Effectiveness of combined techniques vs passive recovery in competitive squash players: A crossover study

Efectividad de técnicas combinadas vs recuperación pasiva en jugadores competitivos de squash: Un estudio cruzado

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Abstract

Objective: This study examined the effects of two recovery techniques, combined techniques and passive recovery, on physiological, neuromuscular, and psychophysiological performance in competitive squash players during three days of simulated matches.
Methodology: Eleven elite squash players (age: 15 ± 5 years; height: 172.80 ± 8 cm; body mass: 65.05 ± 11.46 kg) participated in a crossover-designed study. Blood lactate levels, countermovement jump, perceived exertion, and recovery were assessed before, after, and 48 hours post-match. Statistical analyses included Student's *t*-test or Wilcoxon test, as well as repeated measures ANOVA or Friedman + Wilcoxon tests for intra-week analyses.
Results: Significant differences were observed in pre-match lactate levels between the first and third weeks ($t = -5.81$; $p < .01$) and in post-match lactate levels ($t = -2.42$; $p < .03$). No significant differences were found for countermovement jump pre-match ($p < .50$) or post-match ($p < .15$). Perceptual parameters such as sleep, stress, fatigue, muscle soreness, and perceived exertion showed no significant differences in pre-match measurements ($p < .14$, $p < .09$, $p < .74$, $p < .51$, $p < .27$) or in post-match muscle soreness and perceived exertion ($p < .39$, $p < .41$).
Discussion: A simulated 45-minute squash match resulted in moderate fatigue, with full recovery within 24 hours. Repeated combined techniques provided no cumulative benefits over time and were equally effective as passive recovery in reversing physiological and neuromuscular changes.
Conclusions: Combined techniques neither enhanced nor impaired the recovery process and were as effective as passive recovery.

Keywords

Combined recovery techniques; fatigue; lactate; performance; racquet sports.

Resumen

Objetivo: Se examinó los efectos de dos técnicas de recuperación, combinadas y recuperación pasiva, sobre el rendimiento en jugadores competitivos de squash durante tres días de partidos simulados.
Metodología: Once jugadores de nivel élite (edad: 15 ± 5 años; estatura: 172.80 ± 8 cm; masa corporal: 65.05 ± 11.46 kg) participaron en un diseño cruzado. Los niveles de lactato en sangre, el salto con contramovimiento, la percepción de esfuerzo y la recuperación se midieron antes, después y 48 horas después de cada partido. Se realizó la prueba *t* de Student o Wilcoxon y ANOVA de medidas repetidas o las pruebas de Friedman + Wilcoxon para análisis intra-semanales.
Resultados: Se observaron diferencias en los niveles de lactato prepartido entre la primera y tercera semanas ($t = -5.81$; $p < .01$) y en los niveles de lactato postpartido ($t = -2.42$; $p < .03$). No se encontraron diferencias en el salto con contramovimiento prepartido ($p < .50$) ni postpartido ($p < .15$). Los parámetros perceptivos como el sueño, estrés, fatiga, dolor muscular y percepción de esfuerzo no mostraron diferencias en las mediciones prepartido ($p < .14$, $p < .09$, $p < .74$, $p < .51$, $p < .27$) ni en las variables postpartido de dolor muscular y percepción de esfuerzo ($p < .39$, $p < .41$).
Discusión: Un partido simulado de squash resultó en fatiga moderada, con recuperación completa en 24 horas. Las técnicas combinadas no proporcionaron beneficios acumulativos adicionales.
Conclusiones: Las técnicas combinadas no mejoraron ni perjudicaron el proceso de recuperación y fueron tan efectivas como la recuperación pasiva.

Palabras clave

Deportes de raqueta; fatiga; lactato; rendimiento; técnicas combinadas de recuperación.

Introduction

A squash match can typically last between 30 and 90 minutes for a maximum of five games per match (Montpetit, 1990). The duration ranges from 11 to 12 minutes per game for professional players, compared to six to eight minutes per game in lower categories (Montpetit, 1990). This, along with playing at high levels of intensity, makes this sport exceptionally physical and challenging (Chin et al., 1995). Squash is clearly a physically demanding sport that requires significant endurance skills and strength. Furthermore, it can be difficult for players to maintain their composure and stress levels within manageable parameters without falling into excessive levels of fatigue (Chin et al., 1995; Girard et al., 2007; Girard & Millet, 2009).

Squash athletes, from a young age, experience high levels of stress leading to multifactorial fatigue, which is a consequence of variables such as playing style, gender, training status, age, playing surface, type of ball, and environment (Fernández-Fernández et al., 2009; Mujika et al., 2018; Pluim et al., 2007). The density of competitions in this sport, where players participate in one or two matches per day, increases physical demands and the likelihood of injuries (Fyfe et al., 2019; González, 2018). This frequency of play challenges maintaining the recommended training-competition balance of 40–60%, crucial for preventing injuries and avoiding burnout (Jayanthi et al., 2009; Kovacs, 2015; United States Tennis Association, 2021).

