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Effects of localized arm fatigue, general fatigue, and elbow bracing on shooting accuracy and shoulder proprioception: a randomized crossover study

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ABSTRACT

Objectives: This study aimed to comparatively investigate the effects of localized arm fatigue, general fatigue, and elbow brace use on proprioceptive accuracy and shooting accuracy in amateur female basketball players.
Methods: Fifty-two amateur female basketball players (mean age: 23.08±2.02 years) participated in a randomized crossover study. Participants underwent three experimental conditions: localized arm fatigue, general fatigue, and brace application, each tested on separate days with a 48-hour washout period between sessions. Proprioceptive accuracy was assessed using the Joint Position Sense Error (in degrees), and shooting accuracy was evaluated based on shot success percentage. Fatigue perception was measured using the Borg Rating of Perceived Exertion Scale. Statistical analyses included Friedman and Wilcoxon signed-rank tests with Bonferroni correction for multiple comparisons.
Results: Localized arm fatigue significantly decreased shooting accuracy (from 53.16% to 38.83%, P=0.014) and increased proprioceptive error (from 5.40° to 8.65°, P=0.003). General fatigue resulted in a moderate increase in proprioceptive error (from 4.05° to 5.35°, P=0.049) but did not significantly affect shooting accuracy (P=0.090). The use of an elbow brace improved proprioceptive accuracy (error reduction from 5.30° to 3.00°, P=0.035) and marginally enhanced shooting performance (increase from 48.33% to 54.83%, P=0.027). Strong negative correlations were found between proprioceptive degradation and shooting accuracy after localized fatigue (r= –0.787, P<0.001).
Conclusions: Localized arm fatigue impairs proprioception and shooting accuracy more severely than general fatigue. Elbow bracing mitigates these impairments, suggesting its use as an intervention to maintain technical performance under fatigue in basketball athletes.
Keywords: Proprioception, localized fatigue, elbow brace, shooting accuracy, basketball, crossover study

Fatigue is a pervasive physiological phenomenon that affects various dimensions of athletic performance, including muscular strength, coordination, sensorimotor control, cognitive processing, and technical execution [1]. In sports that demand a combination of endurance, precision, and motor control - such as basketball - fatigue can disrupt not only physical outputs but also fine motor skills essential for

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successful skill-based actions [2]. One of the most fatigue-sensitive elements of basketball performance is shooting accuracy, which requires sustained motor precision and neuromuscular coordination under both physical and mental stress [3].

Numerous studies have documented that fatigue - whether systemic or task-specific - can lead to decrements in shooting accuracy, reaction time, and joint stability. Li *et al*. [4], in a recent meta-analysis, demonstrated that moderate physical fatigue significantly reduces two-point shot success, while severe fatigue impairs both two- and three-point accuracy. Furthermore, mental fatigue was found to compromise shooting accuracy, underscoring the multifactorial nature of fatigue-related performance decline. However, despite a growing body of evidence, the mechanisms through which different types of fatigue exert their effects remain insufficiently understood, particularly regarding localized versus systemic fatigue pathways.

Localized muscle fatigue - especially in the upper extremities - may disproportionately affect technical performance by impairing proprioception, a critical component of motor control. Proprioception enables athletes to perceive joint position and movement, allowing for precise execution of complex motor tasks. Shoulder joint proprioception, in particular, plays a central role in upper-limb-dominant movements such as shooting in basketball. Previous findings have indicated that fatigue impairs joint position sense, which may, in turn, deteriorate shooting mechanics and consistency [5-7].

At the same time, proprioceptive aids - such as elbow braces - have been suggested as a potential strategy to counteract fatigue-induced impairments. These braces provide mechanical support and stimulate cutaneous and joint mechanoreceptors, thereby potentially enhancing sensorimotor integration and joint awareness under fatigued conditions [8, 9]. Yet, despite promising theoretical frameworks, few controlled studies have directly evaluated the effectiveness of elbow bracing in mitigating performance deficits due to fatigue.

To date, most studies have either evaluated fatigue in general terms or failed to distinguish between different types of fatigue and their unique consequences. Although proprioception has often been evaluated under fatigue conditions, to the best of our knowledge, there are no randomized crossover studies in the literature that simultaneously examine these effects alongside interventions such as elbow bracing. Additionally, amateur female basketball players remain underrepresented in this research field, despite their growing participation in competitive sports.

