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COLD WATER IMMERSION AND PASSIVE RECOVERY IN FATIGUE MANAGEMENT DURING HANDBALL

Inmersión en Agua Fría y Recuperación Pasiva en el Manejo de la Fatiga Durante el Balonmano

Imersão em Água Fria e Recuperação Passiva no Gerenciamento da Fadiga Durante o Handebol

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Abstract

The purpose of this study was to investigate the effectiveness of the continuous cold-water immersion (CCWI) protocol and passive recovery in maintaining the physical performance of sub-elite handball players during a congested tournament. Thirty-two players (19 women and 13 men) of eight clubs participated in a 3-days tournament (one match per day with a total of twelve matches). External (relative distance, accelerations, maximum acceleration, maximum and average speed, total impacts, accelerations/decelerations difference, and player load) and internal load (maximum and average heart rate) were assessed using Magnetic, Angular Rate and Gravity (MARG) sensor worn by players during all games. Participants were randomly divided into two recovery groups: a) whole body CCWI (12ºC for 12min) and b) control (23ºC, 12min passive sit rest). Statistical analysis was composed of two-way analysis of variance (recovery protocol x matches) in each sex. There were no differences ($p > 0.05$) in internal or external load variables between recovery groups during the tournament in men or women. Continuous cold-water immersions are as effective as passive recovery in maintaining external and internal physical demands during a congested tournament in handball.

Keywords: recovery; cold-water; team sports; congested-schedule; rehabilitation; team sports; cryotherapy.

Resumen

El propósito de este estudio fue explorar la efectividad del protocolo de inmersión continua en agua fría (CCWI) y la recuperación pasiva para mantener el rendimiento físico de los jugadores de balonmano sub-élite durante un torneo congestionado. Treinta y dos jugadores (19 mujeres y 13 hombres) de ocho clubes participaron en un torneo de 3 días (un partido por día con un total de doce partidos). La carga externa (distancia relativa, aceleraciones, aceleración máxima, velocidad máxima y media, impactos totales, diferencia de aceleraciones / desaceleraciones y carga del jugador) y carga interna (frecuencia cardíaca máxima y media) se evaluó mediante un sensor magnético, de velocidad angular y gravedad (MARG). usado por los jugadores durante todos los juegos. Los participantes se dividieron aleatoriamente en dos grupos de recuperación: a) CCWI de cuerpo entero (12ºC durante 12 min) y b) control (23ºC, 12 min de reposo pasivo sentado). El análisis estadístico se compuso de análisis de varianza de dos formas (protocolo de recuperación x coincidencias) en cada sexo. No hubo diferencias ($p > 0.05$) en las variables de carga interna o externa entre los grupos de recuperación durante el torneo en hombres o mujeres. Las inmersiones continuas en agua fría son tan efectivas como la recuperación pasiva para mantener las demandas físicas externas e internas durante un torneo congestionado de balonmano.

Palabras clave: recuperación; agua fría; deportes de equipo; horario congestionado; rehabilitación; crioterapia.

Resumo

O objetivo deste estudo foi explorar a eficácia do protocolo de imersão contínua em água fria (CCWI) e recuperação passiva para manter o desempenho físico de jogadores de handebol de elite durante um torneio congestionado. Trinta e dois jogadores (19 mulheres e 13 homens) de oito clubes participaram de um torneio de 3 dias (uma partida por dia com um total de doze partidas). Externa (distância relativa, acelerações, aceleração máxima, velocidade máxima e média, impactos totais, diferença de acelerações / desacelerações e carga do jogador) e carga interna (frequência cardíaca máxima e média) foram avaliadas usando sensor Magnético, Taxa Angular e Gravidade (MARG) usado pelos jogadores durante todos os jogos. Os participantes foram divididos aleatoriamente em dois grupos de recuperação: a) CCWI de corpo inteiro (12ºC por 12min) eb) controle (23ºC, repouso sentado passivo de 12min). A análise estatística foi composta por duas formas de análise de variância (protocolo de recuperação x jogos) em cada sexo. Não houve diferenças (p> 0,05) nas variáveis de carga interna ou externa entre os grupos de recuperação durante o torneio em homens ou mulheres. As imersões contínuas em água fria são tão eficazes quanto a recuperação passiva para manter as demandas físicas externas e internas durante um torneio congestionado de handebol.