Additionally, factors such as frequent intercontinental travel, especially common among Latin American players even in junior categories, add complexity to the competitive phase (Kovacs, 2015). Players must adapt to varied conditions, such as different climates and playing environments, significantly influencing the type and quality of the recovery process (Porta & Sanz, 2006; Roetert et al., 2005; Roetert & McEnroe, 2006). According to Montanus (2016), the most important areas that need to be addressed when considering recovery strategies are as follows: a) work/rest ratio; b) nutrition; c) physical therapies; d) psychological skills. In the present study, we specifically focused on the work/rest ratio through the structure and scheduling of simulated squash matches and recovery interventions, without modifying other factors such as nutrition, physical therapies, or psychological skills.

This requires not only adequate physical preparation but also consideration of psychological and logistical aspects affecting performance (Kellmann & Beckmann, 2018; Tavares et al., 2019). Hence, it is crucial to employ simple methods for measuring fatigue. The Rating of Perceived Exertion (RPE) is an effective and widely recognized method in this context, both in practice (Gomes et al., 2015) and in high-level sports (Haddad et al., 2017). Moreover, questionnaires like Hooper's, which assess aspects such as muscle pain, fatigue, stress, and sleep quality, are valuable tools for identifying early signs of overexertion in high-performance athletes (Hooper & Mackinnon, 1995).

It is essential for athletes to be aware of the variety of recovery techniques currently available. 80% of junior racquet sports players use methods such as foam rolling, cold water immersion (CWI), hot baths, and protein intake (Poignard et al., 2020). However, the effectiveness of CWI in limiting fatigue shows contradictory results, and its applicability in real-life conditions is questionable (Abaïdia et al., 2017; Ascensão et al., 2011; Bahnert et al., 2013; Fyfe et al., 2019; Hausswirth et al., 2011; Higgins et al., 2017; Kellmann & Beckmann, 2003; Leeder et al., 2012; Pooley et al., 2020; Tavares et al., 2019).

On the other hand, combined techniques (CT) have proven beneficial in racquet sports recovery, favoring less costly techniques that do not require specialized personnel, such as using pools, saunas, and cryotherapy (Duffield et al., 2014; Wiewelhove et al., 2021). CWI and cryotherapy have been found not superior to passive recovery (PR), suggesting the importance of integrating active recovery techniques and rest (Poignard et al., 2020). Passive stretching, although popular, has not been shown to be effective in reducing fatigue, enhancing performance, or preventing injuries, though individual variations exist in its effectiveness (Behm et al., 2016; D'Anna & Paloma, 2015; Raeder et al., 2017; Van Hooren & Peake, 2018). These methods do not seem to improve physical performance or relieve pain (Afonso et al., 2021; Dupuy et al., 2018). However, regular application of a CT may offer greater benefits than the isolated use of a single technique (Dupuy et al., 2018; Fleming et al., 2018; Poignard et al., 2020; Wiewelhove et al., 2021). While some recovery techniques are effective in certain racquet sports (Poignard, 2020), in squash, scientific evidence is limited, and their effectiveness in a real practical context has not been confirmed. Nutrition, hydration, and sleep are considered fundamental for post-training or competition recovery (Venter, 2012). In summary, the benefits of these techniques are limited, and their effectiveness in sports such as squash is more anecdotal.

This study aimed to evaluate the efficacy of two recovery techniques (CT vs. PR) under conditions of fatigue induced by simulated matches on squash-specific performance monitored over three days of simulated matches with assessment of some associated markers of biological, neuromuscular, and psychophysiological fatigue. (Kovacs, 2007; Reid et al., 2008). Specifically, we used on-court squash matches to simulate the workload and physiological stress elicited by a 45-minute squash match on each of three consecutive days. We hypothesized that there were statistically significant differences in favor of the effect of CT over PR on biological, neuromuscular, and psychophysiological performance, as was assessed by La, CMJ, RPE, and Hooper's questionnaire for limiting post-match fatigue and accumulated fatigue in competitive squash players. This investigation focused on exploring workload, fatigue, and recovery, based on the work of Poignard (2020), and compared two methods of recovery in squash: CT (which included foam rolling, aerobic jogging, and dynamic stretching) versus PR (which consisted solely of rest).