Therefore, the aim of this study was to comparatively investigate the effects of localized arm fatigue, general fatigue, and elbow bracing on proprioceptive accuracy and shooting accuracy in amateur female basketball players. This study is novel in its design, as it simultaneously explores three distinct experimental conditions within the same participant group, providing a within-subject control for inter-individual variability. We hypothesized that localized arm fatigue would produce greater impairments in proprioception and shooting performance compared to general fatigue, and that the use of an elbow brace would mitigate some of these impairments. These findings could have practical implications for designing targeted fatigue management and proprioceptive training interventions in basketball and other precision-dependent sports.

METHODS

This study was conducted between February 2024 and January 2025 at Nuh Naci Yazgan University, Kayseri, Turkey. The sample size was determined through an a priori power analysis, which utilized preliminary data from a previous study conducted by our research team and presented at a national sports science conference [10]. In that preliminary study, a moderate effect size (r=0.38) was observed for the association between arm fatigue and shooting accuracy. The sample size calculation in the current study was based on this published conference data provided by the same research group. Based on this effect size, a two-tailed analysis with an alpha level of 0.05 and a desired power of 0.80 indicated that a minimum of 52 participants would be necessary. Participants were active basketball players, training at least three days a week, aged below 35, and free from health issues or injuries within the past year that could affect performance. Only individuals with a minimum of five years of experience in amateur-level basketball were included. Participants with any history of orthopedic surgery were excluded. Participants were also screened to ensure no history of upper limb injuries or surgeries within the past 12 months.

All participants confirmed current injury-free status through pre-study interviews and physical clearance by the supervising physiotherapist.

The study was conducted in accordance with the Declaration of Helsinki, and was approved by the Nuh Naci Yazgan University Scientific Research and Publication Ethics Committee (protocol code 2024/002-01, approval date: 12 February 2024).

Age, body weight, and height were recorded for each subject. Body mass index (BMI) was calculated using the body weight/height2 (kg/m2) formula.

Study Design

This study employed a randomized crossover experimental design, involving 52 amateur female basketball players actively engaged in regular training. Each participant underwent three distinct experimental conditions—localized arm fatigue, general fatigue, and elbow bracing - across three separate testing days, with the order of conditions randomized and counterbalanced to minimize order effects and learning bias. On each test day, only one condition was assessed to avoid carry-over fatigue or confounding influences, with a 48-hour washout period between sessions to ensure adequate recovery. By allowing each participant to serve as her own control under systematically varied sequences, this counterbalanced crossover structure reduced intra-subject variability, controlled for sequence-dependent effects, and enhanced both the internal validity and statistical power of the study (Fig. 1).

Randomization was performed using a computer-generated random sequence (www.randomizer.org) to assign participants to different experimental conditions on each testing day. The sequence generation and allocation were conducted by an independent researcher not involved in data collection to ensure allocation concealment.

Evaluation and Measurements

The evaluation of Proprioception

Shoulder proprioceptive accuracy was assessed using the Joint Position Sense Error (JPSE) test, a validated method for evaluating joint position sense, particularly in upper limb neuromuscular assessments [11]. The test quantifies the angular deviation between a passively imposed reference position and the participant's attempt to actively replicate it.

Participants were seated with the tested shoulder joint unrestrained to allow movement in the sagittal plane. A reference position was established by passively positioning the dominant arm at 60° and 100° of shoulder flexion. After memorizing this position with eyes open, participants closed their eyes and attempted to replicate the same angle with the contralateral limb. The deviation between the replicated and target angles was measured using a digital goniometer. Each measurement was repeated three times, and the average of the trials was used for analysis. Standardized instructions were given, and no tactile or verbal cues were provided during the test to ensure procedural consistency [11].

Brace Condition and Compression Rationale

In the brace condition, participants wore a commercially available elbow support brace (Nike NKS09-010 NBA Elite), which provides moderate circumferential compression and proprioceptive feedback through mechanoreceptor stimulation around the elbow joint. The brace was worn on the dominant arm throughout both the proprioception test and the shooting trials. The rationale behind brace application was based on evidence suggesting that external joint compression can enhance sensorimotor feedback, improve joint awareness, and mitigate the negative effects of fatigue on proprioceptive acuity.