Palabras clave: recuperação; água fria; esportes coletivos; agenda congestionada; reabilitação; crioterapia.

Introduction

Currently, athletes of most sports, especially in team sports, are required to participate in tournaments where many games are played in a few days (congested schedule) (Martínez-Guardado et al., 2020). The particularities of this competition model with short recovery periods are insufficient for the complete restoration of fitness, leading to a loss of athletes' performance (Gómez-Álvarez et al., 2019; Leeder et al., 2019; Rojas-Valverde, 2021). Previous studies have shown the negative effect of a congested schedule (tournaments where at least three games are played in 3-4 days) in physical performance and movement patterns on basketball and hockey players as a consequence of residual fatigue (Montgomery et al., 2008; Spencer et al., 2005). Besides, recent evidence (Pino-Ortega et al., 2019; Rojas-Valverde et al., 2018) have found greater fatigue, less muscle stiffness and lower kinematic performance in soccer players and youth basketball players throughout the tournament.

The accumulated fatigue during a tournament usually generates a decrease of physiological, functional, perceptual and cognitive levels, which may persist in the days after a competitive match (Nédélec et al., 2012). Unfavourable changes have been found on biochemical parameters (e.g. creatine kinase, CK), inflammatory markers, oxidative stress, and delayed onset muscle soreness (DOMS), which persist 24 to 96 hours after a match (Ispirlidis et al., 2008; Nedelec et al., 2014; Nédélec et al., 2012; Rampinini et al., 2011; Thomas et al., 2017). Given this situation, it is essential to incorporate recovery strategies between games to maintain optimal fitness throughout the tournament (Rattray et al., 2015). For this purpose, cold-water immersion (CWI) has been the most widely used method to minimise muscle fatigue (Sánchez-Ureña et al., 2017; Versey et al., 2013). The CWI has been demonstrated as an effective method for accelerating the recovery processes of high-performance athletes (Leeder et al., 2012a, 2019; Sánchez-Ureña et al., 2015b). In this sense, the CWI has been effective in reducing fatigue produced during congested tournaments in both external (e.g., distance covered, high-intensity actions) and internal workload (e.g., heart rate), as well as improving subjective fatigue and recovery ratings (Rowsell et al., 2011).

However, previous studies found that CWI does not contribute to avoiding neuromuscular fatigue during a congested tournament (G. Rowsell et al., 2011) or after extensive training or competition (G. Rowsell et al., 2009; Sellwood et al., 2007) with detrimental results in neuromuscular function (Peiffer et al., 2009). These results have been confirmed both in continuous and intermittent CWI, with insufficient improvement in the recovery of neuromuscular function at 24 and 48 hours after extensive training for a group of youth athletes (Sánchez-Ureña et al., 2018). In youth (Murray & Cardinale, 2015) and adults (Hohenauer et al., 2015) have been shown that CWI was not efficient in muscle recovery at the meta-analytical level, and only improved subjective pain and recovery scales.

Few studies focus on analysing muscle fatigue that results from a game with high physical demands and the effect of recovery methods in congested tournaments (Leeder et al., 2019). Likewise, few investigations have evaluated the effect of CWI on the athlete's physical performance in competitions (G. Rowsell et al., 2011) and other interventions have been limited to physical testing. Therefore, the purpose of this study was to compare the effect of cold-water immersion versus passive recovery on the kinematic performance of handball players during a congested tournament in sub-elite male and female athletes.

