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ORIGINAL RESEARCH

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Effects of inter-set foot cooling on jiu-jitsu anaerobic performance in Brazilian jiu-jitsu male athletes

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Abstract

Background: Brazilian Jiu-Jitsu (BJJ) athletes often engage in high-intensity, intermittent bouts requiring rapid neuromuscular responses. Inter-set cooling strategies, such as foot cooling (FC), have been proposed to enhance recovery and performance in various sports. However, the efficacy of FC in BJJ-specific anaerobic performance remains unclear. **Methods**: Thirteen male BJJ athletes participated in a randomized crossover study, performing the Jiu-Jitsu Anaerobic Performance Test (JJAPT) under two conditions: with FC and without (CON). Each session comprised three sets of maximal effort, with heart rate (HR) and rating of perceived exertion (RPE) recorded post-set. FC involved immersing the feet in cold water (10 °C) for 2 minutes between sets. **Results**: Total repetitions were significantly lower in FC condition compared to control condition (FC: 268.1 $\pm$ 32.8; CON: 277.3 $\pm$ 27.7; $p = 0.024$, effect size (ES) = 0.15). Both conditions exhibited a significant decline in repetitions across sets ($p < 0.001$), indicating fatigue. HR increased significantly from Set 1 to Sets 2 and 3 in both conditions ($p < 0.05$), with no significant differences between conditions. Similarly, RPE scores rose across sets ($p < 0.001$), with no significant differences between FC and control. **Conclusions**: Inter-set foot cooling decreased the anaerobic performance without change HR, or RPE in BJJ athletes during the JJAPT. These findings suggest that FC may not be an effective recovery strategy in BJJ contexts, potentially due to the sport's reliance on rapid neuromuscular function, which could be impaired by peripheral cooling. Further research should explore alternative cooling methods that align with the specific demands of BJJ.

Keywords

Brazilian jiu-jitsu; Anaerobic performance; Foot cooling; Recovery strategies; Neuromuscular function; JJAPT

1. Introduction

Brazilian Jiu-Jitsu (BJJ) is a grappling combat sport in which well-developed anaerobic capacity and strength-endurance play a crucial role in achieving successful performance [1, 2]. Whether during BJJ competition matches or regular training sessions, the primary objective is to submit the opponent through the application of a stranglehold or joint locks [3, 4]. Equally important, however, is the use of leverage, torsions, and pressure to bring the opponent to the ground and elicit submission through verbal or physical cues ("tap") [5, 6]. To effectively achieve this, BJJ athletes need to sustain high levels of physiological [7, 8], neuromuscular [3], and technical-tactical performance [1, 2], as matches may last from just a few seconds up to 10 minutes. Given the substantial physiological demands of BJJ matches and the occasionally short recovery intervals between successive bouts [9], athletes require high levels of strength-endurance and the capability to rapidly recover from fatigue.

Assessment of sport-specific performance is a key factor in evaluating success in combat sports. Several sport-specific performance tests have been proposed for disciplines such as Taekwondo, Judo, or Wrestling, contributing to progress in those fields [10–12]. Recently, Villar *et al.* [13] introduced the Jiu-Jitsu Anaerobic Performance Test (JJAPT), designed to assess anaerobic performance in BJJ athletes by quantifying the number of repetitions of a sweeping movement (*i.e.*, butterfly lifts). The JJAPT consists of five 1-minute sets of butterfly lifts, interspersed with 45-second recovery intervals, and represents a high-intensity intermittent effort [13]. A subsequent study by da Silva *et al.* [3] demonstrated that the JJAPT exhibits excellent reliability, reproducibility (test-retest), and sensitivity in assessing anaerobic performance of BJJ athletes. These findings suggest that the JJAPT is a valid tool for further interventional studies aimed at enhancing BJJ performance. However, the effects of recovery strategies on JJAPT performance remain unclear and warrant further investigation.

Peripheral cooling strategies have recently gained attention due to their potential to improve neuromuscular activation [14, 15] and anaerobic exercise performance [16, 17]. While some debate remains about the efficacy of such interventions, recent evidence suggests that cooling joints adjacent to active muscles [14] or distal extremities such as the hands [17] or feet [16] may enhance performance, particularly when applied during short recovery intervals. In contrast, direct cooling of the working muscles has been consistently shown to impair performance by reducing muscle temperature below its optimal levels [18].