By applying gentle pressure to the soft tissue around the elbow, the brace may increase afferent input from cutaneous and joint receptors, thereby facilitating central nervous system integration of joint position information. This potential enhancement in joint sense was systematically evaluated by repeating the JPSE protocol while the brace was worn, using the same procedure and angles as in the non-braced condition.

Modified Borg Scale (Borg)

Borg was used to evaluate fatigue levels. This scale ranges from 0 to 10, with each number corresponding to a specific level of perceived fatigue. A score of "0" indicates no fatigue, while "10" represents maximum fatigue. The Borg provides a standardized and reliable measure for assessing both arm and general fatigue levels [12].

Exercise to Fatigue the Arm and General

To induce localized arm fatigue, each participant's one-repetition maximum (1RM) was estimated using

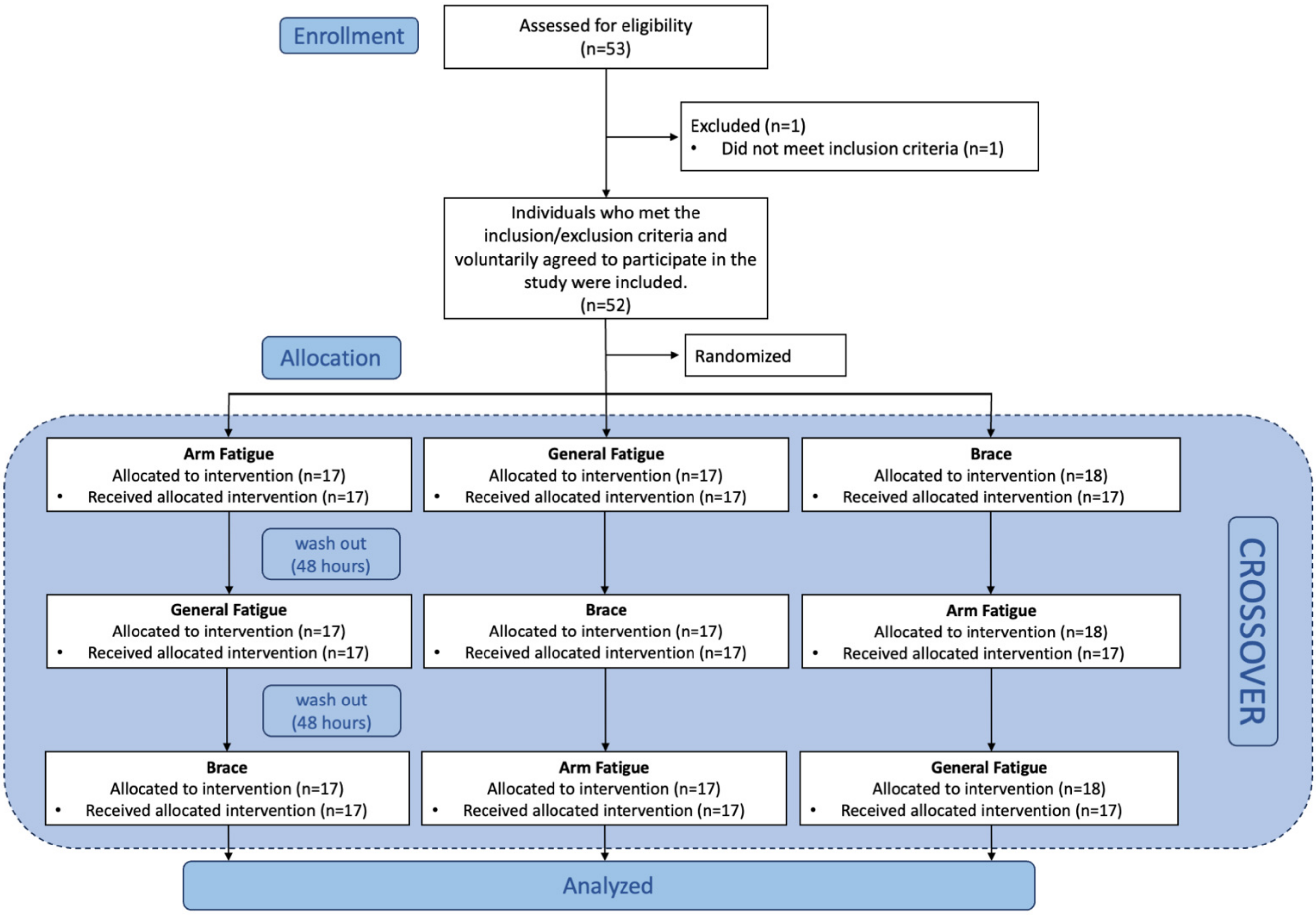

Fig. 1. **Flow chart.**

a submaximal strength testing protocol based on the number of repetitions completed with a given load. This approach allowed for individualized fatigue calculations for both the bench press and shoulder flexion exercises [13].

Based on these estimations, participants performed five sets of 15 repetitions of bench press and shoulder flexion exercises at 60% of their calculated 1RM, with 60 seconds of rest between sets. Exercises were conducted using standard gym equipment under supervision. During the final set, most participants were unable to complete all 15 repetitions independently. At this point, the supervising physiotherapist provided minimal support to ensure participants reached volitional fatigue, defined as the point where the participant could no longer perform repetitions with correct technique without external assistance.

To induce general fatigue, participants engaged in a standardized 60-minute basketball conditioning session supervised by a strength and conditioning coach. This session included aerobic drills such as shuttle runs and agility ladder exercises, plyometric activities including jump squats and lateral bounds, and basketball-specific skill work such as fast break drills and full-court scrimmage play. This combination was designed to simulate the physical and neuromuscular demands typically experienced during actual competitive basketball games.

Fatigue levels were validated through a combination of methods: participants' subjective ratings on the Modified Borg Scale (0-10), verbal confirmation of exhaustion, and observational assessment of decreased movement quality or inability to complete exercises. All sessions were monitored by licensed physiotherapists to ensure participant safety and protocol consistency.

Goal Percentage