Materials and Methods

Participants

Thirty-two sub-elite handball players (19 women and 13 men) participated in this study. Athletes were recruited from eight local clubs in an emerging nation that is a member of the International Handball Federation. The average age of the participants was 20.5 ± 4.0 years, with male players averaging 23.2 ± 5.2 years and female players 18.1 ± 3.8 years. The mean body weight was 69.4 ± 12.9 kg (males: 89.4 ± 30.1 kg; females: 63.1 ± 14.3 kg), and the average height was 1.62 ± 0.10 m (males: 1.73 ± 0.09 m; females: 1.53 ± 0.39 m). The estimated maximal oxygen consumption (VO_2max) was 43.2 ± 5.2 ml/kg/min, with male players averaging 46.3 ± 4.1 and female players 39.4 ± 10.6 ml/kg/min. Participants were included if they were registered handball players aged 16 to 25 years, had at least two years of competitive experience, were free from musculoskeletal injuries or acute illnesses in the four weeks preceding the study, and agreed to abstain from any additional recovery strategies outside those specified in the protocol. All participants (and their legal guardians when applicable) provided written informed consent. Exclusion criteria included the presence of chronic diseases (e.g., cardiovascular, respiratory, or metabolic conditions), contraindications to cold-water immersion (e.g., Raynaud's syndrome, cold urticaria), non-compliance with the assigned recovery protocol, failure to complete any of the scheduled matches, or the use of unreported recovery interventions during the study period. All data/participation was included if: > 40 min of participation during a single match; a total of 96 cases met the inclusion criteria. All participants gave their informed consent, and the study protocol was reviewed and approved by the University´s Institutional Review Board.

Instruments and procedures

Data was collected during an official regional tournament (3 consecutive days, 8 teams, 12 matches) organised in Costa Rica. Teams were divided into two groups by sex. All teams played one game per day against different rivals. At the end of the championship, the team with the most points was the champion. All games were played under official IHF rules (40x20m pitch, two 30-minute periods) and were officiated by referees from the federated association. The games are systematically scheduled at a similar time of the day for each team to avoid inter-day rest bias.

Participants were randomly assigned to two recovery groups using a computer-generated randomisation sequence before the first match: (1) the Cold-Water Immersion (CWI) group (7 men and 13 women), and (2) the Passive Recovery group (6 men and 6 women). Although participants were randomly assigned to the cold-water immersion (CWI) and passive recovery groups, the final distribution resulted in heterogeneous group compositions—particularly with a higher number of female players in the CWI group (13 vs. 6 in the control group). This imbalance reflects the natural availability and participation of female players in the tournament, which limited the ability to stratify randomization strictly by sex while maintaining ecological validity.

Match schedules were standardised across all participants, with each match played at the same time of day to minimise circadian variation. All athletes completed a supervised 15-minute standardised warm-up before each match, consisting of light jogging, dynamic stretching, technical drills, and progressive-intensity sprinting. Recovery interventions were applied immediately after the match in isolated, temperature-controlled rooms. The CWI protocol involved 12 minutes of whole-body immersion in water at 12°C (iCool Compact system, Gold Coast, Australia). At the same time, the Passive group remained seated at room temperature (23°C) for the same duration. The cooling system continuously regulated water temperature and was manually verified every minute to ensure protocol fidelity. This approach aligns with established methodologies in team sport recovery research (Sánchez-Ureña et al., 2018) (see Figure 1).

The water temperature for the cold-water immersion (CWI) protocol was set at 12 °C, a value selected based on previous literature indicating that this range provides an optimal balance between therapeutic efficacy and tolerability in athletic populations. Several studies have demonstrated that immersion in water temperatures between 10–15 °C for 10–15 minutes can significantly reduce muscle soreness, inflammation, and perceived fatigue without causing excessive thermal discomfort or vasoconstrictive risk (Sánchez-Ureña et al., 2017; Versey et al., 2013). The selection of 12 °C aligns with protocols used in earlier investigations on recovery in team sports (e.g., Rowsell et al., 2011), allowing for direct comparison with established findings and supporting ecological validity. Additionally, this temperature falls within the recommended range of whole-body cryotherapy protocols, which aim to moderate post-exercise inflammatory responses and neuromuscular fatigue while ensuring the safety and compliance of athletes.

