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RESEARCH

Impact of recovery strategies on physiological and performance parameters in karate athletes: a randomized crossover study

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Abstract

Purpose Karate training and competition are characterized by high intensity efforts with short recovery periods that typically cause muscle fatigue and functional capacity impairments. This study aimed to examine the effects of different recovery strategies on physiological, tensiomyographic, and physical fitness parameters at pre, post, 0 h, 24 h, 48 h and 72 h after a high-demanding Karate Specific Aerobic Test (KSAT).

Methods Eleven well-trained male karate players (mean ± SD: age: 24 ± 7 years old; weight: 70.3 ± 12.5 kg; height: 174.5 ± 8.7 cm) completed three recovery treatments in three different weeks: cold water immersion (CWI), intermittent pneumatic compression (IPC) and passive recovery (Control). The test battery included measurements of creatine kinase (CK), counter movement jump (CMJ), ballistic push-ups, Sprint time, hand grip strength; and tensiomyographic parameters.

Results Significant improvements in almost all variables over time, regardless of the recovery strategy used, were identified; only a few differences among recovery methods. The use of CWI significantly improved CMJ ($p = 0.04$; $d = 0.98$) and push-ups ($p = 0.03$; $d = 1.03$) respect to IPC method at 0 h-treatment. In addition, significantly lower rectus femoris TS was also observed right after the application of CWI (0 h-treatment) compared to other strategies ($p < 0.05$).

Conclusions The use of alternative treatments in substitution to passive recovery, especially CWI, might be recommended taking into consideration resources, accessibility and time constrains when high levels of DOMS or reduced functional capacity are identified.

Keywords Cryotherapy · Creatine kinase · Intermittent pneumatic compression · Post-exercise recovery · Karate specific aerobic test (KSAT)

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Introduction

The high physiological demands of karate require an optimal combination and balance between aerobic, anaerobic, and strength attributes [1, 2]. Powerful strikes, diverse punches, and swift defensive maneuvers are repeatedly executed during trainings and combats, requiring high levels of power and strength [3–5]. Similarly, anaerobic contribution throughout phosphagen and glycolytic systems plays a key role not only in intense and short bursts of intermittent activity but also in explosive offensive and defensive techniques and movements [6]. Although inconsistent results were observed regarding the importance of VO_{2max} to performance, [6, 7] the elite karate athletes have typically exhibited a remarkable aerobic capacity [2, 8]. To maintain such a high demanding physiological profile, karate players perform intense training sessions on a regular basis [3] resulting in biological and physical stress and ultimately impairments over muscular structures and functional capacity [9–11]. Additionally, due to the nature of karate, the diverse physical capacities are developed simultaneously [4] involving potential negative transference effects in most cases.

Recent investigations have identified tensiomyography (TMG) as a useful non-invasive tool to assess changes in contraction properties and exercise-induced neuromuscular fatigue [12, 13]. Furthermore, a relationship between TMG and muscle damage markers have been determined after eccentric exercise [14]. Exercise-induced muscle damage produced by intense workouts is the acute outcome of mechanical stress on muscle fibers, inflammatory processes, and damage caused by metabolites and the accumulation of metabolic waste products [15, 16]. During high-intensity training, muscle cells undergo stress, causing Creatine Kinase (CK) release into the bloodstream, whereas as muscle repair progresses CK levels decrease [17, 18]. Previous research on martial arts competitions have reported significant muscle damage [19] with CK values increasing after combat [20, 21]. Consequently, those high levels of accumulated fatigue and muscle damage decrease the muscle capacity of producing tension and energy, resulting in performance impairments. In addition, lower functional capacity and specific performance have been observed after high-intensity training without the sufficient recovery [22], indicating the need for a minimum recovery period for an optimal performance. Furthermore, it is crucial to highlight that the format of official kumite (combat) in karate tournaments allows participants to have short resting periods between bouts, which can significantly influence their recovery capacity and performance.