To determine the goal percentages, each player was instructed to attempt fifty free throws, with the number of successful attempts recorded. The percentage of accurate shots was subsequently calculated based on the total attempts.

Experimental Procedure

The study was conducted over three non-consecutive days, and participants were randomly assigned to different experimental conditions each day. On each testing day, all three experimental conditions - localized arm fatigue, general fatigue, and brace use - were administered simultaneously, but to different randomly assigned subgroups of participants (Fig. 1).

Day 1: Participants were randomized into three groups, with each group undergoing one of the experimental conditions (localized arm fatigue, general fatigue, or brace use). Baseline assessments (shoulder proprioception, shooting accuracy, and Borg fatigue score) were performed, followed by the assigned intervention and post-condition assessments.

Day 2: After a 48-hour washout period, participants rotated to a different condition according to a counterbalanced schedule, ensuring that no participant repeated the same condition.

Day 3: After a 48-hour washout period, participants completed the remaining third condition with corresponding baseline and post-intervention measurements.

This design ensured that each participant experienced all three interventions across the study period while minimizing order and learning effects. Each participant served as her own control for comparisons among the three conditions, consistent with the principles of a randomized crossover study.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). Data normality was assessed using the Shapiro-Wilk test. As the data were not normally distributed, nonparametric statistical tests were applied. Overall differences across experimental conditions (rest, after arm exercise, and after routine training) were evaluated using the Friedman test. When significant differences were detected, pairwise comparisons were conducted using the Wilcoxon Signed-Rank Test with Bonferroni adjustment to control for multiple comparisons (adjusted significance threshold: $P<0.0167$). The Bonferroni method was chosen to reduce the risk of Type I error by dividing the standard alpha level (0.05) by the number of pairwise comparisons (3), yielding a corrected significance level for each comparison. Changes in shooting performance, proprioceptive accuracy, and fatigue perception were compared between conditions. Effect sizes (r) were calculated for Wilcoxon tests. Spearman rank correlation analyses were performed to assess the relationships between changes in proprioceptive deflection angles, fatigue perception scores, and shooting accuracy. Statistical significance was set at $P<0.05$, except for pairwise comparisons where the Bonferroni-adjusted threshold was applied.