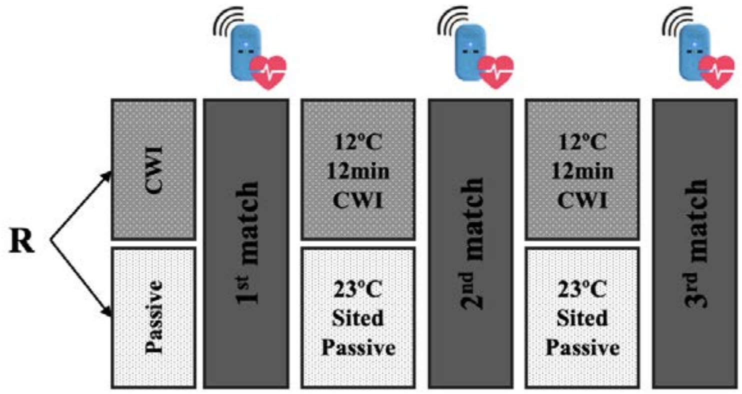

Figure 1. Study design, measurements and recovery protocol group assignment.

Before each game, the Magnetic, Angular Rate, and Gravity (MARG) sensors (WIMUPro, RealTrack Systems, Almería) were attached to each player at the T2-T4 level on the middle of the scapulae using a special neoprene harness. This MARG can measure kinematics through incorporated sensors, including triaxial accelerometers, gyroscopes, magnetometers, heart rate sensors, and indoor tracking sensors such as ultrawide-band. The ultra-wideband system was developed following previously validated and reliable methods (Bastida Castillo et al., 2018) and in specific handball studies (Bastida-Castillo et al., 2018). The microelectromechanical sensors were calibrated following previous research to achieve acceptable reliability and validity during testing (Gómez-Carmona et al., 2019). After calibration and attachment, players did a 15-minute warm-up following the teams' technical staff instructions with handball-specific movements (throwing, catching, speed changes, others).

Variables assessed were selected using the analysis of previous studies (González-Haro et al., 2020; Pino-Ortega et al., 2020) in similar samples as follow: relative distance (m/min), accelerations, maximum acceleration (m/s^2), maximum speed (km/h), average speed (km/h), maximum heart rate (bpm), average heart rate (bpm), total impacts, acceleration/deceleration differences (m/s^2) and player load (au).

Statistical analysis

Descriptive data were reported using mean (M) and standard deviation (SD). The normality of the data was verified by the Kolgomorov-Smirnov exploratory test. A comparative analysis of the data was performed using a mixed analysis of variance (matches x recovery protocols) to verify potential differences in internal and external workload by sex. Bonferroni post-hoc correction was performed when it was necessary. Per cent change (Δ%) pre- and post-measurements was calculated as: [(value post–value pre)/value pre] × 100. The magnitude of the differences was analysed using partial omega squared (ωp^2) and was qualitatively interpreted using the following thresholds: <0.01 (small), <0.06 (moderate), and <0.14 (large) (Cohen, 1988). Alpha was previously set at $p < 0.05$. Data analysis was performed using the Statistical Package for the Social Sciences (SPSS, IBM, SPSS Statistics, v.22.0, Chicago, IL, USA), and graphs were made using Prism software (GraphPad Software, San Diego, CA).

Results

The interactions between recovery groups and matches in each sex, in terms of internal and external workloads, are presented in Tables 1 and 2, respectively. Table 1 presents the kinematic variables of male players across three matches during a congested tournament schedule, comparing recovery strategies: CWI and passive recovery. There were no statistically significant differences between recovery conditions across any of the measured kinematic variables (all p > 0.05). Similarly, effect sizes were small or negligible for all comparisons ($\omega p2$), ranging from -0.06 to 0.02, suggesting limited practical differences between recovery methods. Relative distance covered (m/min) declined over matches for both groups but did not differ significantly by recovery type (F = 0.272, p = 0.764, $\omega p2$ = -0.04).