Method

Participants

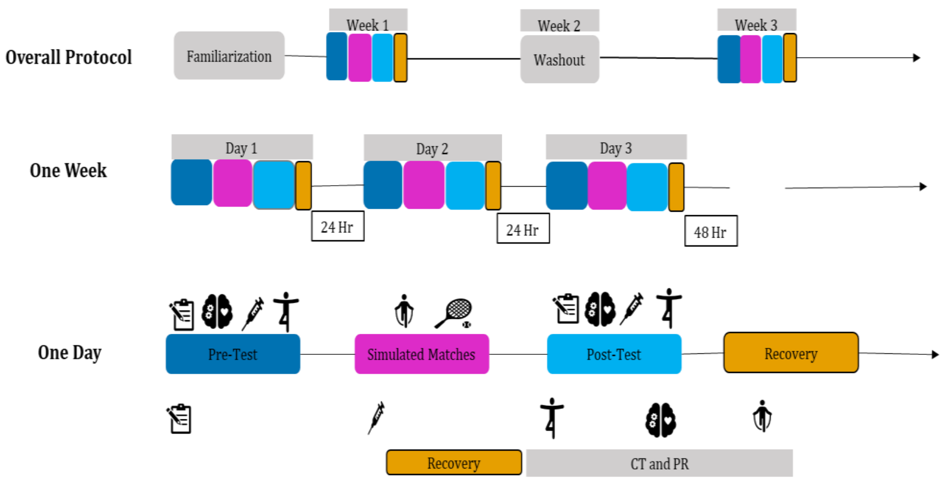
Eleven squash players from elite youth clubs (Medellín, Colombia), all well-trained and ranked in the national system, trained five times per week (Tier 3) during the final phase of the competitive period (McKay et al., 2022). Mean age ± SD/med ± IR = 15 ± 5 years; height = 172.80 ± 8 cm; body mass = 65.05 ± 11.46 kg; BMI = 22.00 ± 2.51 kg/m2; fat mass = 14.94 ± 5.59%; muscle mass = 40.40 ± 2.31%; training experience = 3.00 ± 2 years; volunteered to participate in an explanatory study that established cause-effect relationships in a crossover design. Subjects were recruited through an invitation sent to coaches at Liga Antioqueña de Squash. Recruiting finished once the number of required volunteers was sufficient to calculate a study power of 80%. There were no paid incentives to participate in this study. After the baseline measurement on the first day of week one, all eligible participants were randomly assigned to either CT or PR. This was done by drawing a card with the treatment name from a dark bag. Subsequently, after a one-week washout, participants switched to the alternate intervention. Eligible players were required to have no history of severe injuries, surgeries, or rehabilitation within the past six months. Participants must not have engaged in any strength-endurance program in the four weeks prior to or during the study. Participants were also required to be within a normal weight range, without special diets or creatine supplementation. Additionally, they needed at least a national or regional ranking, two years of competitive experience, and consistent training at least three times per week. Exclusions applied to athletes with recent musculoskeletal injuries (within the last two months), those absent from the initial evaluation, female participants, players under 13 years, and anyone withdrawing from the protocol.

Before the experiment, all participants underwent a medical examination to rule out potential contraindications (cardiovascular risk factors, history of respiratory disease, and hypersensitivity). Players were informed about the procedures as well as the risks associated with the tests and investigations before providing their written consent. The study protocol always followed the universal code of ethics, including the ethical principles for conducting medical research involving human subjects outlined by the Declaration of Helsinki and the administrative, technical, and scientific standards for conducting health research established in Resolution 8430 of the Colombian Ministry of Health.

Procedures

A crossover design was chosen over the traditional parallel group design due to its lower intra-participant variability compared to variability between different participants, reducing the required sample size as per CONSORT guidelines (Dwan et al., 2019). The 45-minute fatigue protocol, based on Poignard (2020) and similar to Wiewelhove et al. (2021), involved simulated matches that mimic the movement patterns and physiological responses typical of high-level professional squash training. Participants first completed a familiarization session with the measurements as well as each recovery intervention. The study lasted three weeks. During the first week, the first intervention was conducted, involving fatigue induction through simulated squash matches with pre- and post-measurements of biological, neuromuscular, and psychological variables, followed by the application of CT techniques, assigned as the initial intervention after randomization. The second week served as a 'washout' period, allowing participants to return to baseline fitness levels. In the third week, the second intervention was conducted, also with fatigue induction and measurements but utilizing passive recovery techniques. Participants were instructed to refrain from exercising during the four days of each testing session, and training sessions performed three days before each testing period were recorded to control for potential residual fatigue from prior intense training. Participants maintained food and hydration diaries 24 hours before and throughout the four days of the first experimental condition, replicating the same diet in subsequent conditions. Testing days (Days 1, 2, and 3) followed similar schedules (±2h) to minimize circadian rhythm effects. Participants were also asked to avoid stimulants and anti-inflammatory medications throughout the three-week protocol. Upon arrival at each session, participants underwent initial measurements, including a psychometric questionnaire, capillary blood sampling for lactate assessment, a neuromuscular test, and a warm-up on the court, followed by squash matches. Post-match measurements were reordered from the pretest sequence to minimize the influence of waiting times on results. These included (i) La activity assessment, (ii) CMJ test, and (iii) Hooper and RPE questionnaires. Finally, participants completed their assigned recovery intervention. On Day 4 (48 hours later), only pretest measurements were conducted. Participants were permitted to drink water ad libitum during all sessions. All testing took place in a temperature-controlled environment (21 °C and 55% relative humidity). The experimental design is illustrated in Figure 1.

Figure 1. schematic of the experimental design.



Measures

Primary, secondary, and observatory outcome measures followed the American College of Sports Medicine's (2013) health-related physical assessment order. To assess biological parameters, blood La activity was measured using a drop of blood (≈25µL) from a finger pulp puncture, analyzed with the Accutrend Plus system (Roche, Basel, Switzerland), calibrated per manufacturer guidelines (Gómez Medina et al., 2015).