Thus, elite karate players would require an optimal recovery to ensure restoration of performance capabilities at normal levels within the next hours [23]. Traditionally, active or passive recovery has been used as typical strategies after hard training session, with contradictory results [24]. In recent years, further recovery methods such as massage, cold or infrared therapies have been identified as more effective and beneficial strategies to restore physiological and functional capacities than passive recovery. Cryotherapy application [24, 25], especially cold water immersion (CWI), significantly reduced delayed onset muscle soreness (DOMS) and CK activity not only after resistance training [26–28] but also in combat sports after high intensity training sessions [29, 30]. Conversely, in terms of muscle power and performance, this therapy promoted similar results to other recovery methods such as active recovery [27]. In recent years, the emergence of intermittent pneumatic compression (IPC) as an alternative therapy to massage seemed to be more effective in cardiac function restoration after strenuous interval training compared to passive recovery [31]. Nevertheless, the impact of both massage therapy and IPC on performance recovery remains uncertain, as well as the comparison of the effectiveness of these interventions. Particularly, the positive effects were only observed for massage when administered in short-term doses following intensive mixed training [32, 33].

To date, the physical fitness performance and physiological effects of different recovery methods after intense training or competition have never been analyzed in karate. Furthermore, no clear evidence of the superior benefits of CWI or IPC over passive recovery have been determined, especially on specific performance. The findings of the present investigation might provide important insights into the best strategies for functional and physiological recovery in elite athletes with demanding training and competition programs. Therefore, the aims of this investigation were to analyze and compare the effects of three recovery strategies (cold water immersion, intermittent pneumatic compression and passive recovery) on physiological, tensiomyographic and physical fitness parameters at pre, post, 0, 24, 48 and 72 h after a high intensity training workout in well trained male karate players. It is hypothesized that CMI and IPC protocols would enhance physiological biomarkers of recovery, muscle internal temperature, and functional capacities compared to passive strategy, especially 24 and 48 h after treatment.

Methods

Experimental approach to the problem

A randomized crossover design was performed to analyze the effects of three different recovery strategies (cryotherapy, intermittent pneumatic compression (IPC) and passive

(Control)) on physical fitness, physiological and tensiomyographic variables after a high intensity training test. In a counterbalanced order, the participants were assessed during the same time of the day and maintaining the room temperature (20–22°C) and humidity (50–60%) of the room controlled during the testing sessions. The participants were instructed to come to the laboratory rested, to avoid caffeine or other stimulants for at least 12 h beforehand and to abstain from vigorous exercise in the preceding 48 h. Before testing, an informative and familiarization session was provided to all participants.

Subjects

A total of 11 well-trained male karate athletes (mean ± SD: age: 24 ± 7 years old; weight: 70.3 ± 12.5 kg; height: 174.5 ± 8.7 cm) voluntarily participated in this study. The inclusion criteria for all participants were: (a) > 15 years of training experience; (b) > 10 h of training volume per week; and (c) being free from injury within the previous 6 months. Any participant under pharmacological treatment or presenting signs of disease during the testing period was excluded from assessment. Information about the potential injuries and benefits from the study was provided and written informed consent was obtained from all athletes. All participants were informed that they could withdraw from the study at any time without giving a reason and without causing any harm to themselves. The University Institutional Review Board (n° UA-2019-04-09) approved the experimental design and procedures of the investigation which was conducted in accordance with the latest Declaration of Helsinki.

Procedures

During 4 consecutive days, for a total of 3 weeks, participants attended the laboratory to complete a testing protocol (Fig. 1). Every week, a single recovery treatment was applied to each participant in a counterbalanced order after the training test. A standardized 15 min warm-up which included self-selected intensity jogging and specific dynamic stretching: hip extensors, hamstrings, hip flexors, and quadriceps femoris, supervised by a 3rd DAN Karate Blackbelt (member of the research staff), was conducted by all participants before the assessment. After approximately 5 min of rest following the end of the warm-up, the subjects carried out a karate specific aerobic test (KSAT) following the procedures described by Nunan [34].

Regarding recovery strategies, CWI treatment involved a complete body immersion in water at 10 °C for 10 min according to the recommendations by Hohenauer et al., [35] whereas Intermittent Pneumatic Compression (IPC) was performed in trunk, upper and lower limbs during 30 min