Resistance exercise studies have shown that hand cooling between sets can increase the number of repetitions performed during high-intensity bench press to exhaustion [17]. Additionally, a recent study reported that leg press exercise combined with intermittent foot cooling (FC) increased total repetitions without raising the rating of perceived exertion (RPE) [16, 19]. These findings support the idea that peripheral extremity cooling may be advantageous for strength performance. Since both static and dynamic hand grip strength and endurance are crucial for competitive success in BJJ [9], FC may offer a promising strategy for enhancing BJJ-specific performance.

To the best of our knowledge, no studies investigated the effects of intermittent peripheral cooling on anaerobic performance in BJJ athletes, defined here as the ability to sustain repeated high-intensity efforts during short recovery intervals, as assessed by the JJAPT. Therefore, the primary aim of the present study was to examine the effects of intermittent FC on anaerobic performance in BJJ athletes. We hypothesized that intermittent FC applied during short recovery periods would enhance the anaerobic performance, as reflected by improved JJAPT outcomes.

2. Materials and methods

2.1 Subjects and ethical approval

Thirteen male regional-level competitive BJJ athletes (age: 20.3 ± 1.4 years, height: 172.1 ± 4.9 cm, body mass: 65.6 ± 5.9 kg, body mass index (BMI): 22.1 ± 1.0 kg/m^2, training experience = 5.4 ± 1.2 years) participated in this study. Participants were recruited and tested between February and June 2025. The sample consisted of three athletes who were blue belts and ten athletes who were purple belts. As inclusion criteria, all athletes were required to hold at least a blue belt and to have a minimum of three years of BJJ training experience. None of the athletes reported using illicit or pharmacological drugs, nor did they report injuries that could affect performance during testing. Participants were asked to maintain their habitual diet throughout the testing period and to refrain from strenuous physical activity, alcohol, and caffeine consumption during the 24 hours prior to all study visits. Participants were informed about the experimental procedures and the possible risks and benefits associated with taking part in the investigation. Additionally, they provided written informed consent prior to participation. All experimental procedures were approved by the Jeonbuk National University Ethics Committee (Ref. No.: JBNU 2024-06-032-001) and conformed to the standard set by the Declaration of Helsinki (2013). The research team included investigators with both exercise physiology expertise and practical experience in Brazilian Jiu-Jitsu. Notably, one investigator is an International Brazilian Jiu-Jitsu Federation (IBJJF)-certified black belt and Ju-Jitsu International Federation (JJIF) international referee (Continental A), with over 12 years of international competitive experience and three years of coaching experience.

2.2 Experimental design

A randomized crossover design was used in the present study. To familiarize participants with the JJAPT, butterfly lift was included as a part of their regular training session for two months (*i.e.*, five training sessions per week). Then, subjects performed two experimental trials, separated by 7 days. To minimize potential diurnal variation on exercise performance, all testing sessions were conducted at the same time of day (±1 h). Participants wore the same personal training attire across both trials; clothing was standardized across conditions and not manipulated as an experimental factor. All sessions were conducted in a climate-controlled indoor facility. Each participant performed usual warm-up routines, followed by JJAPT. The JJAPT was described by Villar *et al.* [13] and consists of performing 5 bouts of maximum repetitions of the butterfly lift movement for 1 minute with a 45-second recovery interval given between bouts. During two experimental trials (Fig. 1), after baseline measurement, participants performed their usual warm-up routine (*e.g.*, stretching, and general mobility) and three sets of JJAPT with 6-minute recovery between sets in control (CON) or FC conditions. Verbal encouragement was provided by the lead experimenter.