RESULTS

Participant characteristics are summarized in Table 1. A total of 52 female basketball players participated in this study. The mean age of the participants was 23.08±2.02 years, and the mean height was 176±12.05 cm. The mean weight was recorded as 68.75±7.58 kilograms, and the mean BMI was calculated to be 22.49±1.21 kg/m². On average, participants reported 9.2±3.0 years of basketball experience and trained 4.2±0.6 days per week.

Descriptive and comparative data on perceived arm and general fatigue across the three experimental conditions (rest, after arm exercise, and after routine training) are presented in Table 2. Fatigue levels were assessed at rest, after localized arm exercise, and after routine training. The analysis revealed statistically significant differences in both perceived arm fatigue and general fatigue scores across the three conditions. For arm fatigue, the mean Borg score at rest was

Table 1. Participant characteristics

Variables	Data (n=52)
Age (years)	23.08±2.02
Height (cm)	176±12.05
Weight (kg)	68.75±7.58
Body mass index (kg/m^2)	22.49±1.21
Years of basketball experience	9.2±3.0
Weekly training frequency	4.2±0.6

Data are shown as mean±standard deviation

Table 2. The comparisons of arm fatigue and general fatigue after arm exercise and routine training

	Rest	After arm exercise	After routine training	Friedman Test χ^2	P value	Effect size (Kendall's W)	95% CI (Arm exercise vs. Rest)	95% CI (Routine training vs. Rest)	Pairwise Comparisons (Wilcoxon Signed-Rank Test, Bonferroni corrected P<0.0167)
Arm fatigue (Borg)	1.00±0.87	7.35±0.96	4.15±0.82	104.00	**<0.001**	1.00	6.00-6.70	2.83-3.47	Rest vs Arm exercise: **P<0.001*** Rest vs Routine training: **P<0.001*** Arm exercise vs Routine training P=0.018 (NS)
General fatigue (Borg)	1.29±0.86	6.37±1.08	4.39±0.85	100.57	**<0.001**	0.97	4.70-5.46	2.77-3.43	Rest vs Arm exercise **P<0.001*** Rest vs Routine training: **P<0.001*** Arm exercise vs Routine training P=0.022 (NS)

Data are shown as mean±standard deviation. CI=confidence interval. Friedman tests were used to assess overall differences among conditions. Pairwise comparisons were conducted using Wilcoxon Signed-Rank Tests with Bonferroni adjustment.

*Statistically significant after Bonferroni correction (adjusted significance threshold: P<0.0167).

NS=not significant after Bonferroni correction.

1.00±0.87, which increased to 7.35±0.96 after arm exercise and to 4.15±0.82 following routine training. The Friedman test indicated a significant overall difference (χ^2=104.00, Kendall`s W=1.00; P<0.001). Post-hoc pairwise comparisons using the Wilcoxon Signed-Rank Test with Bonferroni correction (adjusted significance threshold P<0.0167) showed that arm fatigue scores were significantly higher after arm exercise compared to rest (95% confidence interval [CI]: 6.00-6.70, P<0.001) and after routine training compared to rest (95% CI: 2.83-3.47, P<0.001). However, the comparison between post-arm exercise and post-routine training was not statistically significant after correction (P>0.05). Similarly, for general fatigue, the mean Borg score was 1.29±0.86 at rest, increasing to 6.37±1.08 after arm exercise and 4.39±0.85 after routine training (Table 2). The Friedman test again revealed a significant overall difference (χ^2=100.57, Kendall`s W=0.97; P<0.001). Pairwise comparisons showed that general fatigue scores were significantly higher after arm exercise compared to rest (95% CI: 4.70-5.46, P<0.001) and after routine training compared to rest (95% CI: 2.77-3.43, P<0.001). The difference between post-arm exercise and post-routine training, however, did not reach statistical significance after Bonferroni correction (P>0.05).

