasing joint laxity and contributing to subsequent biomechanical and sensorimotor deficits (Borotikar et al., 2008; Gribble et al., 2009). Although fatigue is prevalent in the general population, with rates ranging from 2.36% to 75.7% (Van't Leven et al., 2010), epidemiological data indicate that men experience a disproportionately higher burden (Ricci et al., 2007). This vulnerability is further intensified with aging, as men lose muscle strength at nearly twice the rate of women, directly heightening their susceptibility to fatigue-related neuromuscular impairments (Goodpaster et al., 2006).

The impact of fatigue becomes particularly critical in older adults due to its association with increased risk of falls, which constitute a major health concern with significant economic and psychological consequences (Campbell et al., 1981). A central component linking fatigue to fall risk is the deterioration of proprioceptive and balance mechanisms, two systems that operate synergistically to maintain postural control and ensure movement accuracy (Kellis & Kouvelioti, 2009; Givoni et al., 2007). Proprioceptive feedback arising from muscle spindles, ligaments, and joint capsules provides essential afferent information for motor programming, dynamic joint stability, and coordinated movement (Ju et al., 2013; Elgohary et al., 2025). This information is continuously integrated with visual and vestibular inputs within the central nervous system to generate effective balance responses (Salavati et al., 2007).

Research examining the effects of fatigue on joint position sense and postural control has yielded conflicting results. While several studies have reported that fatigue impairs knee joint proprioception (Falla et al., 2008; Larochelle et al., 2009; Lattanzio et al., 1997) and reduces balance performance and postural stability (Helbostad et al., 2010), other studies have found no significant changes in joint position sense following fatigue (Gear, 2011; Steib et al., 2013).

The inconsistencies in the literature regarding the effects of fatigue on proprioception and balance, combined with the heightened vulnerability of aging men to neuromuscular decline, underscore the need to investigate how fatigue influences these interdependent systems. Accordingly, this study was designed to examine the impact of induced general

fatigue on knee joint proprioception and balance in healthy elderly men, with the hypothesis that fatigue would significantly impair both proprioceptive accuracy and postural control in this population.

2. METHODS

Sixty-five sedentary healthy elderly men participated in this study, from February to May 2023. Their age, weight, and height ranged from 60-70 years, 65-85 kg, and 160-175 cm, respectively. The participants were identified and recruited using targeted Facebook advertisements and word-of-mouth communication within the local community. The inclusion criteria were healthy non-athletic subjects, free from any musculoskeletal, neuromuscular, vestibular, cardiovascular or respiratory disorders, visual problems, or lower extremity injuries or deformities. Subjects were excluded if they were taking analgesics, energy drinks, or other medication that affect sensation or balance. The purpose and procedure of this study were explained in detail for all participants, and all subjects signed an institutionally approved informed consent form which was approved by the Ethics Committee of the Faculty of Physical Therapy, Beni-Suef University No: FPTBSUREC/0512/15426.

3. INSTRUMENTATION

3.1. *Biodex System 3 pro-isokinetic dynamometer*

A Biodex System 3 pro-multijoint system isokinetic dynamometer (Biodex Medical Inc., Shirley, New York, USA) was used to measure the proprioception accuracy of the knee joint. The Biodex isokinetic dynamometer was a valid and reliable device for joint position sense measurements (Drouin, 2004).

3.2. *Biodex Balance System*

A Biodex stability system (BSS) (Biodex Medical System Inc., Shirley, NY, USA) was used for the dynamic balance assessment. The BSS was a reliable device for static and dynamic balance assessment (Arifin et al., 2014). The system consisted of a circular platform able to tilt up to 20° in a range of 360°; and a display screen that provided visual feedback about the degree of platform displacement. During assessment the subject was instructed to maintain the cursor in the center of the screen to obtain a better balance score. BSS stability levels ranged from 1 to 12, with 1 representing the least-stable level. Balance testing in this study was conducted at a moderate level of 4. Three balance indices obtained by BSS software: Overall stability index (OSI), anterior-posterior stability index (APSI) and medial-lateral stability index (MLSI) with higher scores indicating

weaker postural control. The stability index represents the mean angular displacement of the platform from the level zero-point position.

4. PROCEDURE

Before the evaluation procedures, all participants were given an explanatory session to be aware about the different test steps. All assessment measures were conducted two times on two separate days; one for pre-fatigue assessment and the next day for post-fatigue (the measurement was performed immediately after the fatigue protocol).