The cooling method with cold water immersion has been applied in previous studies [16, 19]. In the present study, the participants immersed their feet up to the distal end of the fibula (lateral malleolus) in buckets filled with water controlled at 10 °C as previous described [16]. The water temperature was chosen based on previous research of foot immersion showing that this temperature is optimal [16]. We monitored the water temperature used digital thermometer (CS-101, Fuyuan Cotronic Technology, Shenzhen, China) throughout the trial and maintained the target temperature by adding crushed ice when needed. This temperature control method has been shown to be effective in our previous experiments [20]. Foot water immersion was applied from the 2nd to 5th minute of the 6-minute recovery period. The one-minute delay from the cessation of exercise to immersion initiation was due to the time taken to transition. Subjects rested in a sitting position in their CON condition without cold water application.

The number of repetitions of butterfly lifts was recorded as the maximal number of movements performed in 1-minute for each of the 5 bouts in each set. The HR was continuously monitored throughout each experimental trial using a Polar transmitter-receiver (OH1, Polar Electro Oy, Kempele, Finland) and averaged across baseline, each set of exercise and recovery period. Rating of perceived exertion (RPE) was provided by each subject through the Borg's scale (1–10) and was taken immediately following cessation of each exercise set.

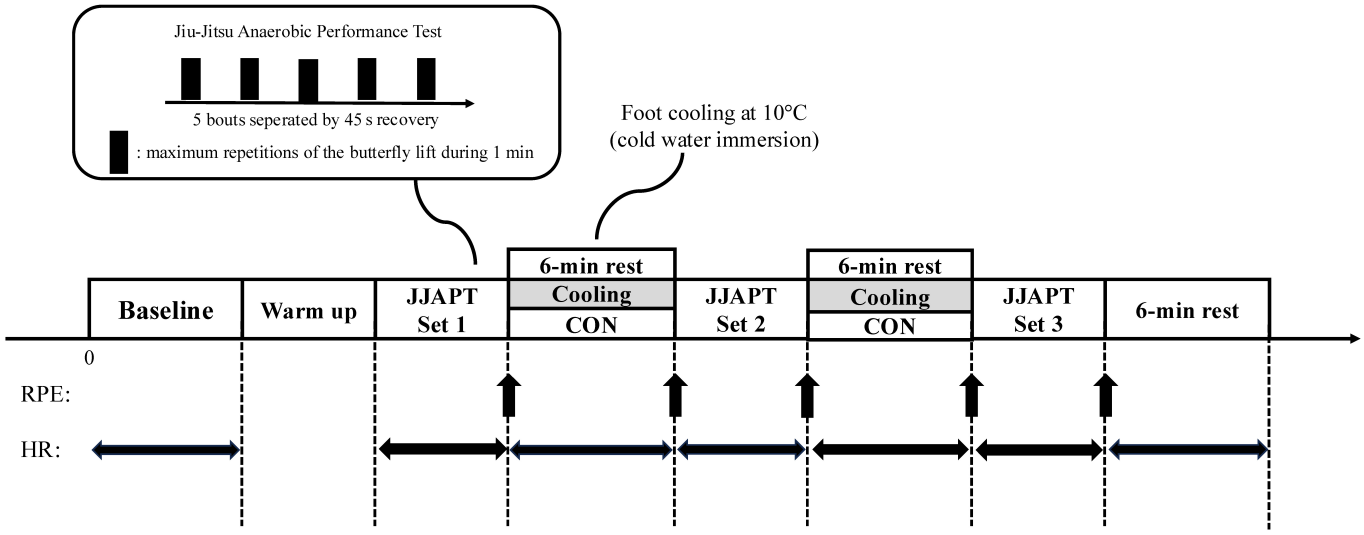

FIGURE 1. Experimental protocol of the JJAPT trial. Schematic representation of the experimental procedures in the control (CON) and foot cooling (FC) conditions. Each session consisted of three sets of the Jiu-Jitsu Anaerobic Performance Test (JJAPT), separated by 6-minute recovery periods. In the FC condition, foot immersion in 10 °C water was performed from the 2nd to 5th minute of recovery. Heart rate (HR) and rating of perceived exertion (RPE) were assessed after each set. Abbreviations: JJAPT, Jiu-Jitsu Anaerobic Performance Test; CON, control; HR, heart rate; RPE, rating of perceived exertion.