For neuromuscular parameters, the CMJ test was conducted using the Chronojump-Boscosystem® jump platform connected to a Windows® laptop, recording jump height with Chronojump software version 1.4.7.0. Participants performed three jumps with 30-second rests, and the best jump was recorded. Feedback was provided to standardize form, ensuring ~90º knee flexion and hands on hips to control arm movement effects. This protocol aligns with literature specifications by González (2018), showing test validity at r = .61–.80; p <.05.

Regarding perceptual parameters, the Hooper Test psychometric questionnaire was administered pre- and post-evaluation to assess subjective perception of general fatigue and recovery (muscle soreness, fatigue, sleep, and stress) on a visual analog scale from 0 to 10. RPE was measured pre- and 30 minutes post-simulated matches using the modified Foster scale (0–10). The RPE-session was calculated by multiplying the RPE by session duration, with total weekly load obtained by summing RPE-session values (Maud & Foster, 2006).

To assess body composition, fat mass and lean body mass were measured using the Tanita MC-780U (Tanita Corporation, Tokyo, Japan) through electrical bioimpedance analysis following ISAK protocols (Silva & Vieira, 2020). Participants' weight and height were recorded using a precision scale (Seca 710, Hamburg, Germany). Fat percentage was derived from bioimpedance scale data, following Alvero-Cruz et al. (2011).

Simulated squash matches

Matches in this study were designed to closely replicate a 45-minute competitive squash match, typically including 50-70% effective playing time (EPT) (Sharp, 1998; Montanus, 2016). Regulatory matches were used to induce fatigue, held on an indoor court with each match structured to achieve approximately 30 minutes of EPT within a 45-minute session. Players were verbally encouraged to exert maximum effort throughout (Kovacs, 2007; Poignard, 2020; Reid et al., 2008). Participant matchups were determined as follows: (i) players were matched within the same category based on the rankings of the Colombian Squash Federation (first through fifth categories); (ii) pairs were assigned daily according to arrival order while respecting category criteria; (iii) if a player lacked a partner within the same category, they were permitted to compete against a player from a higher category to ensure optimal performance conditions.

Recovery Interventions

Recovery techniques were administered within 30 minutes following the simulated fatigue condition, under professional supervision by personnel with 15 years of experience at the Liga Antioqueña de Squash headquarters. For the CT technique, players began with a five-minute aerobic jog around the court, gradually decreasing physical effort intensity. The jog intensity was individually adjusted using the "talk-test" described by Foster et al. (2008), ensuring players could converse without difficulty, keeping activity at a moderate level, and preparing the body for the next recovery phase. Next, players performed 10 minutes of active stretching based on the protocol by Faigenbaum et al. (2006), moving from one end of the court to the other, covering a total of 14 meters. Ten-second intervals between stretches were used to enhance technique effectiveness, with the talk-test employed to maintain appropriate intensity. The final recovery phase consisted of 15 minutes of foam rolling, following Prieto's (2020) protocol. This self-massage focused on specific muscle groups, including quadriceps, hamstrings, calves, tensor fasciae latae, adductors, and glutes. Players completed two sets of four repetitions per muscle group, with 45 seconds of work and 15 seconds of rest between sets. In the RP technique, players were asked to remain seated quietly in a closed, well-ventilated room at a controlled temperature of ~20°C for a brief mental and physical rest period of up to 10 minutes. Players were allowed to hydrate freely to replenish fluids lost during exercise without consuming other substances or foods. They were also advised to avoid supplements and follow a regular diet to support natural recovery processes.

Data analysis

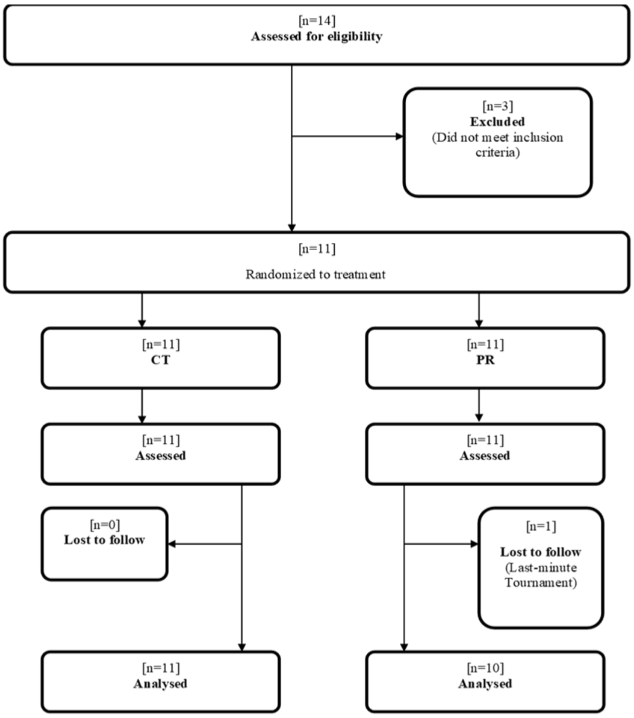
All analyses will be conducted according to the intention-to-treat principle, and to manage missing data, multiple imputation procedures will be used to replace missing values for the primary variables of interest. Descriptive statistics were reported as means and standard deviations in cases of normality and otherwise as medians and interquartile ranges. The Shapiro-Wilk normality test ($n<30$) was conducted for week one and week three for the objectives (blood lactate, CMJ, and Hooper/RPE test). Homoscedasticity was checked with Levene's test. In the case of normal distribution for the analysis between weeks, the recommendation (González et al., 2020) for statistical analysis in crossover studies was followed, implementing the use of the Student's *t*-test for related samples for each variable and comparing the differences between protocols. When there was no normal distribution, the non-parametric Wilcoxon test for related samples was conducted to determine the differences. Likewise, for the intra-week analysis in case of normal distribution, a repeated measures ANOVA was performed. When there was no normal distribution, the Friedman's one-way test was performed, followed by pairwise Wilcoxon tests to determine where the differences were.