4.1. Proprioception assessment

The passive extension-active replication method of the knee was assessed for only the dominant lower extremity for all participants to facilitate the testing setup and because previous studies reported no proprioceptive differences between dominant and non-dominant extremities (Jerosch & Prymka, 1996). For proprioception assessment of the knee joint, the participants were asked to sit on the chair of the Biodex System in a comfortable position, with a belt across the trunk, pelvis, and thigh. The distal tibia was fixed to the dynamometer's lever arm. The knee joint axis was aligned with the mechanical axis of the dynamometer through the lateral femoral condyle in the sagittal plane. The seatback was inclined at a 70-80° angle with seat orientation at 90°. The dynamometer head tilted at 0° and the orientation was at 90°. Participants were asked to close their eyes with the leg flexed at 90° for angle replication. At a rate of about 10° per second, the subject's leg was passively extended to reference angles of 45°. This angle was held for 10 seconds and then passively returned to the flexion starting position. To replicate the reference angle, the subject was asked to extend the leg and push the red button on the handheld device when they reached the reference angle. The test was repeated three times with 30 seconds of rest between each trial. The degree difference between the index angle and the reproduced angle [Joint Position Error (JPE)] reflected the subject's ability to estimate the joint position. The average of the three trials was calculated and used in the statistical analysis (Saleh & Abd El-Hakim Abd El-Nabie, 2018).

4.2. Balance assessment

At first, the support rails and biofeedback display screen of the BBS system were adjusted for each participant to ensure comfort and safety during the test procedure, then each participant was trained 1 minute for adaptation to the machine. During the test, the participants were instructed to stand on the biodex platform in the most comfortable posture with

arms by sides and to look straight ahead to the display screen. Visual feedback of the cursor on the screen grid guides the feet adjustment to achieve the platform stability. The participant's feet were adjusted to a position where they were able to maintain the platform stability. When the test starts, the platform unlocks and starts to displace in different directions. The participants tried to maintain the cursor centered on the screen grid and maintain balance. Balance testing consisted of three trials, each assessment took 20seconds with a rest period of 20 seconds between trials (Pugh et al., 2011). The average of the three trials was calculated and used in the statistical analysis.

4.3. General muscle fatigue protocol

General muscular fatigue was induced in all participants through an aerobic exercise protocol. Each participant ran on a treadmill for 21 minutes, with the speed gradually increasing from 2.7 to 9.6 km/h in accordance with the Bruce fatigue protocol (Bruce et al., 1973). This protocol has been compared with other similar fatigue protocols using various indices, including oxygen consumption rate, maximum heart rate, and blood pressure, with findings indicating no significant differences between them (Pollock et al., 1976). To ensure the achievement of general muscular fatigue, participants' heart rates were visually monitored and maintained above 60% of their maximum heart rate during the final 10 minutes of exercise. The maximum heart rate for each participant had been determined one week prior to the testing session.

4.4. Sample size Calculation

To avoid type II errors, sample size calculation was performed prior to the study using G*POWER statistical software (version 3.1.9.2). Calculation was made using repeated measures-within factors, $\alpha=0.05$, $\beta=0.2$, and effect size = 0.25; and revealed that the required sample size for this study was N=65.

4.5. Statistical analysis

The scores of knee joint proprioception, and balance indices were compared between before and after fatigue protocol. Repeated measure design was conducted for comparison of JPE of knee joint, OSI, APSI, and MLSI between pre-fatigue state and post-fatigue state. A $p < 0.05$ was set as the level of significance. The statistical package for social studies (SPSS) version 25 for Windows (IBM SPSS, Chicago, IL, USA) was used for statistical analyses.

5. RESULTS

5.1. Participants' characteristics

The participants' characteristics including age, weight, height and BMI are presented in Table 1.

Table 1: Mean age, weight, height and BMI of the participants.

	Mean \pm SD
Age [years]	64.1 \pm 3.8
Weight [kg]	71.36 \pm 5.2
Height [cm]	161.22 \pm 6.21
BMI [kg/m ²]	24.9 \pm 0.5

SD: Standard deviation; BMI: Body Mass Index

5.2. Effect of fatigue on knee joint proprioception, and balance indices.

Table 2 shows descriptive statistics of dependent variables as well as the significant level of comparison between pre-fatigue state and post-

Table 2: Comparison of mean value of knee joint position error, overall stability, anterior-posterior stability, and medial-lateral stability index between pre and post fatigue.

	Pre fatigue (Mean \pm SD)	Post fatigue (Mean \pm SD)	MD (95% CI)	p-value
JPE of knee joint	3.53 \pm 1.31	5.86 \pm 1.52	-2.33 (-1.18: -1.07)	0.001
OSI	2.47 \pm 0.5	3.65 \pm 0.7	-1.18 (-1.61: -1.11)	0.001
APSI	3.18 \pm 1.1	5.81 \pm 1.46	-2.63 (-2.26: -1.51)	0.001
MLSI	2.27 \pm 0.65	4.4 \pm 1.13	-2.13 (-2.24: -1.68)	0.001

SD: Standard deviation, MD: Mean difference, CI: Confidence interval, p-value: level of significance, JPE: Joint Position Error, OSI: Overall Stability Index, APSI: Anterior-Posterior Stability Index, MLSI: Medial-Lateral Stability Index.