2.3 Statistical analyses

All data values are reported as mean ± standard deviation (SD). The normality of the dependent variables was determined using the Shapiro-Wilk test and the homogeneity of variance using the Brown-Forsythe and Welch Analysis of Variance (ANOVA) tests. A two-way repeated ANOVA (condition × time) was used to test for differences in repetitions, HR, and RPE. A priori simple main effects were examined with a Bonferroni correction for multiple planned comparisons where applicable. The alpha for significance was set a priori at $p < 0.05$ for all comparisons.

Partial eta-squared (η^2) was calculated to estimate the effect size of the two-way ANOVA (main effects and interaction), in which values of 0.01, 0.06, and above 0.14 represent small, medium, and large effects, respectively. In addition, effect size was calculated (mean difference divided by the pooled standard deviation) to determine the practical relevance (if $p <$ 0.05 was found) and classified as small (0.2–0.49), moderate (0.5–0.79), or large (≥0.8). All statistical calculations were performed using Prism 10 software (GraphPad Software, San Diego, CA, USA).

3. Results

Fig. 2A presents the total repetitions completed throughout the entire experimental protocol. The results showed lower total repetitions in the FC condition compared to the control condition (CON: 277.3 ± 27.7 *vs.* FC: 268.1 ± 32.8, p = 0.024, ES = 0.15). Repetitions per set are displayed in Fig. 2B. A significant main effect of time indicated decreased performance across the sets ($p < 0.001$, $\eta^2 = 0.614$). Specifically, repetitions significantly declined from Set 1 to Set 3 in both conditions (CON: 95.4 ± 8.4 *vs.* 88.6 ± 10.6, $p < 0.001$, ES = 0.33; FC: 92.8 ± 10.2 *vs.* 85.8 ± 12.2, $p < 0.001$, ES = 0.30). However, no differences between conditions were observed in any individual set (Set 1: $p = 0.481$, ES = 0.12; Set 2: $p = 0.352$, ES = 0.18; Set 3: $p = 0.543$, ES = 0.09). Repetitions per bout within each set are shown in Fig. 2C. Again, a significant main effect of time indicated a performance decrease across bouts ($p < 0.001$, $\eta^2 = 0.738$). Although significant main effects of condition ($p = 0.034$, $\eta^2 = 0.204$) and the condition × time interaction ($p = 0.045$, $\eta^2 = 0.187$) were found, no differences between conditions were observed in any individual bout.

Changes in HR during exercise and recovery are depicted in Fig. 3. Baseline HR was similar between the FC and CON conditions (FC: 65.1 ± 8.2 beats·min^{-1} *vs.* CON: 65.6 ± 7.5 beats·min^{-1}, $p = 0.873$). During exercise (Fig. 3A), a significant main effect of time was observed ($p < 0.001$, $\eta^2 = 0.977$, with HR significantly increasing from Set 1 to subsequent sets in both conditions (CON: Set 1, 148.0 ± 10.7 *vs.* Set 2, 156.9 ± 10.8 beats·min^{-1}, $p < 0.001$, ES = 0.42; Set 3, 156.5 ± 10.6 beats·min^{-1}, $p = 0.018$, ES = 0.41; FC: Set 1, 152.3 ± 13.7 *vs.* Set 2, 161.7 ± 11.5 beats·min^{-1}, $p = 0.001$, ES = 0.35; Set 3, 161.5 ± 12.7 beats·min^{-1}, $p = 0.003$, ES = 0.33). However, no significant effects for condition or interaction were found ($p > 0.05$ for both). During recovery (Fig. 3B), no significant main effects or interaction were observed ($p > 0.05$). *Post-hoc* analysis indicated a higher HR at Set 3 compared to Set 1 in FC (Set 1, 151.6 ± 15.0 *vs.* Set 3, 160.0 ± 14.2 beats·min^{-1}, $p = 0.014$, ES = 0.28).

The changes in RPE across sets under both conditions are presented in Fig. 4. A significant main effect of time was found ($p < 0.001$, $\eta^2 = 0.362$). RPE significantly increased from Set 1 to Sets 3 in the control condition (8.3 ± 0.9 *vs.* 9.4 ± 0.8, $p < 0.001$, ES = 0.54). There were no significant differences in RPE between CON and FC conditions at any set (Set 1: p = 0.883, ES = 0.03; Set 2: $p = 0.192$, ES = 0.25; Set 3: $p = 0.928$, ES = 0.02).