Number of accelerations remained stable or increased slightly across matches, again with no effect of recovery (F = 0.02, p = 0.981, $\omega p2$= -0.06). Maximum acceleration showed small, non-significant differences across time and conditions (F = 0.302, p = 0.742, $\omega p2$ = -0.05). Maximum and average speeds slightly declined across matches but were not influenced by the *recovery* strategy (both p > 0.35; $\omega p2$ = 0 to -0.04). Heart rate responses (maximum and average) were similar between groups, with negligible interaction effects (F = 0.01 to 0.103, p = 0.903 to 0.743, $\omega p2$ = -0.05 to 0.00). Total impacts and acceleration-deceleration differences did not differ between groups or across time (F = 1.3 and 1.292 respectively; p > 0.28; $\omega p2$ = -0.06 and 0.00). Player load slightly decreased over the tournament but showed no interaction with recovery method (F = 0.097, p = 0.908, $\omega p2$ = -0.02). These findings indicate that cold-water immersion did not confer a statistically or practically meaningful advantage over passive recovery in maintaining kinematic performance during a congested handball tournament in male athletes.

Table 1. Kinematic men's responses during a congested-fixture period by the recovery method.

Variables	Recovery	1st Match	2nd Match	3rd Match	*F*	*p* value	ω_p^2	*Rating*
Relative Distance (m/min)	CWI	67.6 ± 23.3	65.9 ± 18.5	59.3 ± 18.8	.272	.764	-.04	*Small*
	Passive	66.5 ± 16.9	62.1 ± 17.1	66.1 ± 16.1				
Accelerations (n)	CWI	1086.9 ± 240.4	989.7 ± 296.8	1167.7 ± 295.3	.02	.981	-.06	*Small*
	Passive	1100.6 ± 236	1046 ± 260.4	1214.3 ± 301.9				
Maximum Acceleration (m/s^2)	CWI	3.9 ± .5	3.5 ± .4	3.4 ± .6	.302	.742	-.05	*Small*
	Passive	3.5 ± .4	3.2 ± .3	3.3 ± .6				
Maximum speed (km/h)	CWI	21 ± 2.1	19.8 ± 2	20.7 ± 2.5	1.021	.372	0	*Small*
	Passive	20.5 ± 2.3	20.6 ± 1.6	19.2 ± .9				
Average speed (km/h)	CWI	4.8 ± 1.2	4.8 ± .9	4.2 ± 1	.279	.758	-.04	*Small*
	Passive	4.7 ± 1	4.7 ± .9	4.6 ± .9				
Maximum heart rate (bpm)	CWI	179.3 ± 31	176.2 ± 15.6	175 ± 9.9	.01	.995	-.06	*Small*
	Passive	184.8 ± 13.9	181.2 ± 17.6	179 ± 11.8				
Average heart rate (bpm)	CWI	153.7 ± 28.5	150.5 ± 17.2	145.6 ± 11	.103	.903	-.06	*Small*
	Passive	160 ± 14.8	156.8 ± 23	158 ± 15.6				
Total impacts (n)	CWI	1560.4 ± 974.8	1333.8 ± 738.2	1320.4 ± 902.7	.13	.879	-.06	*Small*
	Passive	1120.2 ± 589.8	1026.3 ± 569	1190.2 ± 543.3				
Acceleration/deceleration difference (m/s^2)	CWI	-2 ± 7.4	3 ± 6.6	1.9 ± 4.5	1.292	.289	0	*Small*
	Passive	5.2 ± 5.7	1.2 ± 2.9	7.3 ± 12.7				
Player Load (au)	CWI	59.5 ± 30.4	55.8 ± 24.5	53.1 ± 29	.097	.908	.02	*Small*
	Passive	53.3 ± 20.7	49.8 ± 18.7	54.7 ± 23.3				