The significance level was set at $p \leq .05$ and the power at 80% for this study. Similarly, the effect size (ES) for variables with normality was interpreted according to the criterion used by Cohen's d (1988) as follows: <0.2= trivial, <0.2-0.4= small, <0.5-0.7= moderate, >0.7= large. Likewise, for the effect size in non-normal variables, Hedges' g was used. Finally, relative percentage changes were calculated as ([post-test value – pretest value]/pretest value) x 100. The data were analyzed with the IBM SPSS Statistics version 25 program (IBM Corp., Armonk, NY, USA).

Results

A total of 14 athletes were selected between August and December 2022. Three participants were excluded from the study because they did not meet the age inclusion criteria (two participants), and one was excluded due to gender (a female) (Figure 2). The participants were males with an average age of 15 years (IQR = 5 years). During the third week, it was not possible to evaluate one of the participants because he had to participate in a championship and could not attend; however, it was possible to apply the complete evaluations from the first week. Regarding baseline data, the quantitative variables show that age (p =.02), sporting experience (p <.001), and height (p =.04) did not have a normal distribution. During the washout week, there were significant differences for pretest sleep (p =.03) and posttest lactate (p <.001). No adverse events occurred during the study.

Figure 2. Flowchart of the crossover study. CT = Combination of Techniques; PR = Passive Recovery.



Note: adapted from CONSORT statement, extension to randomized crossover trials, 2010.

Final values from psycho-perceptual questionnaires (Table 1, Table 2), blood lactate levels and CMJ jump heights (Table 3 and Figure 3) were conducted pre- and post-match to assess the psychophysiological, biological, neuromuscular effects. A significant increase in pre and post lactate levels was observed in the third week compared to the first, p <.01 (M = 2.07 mmol/L; SD = 0.30; SE = 0.09; t (11) = -5.81) vs. (M = 1.70 mmol/L; SD = 0.20; SE = 0.06) and p <.03 (Mean = 4.27 mmol/L; SD = 1.29; SE = 0.38; t (11) = -2.42) vs. (M = 3.6 mmol/L; SD = 1.11; SE = 0.33), respectively. In CMJ jumps, participants observed no significant differences for premeasurements p =.50 (MED = 34.91 cm; IQR = 2.9; Z = -0.66) vs. (MED = 34.65 cm; IQR = 2.6) and postmeasurements p =.15 (MED = 38.22 cm; IQR = 4.5; Z = -1.42) vs. (MED = 37.30 cm; IQR = 5.2), respectively. Finally, the psycho-perceptual measurements of sleep, stress, fatigue, pain, and RPE showed no significant differences in premeasurements for sleep *p* =.14; stress *p* =.09; fatigue *p* =.74; muscle pain *p* =.51; RPE *p* <.31. Similarly, for postmeasurements of pain and RPE, *p* =.39; *p* =.41, respectively.

Blood lactate, CMJ, and psycho-perceptual questionnaires were also compared on the same days across different weeks, and it was found that on day one of both weeks: Blood lactate post showed a statistically significant increase in week one compared to week three, *p* =.10 (MED = 2.9 mmol/L; IQR = 0.4; *Z* = -2.59) vs. (M = 2.20 mmol/L; IQR = 0). On day two, there was a statistically significant increase in lactate pre, during week three compared to week one, *p* <.01 (M = 2.11 mmol/L; SD = 0.36; SE = 0.11; *t* (11) = -3.73) vs. (M = 1.46 mmol/L; SD = 0.36; SE = 0.10). Similarly, on day three, there was an increase in lactate post, in week three compared to week one, *p* <.01 (M = 5.97 mmol/L; SD = 2.50; SE = 0.75; *t* (11) = -3.36) vs. (M = 3.45 mmol/L; SD = 1.45; SE = 0.43), and finally, on day four, there were no statistically significant differences between the lactate samples, *p* =.34. Regarding CMJ on day one, participants did not show significant differences in measurements pre, *p* =.68, and post, *p* =.26. On day two, participants did not show significant differences in measurements pre, *p* =.59, and post, *p* =.59. On day three, there was a statistically significant decrease in the height of the CMJ pre in week three compared to the first week, *p* =.04 (MED = 32.50 cm; IQR = 1.7; *Z* = -2.00) vs. (MED = 35.20 cm; IQR = 1.1). On the other hand, no significant differences were shown post matches, *p* =.39, and consecutively, there were no statistically significant differences on day four, *p* =.24. Regarding the psycho-perceptual variables, on day one, participants observed a statistically significant deterioration in sleep quality in the third week compared to the first, *p* =.03 (M = 2.00; IQR = 0; *Z* = -2.12) vs. (M = 3.00; IQR = 2.0). On day two, participants observed a significant deterioration in sleep quality in the first week compared to the third, *p* =.03 (M = 3.18; SD = 1.83; SE = 0.36; *t* (11) = 2.46) vs. (M = 2.27; SD = 0.30). On day three, there were no statistically significant differences in sleep, stress, fatigue, pain, and RPE; *p* =.16; *p* =1.00; *p* =.43; *p* =.23; *p* =.85; *p* =.31; *p* =.67, respectively. On day four, there were no statistically significant differences in the samples of sleep, stress, fatigue, pain, and RPE measured only pre matches, *p* =.31; *p* =1.00; *p* =.43; *p* =.31; *p* =1.00, respectively.