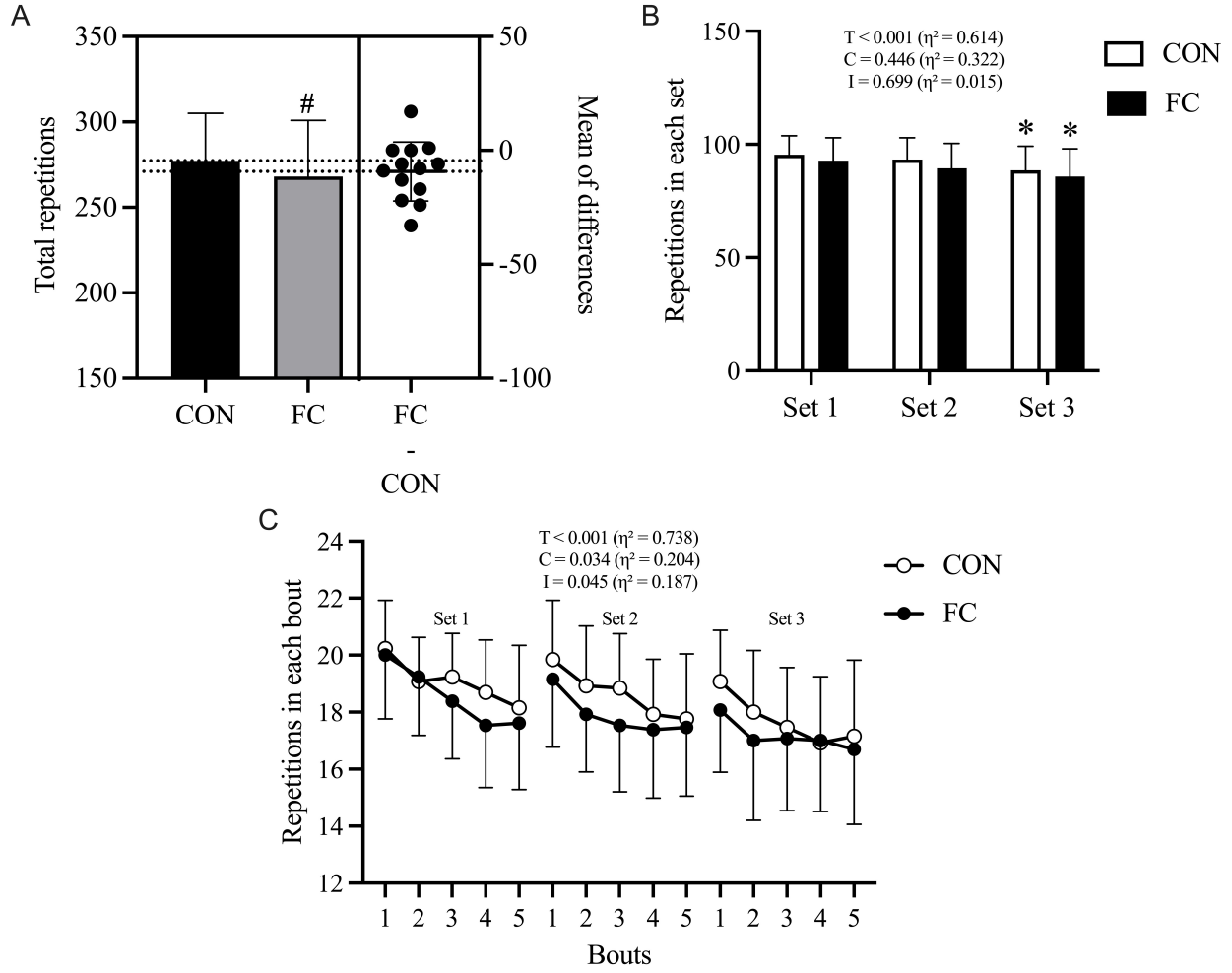

FIGURE 2. Effects of foot cooling on anaerobic performance across sets and bouts. (A) Total repetitions during the entire experiment; (B) repetitions for each set; (C) repetitions for each bout under control (CON) and foot cooling (FC) conditions. Total repetitions (A) were analyzed using a paired *t*-test. Repetitions per set and per bout (B,C) were analyzed using a two-way repeated-measures ANOVA (condition × time). Data are presented as mean ± SD (n = 13). *$p < 0.05$ *vs.* Set 1. #$p < 0.05$ *vs.* CON. Abbreviations: CON, control; FC, foot cooling.