CWI= Cold Water Immersion

Table 2 summarises the external load variables of female handball players over three consecutive matches, comparing two post-match recovery strategies: CWI and passive seated recovery. No statistically significant interaction effects were found between recovery method and match number for any of the kinematic variables (all $p > 0.05$). Effect sizes were all rated as small or trivial, with ωp2 values ranging from -0.03 to 0.00, suggesting a limited practical impact of the recovery strategy. Relative distance (m/min) showed a progressive decline across matches in both groups, with no significant differences between recovery conditions ($F = 0.186$, $p = 0.831$, $\omega p^2 = -0.02$). The total number of accelerations remained stable throughout the tournament regardless of recovery strategy ($F = 0.865$, $p = 0.428$, $\omega p^2 = 0.00$). While maximum acceleration exhibited a non-significant trend toward an increase in the CWI group and a slight decrease in the passive group, the interaction was not statistically relevant ($F = 0.073$, $p = 0.93$, $\omega p^2 = -0.03$). Similarly, maximum and average speeds did not differ significantly between groups (F = 0.439 and 0.059, p = 0.648 and 0.946, respectively), with small effect sizes (ωp^2 = -0.02 and -0.03). Heart rate responses, both maximum and average, showed comparable patterns between conditions (p = 0.466 to 0.511), with trivial associated effects (ωp^2 = 0 to -0.01). Finally, total impacts, acceleration/deceleration difference, and player load were unaffected by the recovery method or match order ($p > 0.17$; ωp^2 = -0.02 to 0.00), reinforcing the lack of differential effect between cold-water immersion and passive recovery in mitigating performance decline.

Table 2. Kinematic women's responses during a congested-fixture period by the recovery method.

Variables	Recovery	1st Match	2nd Match	3rd Match	*F*	*p* value	ω_p^2	*Rating*
Relative Distance (m/min)	CWI Passive	68.6 ± 18.6 57.9 ± 17.6	69.2 ± 18.4 62.3 ± 22	65.3 ± 17.7 62.9 ± 19.6	.186	.831	-.02	*Small*
Accelerations (n)	CWI Passive	1011.3 ± 197.2 818 ± 136	986.1 ± 244.2 1004.3 ± 226.3	1015.9 ± 289.2 907.4 ± 185	.865	.428	0	*Small*
Maximum Acceleration (m/s^2)	CWI Passive	3.1 ± .4 3.1 ± .4	3.2 ± .4 3 ± .6	3.3 ± .5 3.2 ± .5	.073	.93	-.3	*Small*
Maximum speed (km/h)	CWI Passive	18.4 ± 1.4 18.1 ± 2	19 ± .9 19 ± 2.7	19.8 ± 1.7 18.6 ± 2.2	.439	.648	-.02	*Small*
Average speed (km/h)	CWI Passive	5 ± .7 4.8 ± 1.2	5.1 ± .8 4.6 ± 1.1	4.9 ± .9 4.6 ± 1	.059	.946	-.3	*Small*
Maximum heart rate (bpm)	CWI Passive	189.3 ± 20.7 192.6 ± 12.5	195.3 ± 18.3 194.8 ± 10.2	190.5 ± 11.6 183 ± 24.9	.466	.63	-.02	*Small*
Average heart rate (bpm)	CWI Passive	169.5 ± 25.9 165.4 ± 15.6	167.6 ± 20.9 172.3 ± 12.9	166.5 ± 12.8 156.8 ± 26.8	.511	.603	-.01	*Small*
Total impacts (n)	CWI Passive	1225.2 ± 698.1 764.2 ± 371.1	1292.3 ± 602.4 892 ± 371.1	1229.5 ± 602.4 840.7 ± 370.8	.016	.984	-.3	*Small*
Acceleration/deceleration difference (m/s^2)	CWI Passive	2.8 ± 8.7 -.8 ± 3	2.1 ± 7.3 5 ± 9.9	3.4 ± 5.6 4.3 ± 8.2	.725	.489	0	*Small*
Player Load (au)	CWI Passive	59.8 ± 21.9 40 ± 16.1	60.1 ± 22.1 48.3 ± 17.4	55.7 ± 20.7 42.8 ± 14.7	.172	.843	-.02	*Small*