The intraweek analysis revealed statistically significant differences in lactate levels both in the first and third weeks before and after matches *p* <.01; *p* =.03; *p* <.01; *p* <.01; *p* <.01, respectively. Regarding the CMJ, there were statistically significant differences in jump height before and after matches in the third week *p* <.01; *p* <.01, respectively, and only after matches in the first week *p* <.01. Finally, there were statistically significant differences in the perception of RPEs before matches in the first week *p* <.01 and the third week *p* <.01. Likewise, there was a significant increase in sleep quality (*p* =.05) in the third week.

Table 1. Biological, neuromuscular and perceptual parameters, combination of techniques (CT) and passive recovery (PAS), as well as their differences with normal distribution

Variables	CT		PAS		CT vs PAS			
	M	SD	M	DE	t	p	%	ES
Sleep (1-10)	2.86	.76	2.59	.59	1.60	.14	.10	.39
Stress (1-10)	2.36	.72	2.07	.69	1.83	.09	.14	.41
Fatigue (1-10)	2.15	.57	2.09	.49	.33	.74	.03	.11
Muscle Pain Pre (1-10)	1.80	.49	1.91	.49	-.68	.51	-.06	.22
Muscle Pain Post (1-10)	3.33	1.04	3.03	1.28	.89	.39	.10	.25
Lactate Pre (mmol)	1.70	.20	2.07	.30	-5.81	.01**	-.18	1.45
Lactate Post (mmol)	3.60	1.11	4.27	1.29	-2.42	.03*	-.16	.60

Note. combination of techniques (CT); passive recovery (PAS); mean (M); standard deviation (SD); significance value (p ≤ .05); Student's t statistic (t); 95% confidence interval (CI 95%); percentage difference (%); Cohen's effect size (ES).

Table 2. Biological, neuromuscular and perceptual parameters, combination of techniques (CT) and passive recovery (PAS), as well as their differences with not normal distribution

Variables	CT			PAS			CT vs PAS			
	MED	SD	IQR	MED	SD	IQR	Z	p	%	ES
RPE Pre (1-10)	2.30	.66	1	2.16	.40	.25	-.99	.31	.06	.25
RPE Post (1-10)	4.52	.79	1	4.82	1.15	1.67	-.82	.41	-.06	.30
CMJ Pre (cm)	34.91	1.86	2.95	34.65	2.58	2.63	-.66	.50	.01	.11
CMJ Post (cm)	38.22	3.78	4.50	37.30	3.21	5.20	-1.42	.15	.02	.02

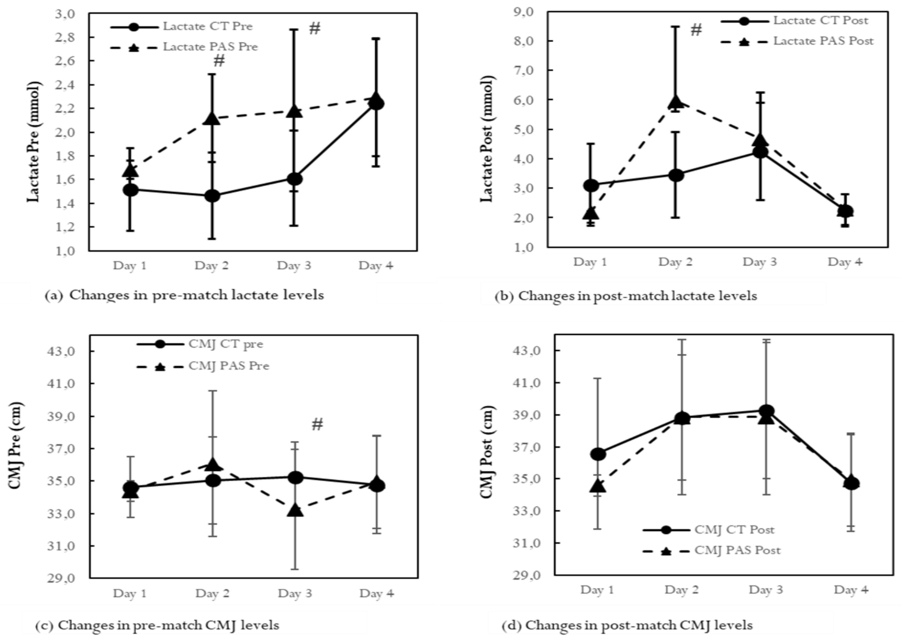
Note. combination of techniques (CT); passive recovery (PAS); median (Med); standard deviation (SD); interquartile range (IQR); Z statistic (Z); significance value (p ≤.05); percentage difference (%); Hedges' g effect size (ES).