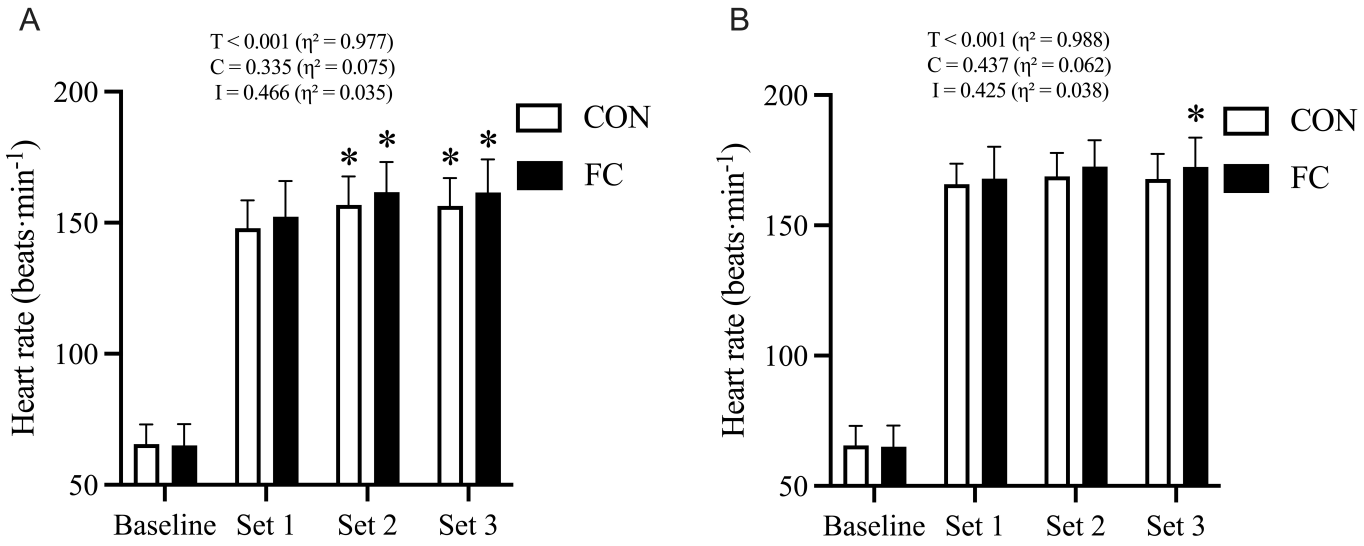

FIGURE 3. Heart rate responses across exercise and recovery. (A) Mean heart rate (HR) during each set of the JJAPT under CON and FC conditions. (B) HR during recovery periods. A two-way repeated-measures ANOVA (condition × time) was used to assess differences across sets. Data are presented as mean ± SD (n = 13). *$p < 0.05$ *vs.* Set 1. Abbreviations: FC, foot cooling; CON, control.