CWI= Cold Water Immersion

Discussion

The purpose of this study was to compare the effects of cold-water immersion (CWI) and passive recovery on internal and external workloads during a congested tournament in male and female handball players. The main findings indicate that neither recovery protocol elicited significant differences in kinematic or physiological markers across the three matches in either sex. These results align with prior evidence suggesting that while CWI may alleviate symptoms of muscle soreness and inflammation, its effectiveness in enhancing neuromuscular recovery and performance remains inconsistent.

CWI exerts its effects primarily through vasoconstriction, reduced blood flow, and decreased cell membrane permeability, which collectively mitigate post-exercise inflammation, edema, and perceived soreness (Malanga et al., 2015), leading to a decrease in inflammation and edema caused by damage during sports practice (Sánchez-Ureña et al., 2015a). This reduction in edema and inflammatory mediators (e.g. leukocytes, cytokines) is associated with lessening of pain perception and muscle swelling. The local anaesthetic effect of CWI refers to induced neurapraxia, by a reduction in the activation threshold of tissue nociceptors and a decrease in conduction velocity of nerve synapses (Malanga et al., 2015). Considering these effects cascade, and an additional effect on central fatigue-related markers, CWI is reported as an effective strategy to reduce muscle soreness and swelling following strenuous exercise, but its effectiveness for the recovery of muscle variables related to performance is not yet confirmed (Leeder et al., 2012b).

However, these mechanisms appear insufficient to translate into improvements in key performance metrics, such as speed, acceleration, or player load, particularly in the context of short recovery windows and high competition demands. Previous studies in soccer, basketball, and rugby have reported similar outcomes, where CWI failed to enhance measures related to power output or repeated sprint ability (Rowsell et al., 2011). In the case of the present study, the potential anti-inflammatory benefits of CWI on recovery during congested fixture periods, especially in team sports, have not been studied in-depth and need more analysis. These sports are characterised by actions with moderate to high mechanical stress (e.g. eccentric exercises) and high metabolic cost (e.g. high-intensity exercise, sprints), compromising competition performance (Leeder et al., 2012b). Repeated actions with a high component of intensity and mechanical stress could impact muscle contractibility due to metabolic disturbances, followed by structural disruption of muscle fibres (Higgins et al., 2017). These consequences of exercise strongly compromise muscle strength and power, two main factors of physical performance essential to team sports actions, such as running, jumping, with CWI having no significant recovery effect (Leeder et al., 2012b; G. J. Rowsell et al., 2009).

The demands for playing 2-3 matches in a few days dramatically elevate the physical, physiological and psychological stress imposed on the players (Carling et al., 2016), with an increase of injury risk, muscle damage and/or inflammation, which results in a significant decrease of fitness level (Arruda et al., 2015; Dellal et al., 2013; Ekblom, 1986; Pino-Ortega et al., 2019). This fatigue has a great effect on soccer kinematics with marked declines in the anaerobic capacity as well as repeated high-speed running performance for up to 72-h post-match (Ascensão et al., 2008; Rollo et al., 2014). The evidence suggests that CWI does not affect physical performance in those variables related to muscle strength and power development (Fröhlich et al., 2014). This information supports the results of this study, which found no effect on external load variables in matches when comparing the control group with the CWI groups. Despite recovery strategies aiming to facilitate a return to normal function and activity, one single application of CWI seems to be ineffective in boosting recovery variables related to external load in team sports (Higgins et al., 2017). Congested schedules, such as those involving two to three matches within a few days, are well-documented to increase physiological, physical, and psychological stress, thereby elevating the risk of injury, muscle damage, and performance decline (Arruda et al., 2015; Carling et al., 2016). However, as observed here, a single application of CWI may not be sufficient to counteract the cumulative effects of match-induced fatigue. Factors such as match outcome, playing position, opponent level, and match location likely play a greater role in shaping external load metrics than recovery strategy alone.