Table 3. Fatigue Indicators Measured with Lactate and CMJ

	Protocol	Day 1	Day 2	Day 3	Day 4
			LACTATE		
Mmol	CT	3.10 ± 1.39	3.45 ± 1.45	4.24 ± 1.65	2.24 ± 0.53
	PAS	2.18 ± 0.04	5.97 ± 2.50	4.67 ± 1.58	2.29 ± 0.49
			CMJ		
Cm	CT	36.57 ± 4.71	38.82 ± 3.91	39.27 ± 4.25	34.75 ± 3.00
	PAS	34.59 ± 0.65	38.85 ± 4.82	38.85 ± 4.82	34.94 ± 2.88

Note: millimoles lactate (mmol); centimeters (cm); standard deviation (±); countermovement jump (CMJ); combination of techniques (CT); passive recovery (PAS).

Figure 3. (a) Changes in pre-match lactate levels between CT and PAS; (b) post-match lactate levels between CT and PAS; (c) pre-match CMJ levels between CT and PAS; (d) post-match CMJ levels between CT and PAS.



Note. values are expressed as mean and standard deviation (M ± SD); CT = Combination of Techniques; PAS = Passive Recovery; # significance value ($p \leq .05$).

Discussion

This study investigated the effects of two recovery techniques, CT and PAS, on biological, neuromuscular, and perceptual parameters of accumulated fatigue and specific squash performance across three consecutive days of simulated matches in competitive players. Findings indicate significant elevations in muscle soreness, neuromuscular and perceptual fatigue, and metabolic stress, regardless of the recovery mode. These results align with previous research demonstrating that physical performance is adversely affected, and recovery is compromised following prolonged and repeated competitive matches over consecutive days in racket sports (Gescheit et al., 2015; Ojala & Häkkinen, 2013; Poignard, 2020; Wiewelhove et al., 2021). Consecutive days of squash matches led to a slight increase in fatigue, as measured by blood lactate, although neuromuscular function and psycho-perceptual performance were not altered throughout the protocol.

During the washout period, significant differences were observed in sleep and pre-match lactate levels, indicating that the washout was insufficient. This insufficiency may be due to factors such as diet, rest, environmental conditions, and cognitive fatigue, which could influence fatigue manifestations (Montanus, 2016; Poignard, 2020; Wiewelhove et al., 2021). However, for variables such as stress, fatigue, muscle soreness, RPE, and CMJ, the washout period was adequate. Extending the washout time is advised for variables not at baseline, as well as adjusting for effort intensity, match volume, and competition level.

In relation to biological markers of fatigue, there was a general increase in blood lactate levels across the three days of the protocol and the two weeks of recovery technique application. During the PAS week, participants showed a significant increase in pre-match lactate levels (2.07 mmol/L) compared to the CT week (1.70 mmol/L). A similar pattern was observed post-match, with lactate levels in the PAS week (4.27 mmol/L) higher than in CT (3.6 mmol/L). Although there were statistical differences in lactate in this study, these do not represent practical values that could influence the overall recovery perception (Poignard, 2020; Wiewelhove et al., 2021). Lactate, averaged over the two intervention weeks, did not exceed the lactate threshold (4 mmol) on most days, meaning it was not highly fatiguing. Such volumes (45 minutes of match play) allow for rapid lactate clearance (<3 min) (Aguilar Quito, 2020), compared to values above the threshold reported for squash (>6 mmol) (Montanus, 2020).

Muscle damage following three consecutive squash matches was minimal and did not significantly impact neuromuscular function (CMJ) or performance. Differences in CMJ height were under two centimeters, not reaching the practical threshold of at least 40 cm for competitive athletes (González, 2018). This finding aligns with Poignard (2020) and Wiewelhove et al. (2021) but diverges from results reported by Gescheit et al. (2015) and Ojala & Häkkinen (2013), possibly due to protocol differences. Recovery of physical capacities, such as sprinting and explosive strength, is typically achievable within 24 hours (Girard et al., 2014; Poignard, 2020).

Post-match increases in RPE, sleep disturbances, and muscle pain were observed; however, these changes did not hold practical significance across recovery protocols. Analyzing results over different weeks revealed that they did not meaningfully impact the overall sense of recovery. Furthermore, the psycho-perceptual questionnaires proved insufficiently sensitive to detect notable individual variations over consecutive competition days, underscoring their limitations in accurately reflecting subtle fatigue and recovery effects (Montanus, 2016; Poignard, 2020; Wiewelhove et al., 2021).