The effects of arm fatigue, general fatigue, and brace use on shooting accuracy and shoulder proprioception were analyzed and are presented in Table 3. Following localized arm fatigue, a significant decrease in shooting accuracy was observed. The median shooting percentage declined from 53.16% (range: 18-82%) before arm fatigue to 38.83% (range: 16-68%) after arm fatigue, with the Wilcoxon Signed-Rank Test yielding a statistically significant result (z= –2.447, r=0.34, 95% CI: 0.07-0.56; P=0.014). This represents a moderate effect size, suggesting that arm fatigue has a meaningful impact on shooting accuracy. Additionally, shoulder proprioceptive accuracy deteriorated, as evidenced by an increase in the median deflection angle from 5.40° (range: 3.17°-8.83°) to 8.65° (range: 4.50°-13.50°) after arm fatigue (z= –2.981, r = 0.41, 95% CI: 0.15-0.61; P=0.003), corresponding to a moderate-to-large effect size. In the brace condition, the use of an elbow brace positively influenced both shooting accuracy and proprioceptive control. The median shooting percentage improved from 48.33% (range: 30-66%) without the brace to 54.83% (range:

Table 3. Comparison of goal percentage and proprioception deflection angle according to arm fatigue, general fatigue and brace use

	Before arm fatigue	After arm fatigue	Z value	r	95% CI	P value
Goal percentages (%)	53.16 (18-82)	38.83 (16-68)	-2.447	0.34	0.07-0.56	**0.014***
Proprioception (Deflection angle)	5.40 (3.17-8.83)	8.65 (4.50-13.50)	-2.981	0.41	0.18-0.61	**0.003***
	With braces	**Without braces**				
Goal percentages (%)	54.83 (40-70)	48.33 (30-66)	-2.208	0.31	0.04-0.53	**0.027***
Proprioception (Deflection angle)	3 (0.30-6.14)	5.30 (3.07-8.34)	-2.005	0.28	0.01-0.51	**0.035***
	Before general fatigue	**After general fatigue**				
Goal percentages (%)	54.33 (24-74)	49.16 (20-70)	-1.694	0.23	-0.05-0.47	0.090
Proprioception (Deflection angle)	4.05 (0.50-7.40)	5.35 (3.42-7.43)	-2.275	0.32	0.04-0.54	**0.049***

Data are shown as median (minimum-maximum). Negative z-values indicate a decline in shooting performance or proprioceptive accuracy after intervention.

*P<0.05, Wilcoxon Signed-Rank Test.

40-70%) with the brace (z=–2.208, r=0.31, 95% CI: 0.04-0.54; P=0.027), indicating a moderate effect size. Similarly, shoulder proprioceptive accuracy was enhanced, with the median deflection angle decreasing from 5.30° (range: 3.07°-8.34°) without the brace to 3.00° (range: 0.30°-6.14°) with the brace (z= –2.005, r=0.28, 95% CI: 0.01-0.51; P=0.035), also reflecting a small-to-moderate effect. Regarding general fatigue, no statistically significant change was found in shooting accuracy. The median shooting percentage decreased slightly from 54.33% (range: 24-74%) to 49.16% (range: 20-70%) following general fatigue (z= –1.694, r=0.23, 95% CI: –0.05-0.47; P=0.090), corresponding to a small effect size. However, a statistically significant impairment in shoulder proprioceptive control was observed, with the median deflection angle increasing from 4.05° (range: 0.50°-7.40°) to 5.35° (range: 3.42°-7.43°) after routine training (z= –2.275, r=0.32, 95% CI: 0.05-0.55; P=0.049), which reflects a moderate effect size.

Correlation analyses revealed a moderate, statistically significant negative association between perceived arm fatigue and shooting performance following arm-specific fatigue (r= –0.469, P=0.033, Table 4). Moreover, changes in proprioceptive deflection angles before and after arm fatigue demonstrated a strong negative correlation with shooting accuracy (r= –0.787, P<0.001), suggesting that greater proprio-

Table 4. Relationship between arm fatigue, general fatigue, and proprioceptive deflection angle with goal percentage

	Goal percentages (%)			Goal percentages (%)	
After arm exercise	**r**	**P value**	**After routine training**	**r**	**P value**
Arm fatigue (Borg)	-0.469	**0.033***	**Arm fatigue (Borg)**	-0.344	**0.046***
General fatigue (Borg)	-0.245	0.063	**General fatigue (Borg)**	-0.076	0.123
Proprioception (Deflection range difference[a])	-0.787	**<0.001***	**Proprioception (Deflection range difference[b])**	-0.566	**0.045***

*P<0.05, Spearman correlation analysis.

[a]Difference in shoulder proprioception deflection angle before and after arm exercise.