It should be considered that external load performance is multifactorial and could be influenced in team sports, specifically in handball, not only by factors related to physical fitness and performance but different contextual factors as: (a) playing position, higher intensity demands in wingers, greater volume in central and laterals and more impacts in pivots (González-Haro et al., 2020; Karcher & Buchheit, 2014); (b) match outcome, winning teams performed more high-intensity actions and technical efficacy respect to losing teams (Gomez et al., 2014; González-Haro et al., 2020), (c) match location, home advantage is found (Gomez et al., 2014; Pic, 2018); or (d) opponents' quality, high-quality teams required higher demands respect to low-quality teams (Michalsik & Aagaard, 2015).

From a practical standpoint, it is important to recognise that recovery in elite team sports is rarely implemented in isolation. Practitioners typically combine CWI with nutritional support, compression garments, massage, rest, and active recovery protocols to optimize recovery outcomes (Delextrat et al., 2013; Martínez-Guardado et al., 2020). Given the logistical complexity and financial cost associated with setting up and maintaining CWI systems (e.g., refrigeration units, portable immersion containers), the absence of clear performance benefits raises concerns about the cost-effectiveness of using CWI as a standalone strategy. In contrast, passive recovery requires minimal resources and yields similar outcomes under the conditions tested here (Delextrat et al., 2013; Martínez-Guardado et al., 2020).

Limitations

While the results of the present study have revealed the effects of cold-water immersion and passive recovery on kinematical and physiological performance during a 3-day congested fixture tournament, with an analysis of the individual effects based on sex, some limitations to the study must be acknowledged. The sample studied is small and comes from an emerging nation, so the results should not be extrapolated to other populations. In this sense, the sample size is sufficient to achieve a representative population and obtain an acceptable effect size, as indicated by https://www.calculator.net/sample-size-calculator.html (a sample size of 30 or more is required to have a 95% confidence level that the real value is within ±10% of the measured value). Besides, although the isolated effect of two recovery protocols has been studied, it would be interesting for future studies to analyse the combination of different recovery protocols, not just the effect of one of them, to optimise the fitness level of athletes throughout matches in this type of congested-schedule tournament.

Practical implications

The present findings suggest that cold-water immersion (CWI) and passive recovery protocols were equally effective in maintaining performance levels during a 3-day congested handball tournament in both male and female players. For practitioners, this indicates that either recovery method may be viable when implemented under logistical or financial constraints, without compromising short-term performance outcomes.

However, given that neither strategy alone significantly improved performance, practitioners at all competitive levels—elite, amateur, and youth—are advised to implement multimodal recovery approaches. These should combine nutritional support (e.g., post-match carbohydrate and protein intake), hydrotherapy (e.g., alternating cold and warm immersion), manual therapy (e.g., massage, myofascial release), compression garments, active recovery (e.g., low intensity cycling or jogging), and sleep optimisation (e.g., environment control, nap scheduling). The integration of multiple low-cost, low-tech strategies may be particularly effective for teams with limited access to advanced recovery technologies.

When planning for congested tournament formats, such as multi-day competitions or weekend leagues with multiple fixtures, staff should prioritise recovery timing (within 30 minutes post-match), session duration (10–15 minutes per modality), and practicality (ease of implementation at the venue). For instance, passive seated recovery in a shaded, cool environment may be more feasible than full-body immersion in youth or regional events without portable equipment. Conversely, teams at professional levels may benefit from scheduled cold-water immersion cycles supported by automated cooling systems, where resources permit.

Ultimately, selecting recovery strategies should involve a cost-benefit assessment, considering not only effectiveness, but also equipment availability, staff expertise, athlete comfort, and logistical feasibility. These results serve as a guide for coaches, sport scientists, and support staff to develop context-specific recovery protocols that align with their athletes' needs, competition schedules, and resource availability.

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