Squash players often use a combination of recovery techniques post-practice or competition (Dupuy et al., 2018). The analgesic, relaxing, and blood flow-enhancing effects of vasoconstriction and hydrostatic pressures may complement each other when combined (Behm, 2018; Dupuy et al., 2018; Ihsan et al., 2016; Leeder et al., 2012; Poignard, 2020). However, in this study, CT did not show superior effects compared to PAS. Possible explanations include: (i) interference between recovery mechanisms. When techniques are combined simultaneously, interference can occur if the mechanisms of one technique obstruct those of another, compared to using each technique independently. For example, cold water immersion produces vasoconstriction, slows cellular metabolism, and reduces hydrostatic pressures, while massage, on the other hand, raises body temperature due to friction, which may conflict with the cooling effect of immersion (Wiewelhove et al., 2021). However, in this study's combination of techniques, identifying interference is more challenging: foam rolling facilitates lactate clearance, reduces muscle soreness, and enhances recovery perception (Poignard, 2020), while active stretching similarly aids in lactate and soreness reduction (Poignard et al., 2020; Sands et al., 2013). Conversely, active recovery (jogging) can deplete muscle glycogen and calcium and increase load and maximum voluntary contraction capacity, potentially interfering with the effects of the other techniques (Afonso et al., 2021; Choi et al., 1994; Poignard et al., 2020). This explanation remains highly speculative, as concrete evidence for the suggested mechanisms of most recovery methods has yet to be established (Poignard, 2020; Wiewelhove et al., 2021). (ii) varying temporal effectiveness of recovery techniques, with active recovery and stretching showing benefits within ~one hour, while foam rolling may take two to four days to show potential benefits (Poignard et al., 2020; Wiewelhove et al., 2021), complicating the identification of optimal timing for combined techniques; (iii) potential design limitations, such as simulated matches and external conditions, difficulty recruiting specific athletes, and possible adaptation to repeated exercises, which may have created a protective effect against fatigue and muscle damage. This highlights the importance of load progression in recovery techniques, similar to other training stimuli (Wiewelhove et al., 2021).

Finally, understanding fatigue in competitions requires analysis of factors such as muscle activation, psychological and environmental demands, and playing surface (Kovacs et al., 2014; Wiewelhove et al., 2021). Intense muscular actions typical in squash, like sprints and rapid racket strokes, induce physical stress and fatigue, highlighting the importance of the stretch-shortening cycle, which can significantly affect neuromuscular tissue (Fernandez-Fernandez et al., 2018; Wiewelhove et al., 2021). Understanding how these factors influence recovery during consecutive competitions is essential for optimizing recovery. This study contributes to the scientific evidence on CT and PR for squash professionals, serving as pioneering research in this field, alongside the works of Poignard (2020), Poignard et al. (2020), and Wiewelhove et al. (2021).

Limitations

This study enabled the design of simulated matches to induce load and fatigue levels similar to real matches, allowing for a comparison of recovery techniques. However, the repetition of standardized 45-minute matches may have created a protective effect, reducing fatigue and muscle damage relative to actual match conditions. Additionally, factors such as opponents, environmental conditions, and mental fatigue may have influenced recovery, as these conditions cannot be fully standardized. The ideal sample size was not achieved due to challenges in recruiting high-competitive-level players, and the PAS week coincided with a local tournament, which may have influenced results.

Moreover, we did not control variables such as ball type, environmental conditions, playing style, or playing surface, which may influence the degree of fatigue experienced. Future research should consider these factors to provide a more comprehensive understanding of fatigue and recovery in squash. Additionally, future research could examine different sequences or modalities of combined techniques to determine if variations in order, duration, or type of activities could yield more pronounced recovery benefits. Such studies may help optimize individualized recovery protocols and better adapt them to specific athletic contexts.

Conclusions

Combined techniques neither enhanced nor impaired the recovery process and were as effective as passive recovery in competitive squash players during a simulated 45-minute match. The study demonstrated that this match leads to moderate fatigue, evidenced by increased blood lactate levels and minor neuromuscular changes. These changes were fully reversed within 24 hours and were not exacerbated by consecutive matches. This suggests that repeated CT application does not provide the additional anticipated benefits over time, and PR is equally effective in reversing physiological and neuromuscular changes within the same recovery window. These findings should be considered in the planning of training and recovery, especially for elite athletes, given the potential impact of perceived sensation and fatigue on performance (Poignard, 2020).

Practical Application

Squash players and coaches should be aware that playing multiple matches on consecutive days increases fatigue and limits full recovery. No significant effects were found between recovery techniques in terms of match performance, load, or recovery markers (biological, neuromuscular, or perceptual). Players and coaches may focus on alternative recovery strategies, different technique combinations, or modified timings (e.g., immediate water immersion post-match, massage, and full warm-ups with activation and dynamic stretching for short-term preparation before matches). However, as CT was not detrimental to recovery, individual preferences, experiences, and beliefs may still influence the choice of CT as a post-exercise recovery strategy.

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