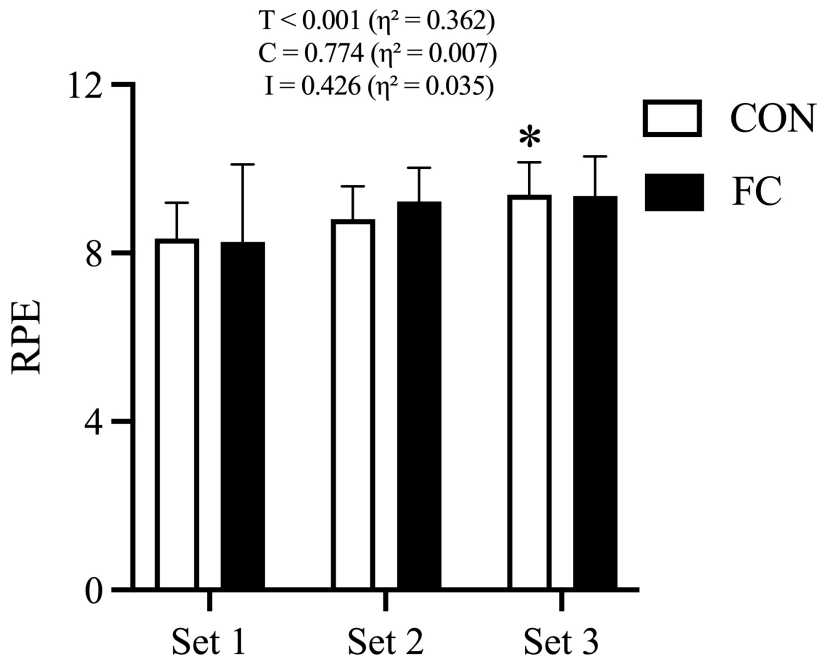

FIGURE 4. Perceived exertion responses across sets. Ratings of perceived exertion (RPE) following each set under CON and FC conditions. Data were analyzed using a two-way repeated-measures ANOVA (condition × time). Data are presented as mean ± SD (n = 13). *$p < 0.05$ *vs.* Set 1. Abbreviations: RPE, rating of perceived exertion; FC, foot cooling; CON, control.

4. Discussion

The present study investigated the effects of intermittent foot cooling (FC) on Jiu-Jitsu-specific anaerobic performance using the JJAPT in Brazilian Jiu-Jitsu (BJJ) athletes. Our primary findings demonstrated significant performance decrements across repeated bouts within each experimental session, evidenced by reductions in repetitions, alongside increased heart rate (HR), and perceived exertion (RPE). Specifically, total repetitions throughout the experiment were significantly lower in the FC condition compared to the control condition (Fig. 2A). However, repetitions within individual sets and bouts (Fig. 2B,C), as well as physiological and perceptual variables (HR and RPE), were not significantly different between the conditions.

To our knowledge, this is the first study to specifically assess the acute effects of intermittent FC on anaerobic performance in BJJ athletes using a validated, sport-specific protocol (JJAPT). The absence of a significant beneficial effect from FC is noteworthy, as recent literature regarding peripheral cooling strategies in other athletic populations has reported mixed outcomes. For example, Cai *et al.* [19] demonstrated improved lower-limb power output following acute FC, attributing these enhancements to greater neuromuscular efficiency and reduced perception of fatigue, potentially mediated by attenuated afferent feedback to the central nervous system. In contrast, Kenville *et al.* [21] observed no improvements in resistance exercise volume after intermittent cooling, findings that align with our results. This inconsistency indicates that the efficacy of cooling interventions is highly dependent upon the specificity of the exercise modality and the anatomical site of cooling application.

Regarding JJAPT outcomes, our results are consistent with prior studies [3, 13] in showing progressive decrements across sets. However, the absolute number of repetitions in our regional-level blue/purple belt athletes (~15–18 reps per bout, ~90 per set) was slightly lower than values typically reported in advanced or world-class cohorts (~19–20 reps per bout, ~95–100 per set). This difference likely reflects the competitive level of our sample, as da Silva *et al.* [3] demonstrated that JJAPT performance discriminates between novice and advanced belt ranks. For BJJ specifically, peripheral cooling of the feet is unlikely to be optimal during competition, whereas it may be more appropriate in training-room recovery contexts, as it may impair neuromuscular efficiency critical for gripping, agility, and rapid positional changes [22]. Future studies should investigate whether cooling applied to alternative sites such as the face or neck could provide recovery benefits while preserving sport-specific performance [23].