[b]Difference in shoulder proprioception deflection angle before and after routine training.

ceptive degradation is closely linked with poorer shooting performance. In contrast, general fatigue exhibited a weaker and non-significant relationship with shooting accuracy (r= –0.245, P=0.063). Nevertheless, the changes in proprioceptive deflection after general fatigue were moderately and negatively correlated with shooting performance (r= –0.566, P=0.045).

DISCUSSION

This study aimed to investigate the effects of localized arm fatigue, general fatigue, and elbow brace use on shooting accuracy and shoulder proprioception in amateur female basketball players. The key findings indicated that localized arm fatigue significantly impaired both shooting accuracy and shoulder joint position sense, whereas general fatigue had a lesser impact, affecting proprioception but not shooting accuracy. In contrast, wearing an elbow brace during performance trials appeared to enhance both shooting accuracy and proprioceptive control. These results suggest that different types of fatigue may elicit distinct neuromuscular effects, and that external joint support - such as an elbow brace - can provide both proprioceptive and performance-related advantages.

Muscle fatigue has been widely reported to compromise motor control and coordination, particularly in movements requiring fine neuromuscular precision, such as shooting. Enoka and Duchateau [1] demonstrated that fatigue alters motor unit recruitment patterns and reduces execution accuracy during skilled tasks. Additionally, Gandevia [14] highlighted that fatigue not only reduces muscle force production but also impairs proprioceptive feedback mechanisms that are critical for fine motor adjustments. These disruptions can collectively undermine athletic performance during precision tasks. In line with these findings, the present study demonstrated that localized arm fatigue significantly impaired both shooting accuracy and shoulder proprioception in amateur female basketball players. The very high Kendall’s W values obtained for fatigue induction (W=1.00 for localized and W=0.97 for general fatigue) support the robustness and reliability of the applied fatigue protocols. Moreover, a strong negative correlation was found between arm fatigue levels and shooting performance, indicating that fatigue affecting specific muscle groups responsible for technical execution can substantially reduce task efficiency. The observed increase in proprioceptive deflection angles under fatigue conditions further supports the notion that proprioceptive degradation is a key contributor to performance deterioration during fatigue.

Previous research has shown that the type and severity of fatigue can have varying effects on motor performance. For example, Uygur *et al*. [3] reported that elite male basketball players were able to maintain consistent free throw kinematics despite fatigue, suggesting that this may be due to the development of automatic motor patterns and stabilization strategies through training. Similarly, a meta-analysis by Li *et al*. [4] demonstrated that both severe physical fatigue and moderate mental fatigue can negatively affect basketball performance, though the extent of the impact may vary depending on the task type and athlete profile. Zhang *et al*. [15] also emphasized that tasks involving isolated and precision-based movements are more sensitive to localized fatigue rather than systemic fatigue. The findings of the present study are generally consistent with this literature. Following general fatigue induced by routine basketball training, a significant deterioration in shoulder proprioception was observed, whereas shooting accuracy was not significantly affected. This suggests that systemic fatigue may primarily impair sensorimotor control, leading to proprioceptive decline, but this degradation may not immediately translate into measurable performance deficits in amateur-level technical tasks. Compared to studies highlighting the ability of elite athletes to maintain performance under fatigue, the current study’s focus on amateur female players is a notable distinction. These results support the idea that training level and motor control capacity may influence the development of adaptive responses to fatigue.

Another key observation was the potential role of external joint support in maintaining proprioceptive and motor function. Kazemi *et al*. [9] and Cao *et al*. [16] reported that supportive devices like elbow braces can improve joint stability and increase afferent feedback from cutaneous and joint mechanoreceptors, thereby promoting more accurate joint position sense and facilitating smoother motor output. Mechanoreceptors such as muscle spindles, Golgi tendon organs, and Ruffini endings respond to joint movement and pressure changes, sending sensory information to the central nervous system. This process enables refined joint position sense and contributes to enhanced sensorimotor integration [17]. In line with these findings, the present study observed that the use of an elbow brace was associated with improved shoulder proprioceptive accuracy and marginal enhancements in shooting accuracy. Although the improvement in shooting percentage did not reach strict significance levels following multiple comparison corrections, the enhanced proprioceptive control demonstrated a small-to-moderate effect size (Cohen's d = 0.46), indicating potential practical significance. These findings reinforce the idea that external stabilization can contribute meaningfully to performance maintenance by enhancing afferent feedback pathways, even in the absence of statistically significant performance changes.