6. DISCUSSION

This study was conducted to examine the impact of general muscle fatigue on knee joint proprioception, and balance in healthy elderly men. The results showed that fatigue increased the JPE of the knee joint. Also, it increased the OSI, APSI, and MLSI. This was coincident with the findings of Rozzi et al. 2000 who concluded that fatigue can change the properties of joints proprioception, and increase the discharge threshold of muscle spindle, which can then disturb the afferent feedback and alter joint awareness. Moreover, Proske & Gandevia, 2012 found that muscle fatigue changes the joint sense of position and movement feedback, which possibly will decrease the ability to monitor changes in postural stability that limits the ability to control posture and movement.

The results of the current study regarding knee joint proprioception deficits after general fatigue concur with findings of Okhravi et al. 2015 who found a significant difference in the head and neck proprioception in a group of young healthy adults exposed to a general fatigue task when compared to a control group. In addition, the result supported by Givoni et al. 2007 who reported that after exercising the quadriceps muscle, there was a significant increase in the sense of position errors of the knee joint.

Moreover, the result came in agreement with Salgado et al. 2015 who examined the effect of pre-match warm-up and post-match fatigue on the knee

fatigue state. There was a significant increase in JPE of the knee joint post-fatigue compared with that pre-fatigue condition ($p = 0.001$). Also, there was a significant increase in OSI, APSI, and MLSI in post-fatigue condition compared with that of pre-fatigue condition ($p = 0.001$).

joint position sense of football players, and they found that, knee joint sense of position increased with warm-up exercise before participation the match and decreased during the match due to muscle fatigue. Also, the result supported by Bazneshin et al. 2015 who reported that in healthy males, the quadriceps muscle fatigue develops an increased error rate of the knee joint reposition angle at 45°. However, the current results came in contradict with Gear, 2011 who investigated the effect of increased fatigue on active reposition sense of the knee joint, and they reported that fatigue does not have a significant effect on active joint reposition sense at 15° and 45° angles of the knee joint flexion. This difference may be attributed to differences in mean age and measured tools between both studies.

Regarding the effect of general fatigue on balance, it was found that general fatigue led to decrease balance. This finding could be explained by the findings of Papa et al. 2015 who found that, acute muscle fatigue altered the lower extremity joint kinematics which was accompanied with a reduced step length. The present results are coincident with the findings of Nagano et al. 2014 who examined the effect of fatigue on controlling the lower limb range of motion, falling risk and walking abilities of young (18–35 years) and older adults (>65 years). They stated that regardless of age, fatigue induced an increased step width, and impaired balance. In addition, there was longer double limb support duration and longer duration of foot clearance were

observed in the non-dominant limb of elderly, which could be unsafe for symmetrical gait.

In the contrary the results disagree with Morrison et al. 2016 who found that, the treadmill-walking task did not cause a significant increased falling risk. This difference may be attributed to differences in mean age and usage of different fatigue protocols. Also, the reduced balance in the current study were not supported by the findings of Joudeh et al. 2018 who evaluated the effect of quadriceps or calf muscles fatigue on static and dynamic balance in healthy males with age ranged from 18 to 30 years, and they reported that this protocol did not perturb standing balance in this age category.

This study was limited to the following: The current study was conducted on healthy elderly men. So, the findings cannot be generalized for other age groups or subjects suffering from musculoskeletal disorders. The assessed outcomes were conducted immediately after the fatigue protocol, while these results may change if tests were performed 15 minutes after the fatigue protocol as reported in the previous studies. Further research work is needed to investigate the effect of fatigue on the reaction times, gait kinematics, and kinetics; in addition to isokinetic parameters such as torque, fatigue and power of the lower-extremity muscles.

7. CONCLUSION

The findings of this study revealed that general

muscle fatigue impairs the proprioception of the knee joint. Furthermore, it inversely affected the postural stability of healthy elderly men. So, the assessment of the joint position sense and balance following activity may give a better imminent view of the overall risks.

CONSENT TO PARTICIPATE

All patients received a thorough explanation of all study procedures before signing a written informed consent that acknowledged the security of their data and recognized the study's nature, purpose, and the opportunity for them to withdraw from it at any time without fear of consequences.

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CONFLICT OF INTEREST

There is no any conflict of interest that may have affected either the conduct or the presentation of this research.

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DATA AVAILABILITY

All relevant data used and/or analyzed during the current study are available upon reasonable request from the corresponding author.

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