Our results revealed a non-significant trend toward reduced total repetitions following FC, contrasting with previous studies suggesting enhanced repetitions during resistance exercise after peripheral cooling [16]. These discrepancies may be explained by differences in exercise characteristics. BJJ performance demands rapid, coordinated, high-intensity movements, heavily reliant on precise neuromuscular activation and optimal muscle temperature [9, 18]. Peripheral cooling likely reduced muscle and skin temperature and slowed down neural conduction velocity, potentially impairing neuromuscular efficiency crucial for maintaining agility and power [24]. Racinais and Oksa emphasized that even slight reductions in muscle temperature could detrimentally affect dynamic muscular performance by slowing metabolic enzyme activity and impairing motor unit recruitment patterns [18]. Therefore, our results support the notion that peripheral cooling, particularly applied directly to extremities crucial for grip and balance, might

compromise critical performance factors in complex sports like BJJ. Thus, caution should be exercised when applying peripheral cooling strategies in sports requiring rapid and coordinated neuromuscular responses, such as BJJ.

Importantly, despite FC showing no significant impact on JJAPT performance, HR responses indicated progressively higher cardiovascular strain from Set 1 to Set 3 in both conditions, aligning with expected physiological responses to high-intensity intermittent exercise [2, 13]. This finding underscores the substantial anaerobic and cardiovascular demands associated with repeated bouts characteristic of BJJ competition. Given the physiological strain and significant decrement in repetitions, effective recovery interventions remain essential to sustain competitive performance in real match scenarios.

Considering the perceptual responses, our study found consistent increases in RPE from Set 1 to Set 3 in both conditions, mirroring the objective physiological stress (HR responses). Interestingly, despite FC's hypothesized benefits in reducing perceived exertion via sensory modulation [14, 19], no significant perceptual differences were observed between conditions. It is plausible that the cooling duration or temperature selected may not have sufficiently affected the perceived exertion or neuromuscular feedback mechanisms during intense exercise [25, 26]. Future research could benefit from exploring varied cooling durations or intensities to identify optimal parameters that might yield perceptual and performance enhancements.

This investigation has several limitations. First, the small sample size (n = 13), although consistent with previous research in similar athletic cohorts, limits the generalizability of findings. Second, participants were regionally competitive but not internationally elite athletes, which may affect the external validity regarding higher competitive levels. Third, although all participants held at least a blue belt with several years of training, performance outcomes may still vary across belt ranks and training experience. Thus, our findings should be interpreted with caution when generalizing to novice (*e.g.*, white belt) or more advanced (*e.g.*, brown/black belt) athletes. Fourth, while the JJAPT is a validated and reliable sport-specific test, it remains a proxy measure of anaerobic capacity and does not capture the full complexity of BJJ performance in training or competition. Finally, we did not measure skin or core temperature changes directly, which limits precise interpretation of the physiological mechanisms underlying the FC intervention.

Given these considerations, future research should investigate cooling strategies applied to alternative anatomical sites (*e.g.*, neck or face), potentially enhancing thermal comfort and perceived recovery without directly impairing muscle function. Additionally, systematically evaluating individual responsiveness to cooling, varying cooling temperatures, exposure durations, and timing relative to performance is warranted. Such studies could provide deeper insight into personalized recovery strategies, potentially leading to significant performance enhancements in high-intensity, complex combat sports like BJJ.

5. Conclusions

In conclusion, this study demonstrated that intermittent foot cooling did not improve anaerobic performance measured by JJAPT in BJJ athletes. While substantial fatigue-induced performance decrements were observed, no significant differences emerged between cooling and control conditions in performance, cardiovascular, or perceptual outcomes. These findings emphasize the critical need to align recovery interventions closely with sport-specific performance demands and highlight the importance of identifying ineffective strategies, thereby guiding future research toward alternative cooling approaches (*e.g.*, face or neck cooling) that may better support performance in BJJ and similar sports.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

AW, SL—methodology; formal analysis; investigation. AW, CH—writing–original draft preparation. DH, CH—validation. All authors writing–review and editing. All authors have read and agreed to the published version of the manuscript. All authors contributed to the conceptualization of the study.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All experimental procedures were approved by the Jeonbuk National University Ethics Committee (Ref. No.: JBNU 2024-06-032-001) and conformed to the standard set by the Declaration of Helsinki (2013). Additionally, each participant was provided written informed consent prior to participation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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