Correlation analyses further reinforced the central role of proprioceptive integrity in performance maintenance. Changes in proprioceptive accuracy were strongly and negatively correlated with free throw success rates after both localized and general fatigue, whereas perceived fatigue levels showed weaker and non-significant associations. This pattern supports the theoretical framework proposed by Gandevia [14], who argued that proprioceptive degradation plays a primary role in fatigue-induced impairments of motor tasks.

From an applied perspective, these findings underscore the importance of incorporating proprioceptive training into athletic preparation and rehabilitation programs. Training interventions focused on improving joint position sense and sensorimotor control could mitigate the adverse effects of fatigue, enhance performance consistency, and reduce injury risks [9, 16]. Coaches and practitioners are encouraged to integrate fatigue management strategies and proprioceptive exercises into regular basketball training routines.

A major strength of the present study is its randomized crossover design, which minimized inter-individual variability by allowing each participant to serve as her own control across different conditions. This methodological approach enhanced statistical precision and reduced confounding effects due to individual differences. However, despite the implementation of washout periods between experimental sessions, the possibility of residual carryover effects cannot be entirely excluded. Future studies should consider longer washout intervals or counterbalanced session orders to further mitigate such limitations.

Limitations and Future Directions

This study has several limitations. First, the sample was limited to amateur female basketball players, which may restrict the generalizability of the findings to other populations, such as male athletes, elite competitors, or different age groups. Second, the experimental fatigue protocols were conducted under controlled laboratory conditions, which may not fully reflect the complex, multifactorial nature of real-game environments where psychological stress, tactical demands, and environmental variability play important roles. Third, the study investigated only the short-term (acute) effects of fatigue, without exploring the long-term consequences of repeated exposure on proprioceptive integrity or skill execution.

Future studies should therefore include broader and more heterogeneous athletic populations and adopt longitudinal designs to assess the sustained impact of fatigue on motor control and performance. Incorporating motion analysis systems or electromyography (EMG) could provide insights into fatigue-induced biomechanical or neuromuscular alterations. Additionally, research simulating game-like settings - including opponent interaction and mental fatigue - would enhance ecological validity. Lastly, intervention-based trials investigating proprioceptive training programs and innovative joint support strategies could bridge the gap between laboratory findings and practical applications in sports settings.

CONCLUSION

This study offers novel insight into how different types of fatigue influence proprioception and performance in basketball. The findings demonstrate that localized arm fatigue significantly impairs both shoulder proprioception and shooting accuracy, while general fatigue predominantly affects proprioceptive accuracy without causing immediate shooting deficits. Furthermore, the use of an elbow brace partially mitigated proprioceptive degradation, indicating that external support may provide a protective effect under fatigue conditions.

These findings carry practical implications for sports scientists, coaches, and rehabilitation specialists. Conditioning programs that include proprioceptive training - such as balance, joint position sense, and reflex-enhancing exercises - may help maintain sensorimotor control during fatigue states. Moreover, strategic use of bracing, especially during high-intensity sessions or post-injury return-to-play protocols, could enhance performance consistency and reduce injury risk. Integrating these approaches into routine training may be particularly beneficial for amateur-level athletes, who may lack the neuromuscular adaptations found in elite performers.

Ethical Statement

This study was approved by the Nuh Naci Yazgan University Scientific Research and Publication Ethics Committee (Decision no.: 2024/002-01, date: 12.02.2024).

Authors' Contribution

Study Conception: UŞ; Study Design: UŞ; Supervision: N/A; Funding: N/A; Materials: UŞ, OY; Data Collection and/or Processing: UŞ, OY; Statistical Analysis and/or Data Interpretation: UŞ, OY; Literature Review: UŞ, OY; Manuscript Preparation: UŞ; and Critical Review: UŞ, OY.

Conflict of interest

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Generative Artificial Intelligence Statement

The author(s) declare that artificial intelligence-based tools were not used for content generation or data analysis during the preparation process of this manuscript. However, AI-assisted technologies (e.g., language models) were employed solely for English language editing and grammar checking. The entire scientific content was developed independently by the author(s) in accordance with research methodology and academic ethical standards.

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