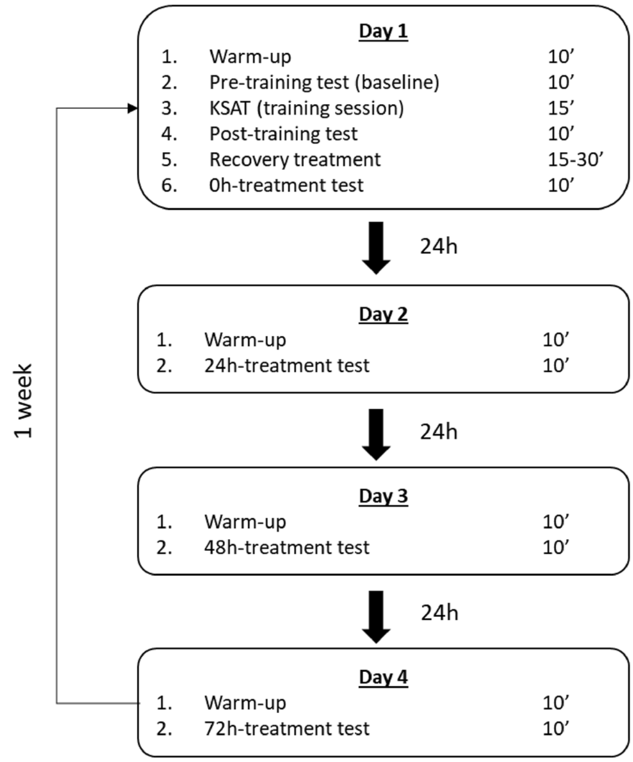

Fig. 1 Schematic diagram of a study protocol session

using a compressed air device (IR Presso High 9102) 70KPA (pressure) following the procedures defined by the manufacturer (IR Technics, Spain). Control strategy consisted in a passive recovery of 20 min while lying in a supine position.

Outcomes measures

Blood samples, physical fitness, and tensiomyographic variables were collected pre-training (baseline), post-training, 0 h post-treatment, 24 h post-treatment, 48 h post-treatment, and 72 h post-treatment for each recovery condition. Each assessment was performed by the same researcher. A blinded researcher who was not directly supervising the recovery protocol or was involved in the data collection subsequently analyzed all outcome measures.

Creatine kinase (CK)

Plasma CK was obtained from a 30-mL capillarized whole-blood sample. For that purpose, a fingertip puncture was performed using a spring-loaded disposable lancet. Subsequently, the whole-blood samples underwent centrifugation (Megafuge 1.0R, Heraeus, Germany) at 3000 rpm for a duration of 10 min to complete plasma separation. The resultant plasma was stored at a sub-zero temperature of -30 °C pending analysis. An Specord M500 spectrophotometer (Zeiss, Germany) was employed to examine the CK concentration of the plasma samples by an optimized ultraviolet (UV) test.

Physical fitness tests

In all physical fitness test undertaken, only the best of three attempts was taken into consideration for posterior analysis and at least 3 min rest was provided to the athletes between trials. The participants were encouraged to do their best throughout all tests performed.

The assessment of lower body power/performance was conducted through the countermovement jump test (CMJ). The participants were allowed to perform a countermovement before the jump until approximately 90° of knee flexion. A Bosco platform (Bosco System, Barcelona, Spain) was utilized to record the athlete's contact time and jump height (in cm) and contact time (in milliseconds).

A ballistic push-up test was used for the determination of upper body power/performance. From a prone position with the hands approximately shoulder width apart on a contact platform (Bosco System, Barcelona, Spain), participants were instructed to descend the chest until it contacted the platform. Subsequently, they were asked to exert maximal explosive force, aiming to achieve full extension of their arms and elevate the upper body as high as possible. Push-up height was calculated based on flight time, which was also measured in milliseconds. The reliability of the flight time measurement in similar push-up protocols has been reported as excellent, with an intraclass correlation coefficient (ICC) of 0.914 and a coefficient of variation (CV) of 5.6% [36]

Sprint time was measured by a 5-m test using two photocells (Witty, Microgate, Italy). Participants completed a standardized 25-m sprint, which included a 15-m acceleration phase, a 5-m flying sprint zone (timed), and a 5-m deceleration zone.

Hand grip strength was determined using a dynamometer TKK 5105 (Takei Scientific Instruments Co., Ltd., Tokyo, Japan). Under the supervision and encouragement of a researcher, participants were required to perform a maximal hand grip for at least 5 s at maximum effort while standing still with the elbow extended and the arm along the body side.

Tensiomyography (TMG)

Muscle contractile properties were assessed using TMG (TMG-100 System electrostimulator, TMG-BMC d.o.o., Ljubljana, Slovenia) as a response to an external induced contraction caused by an electric stimulus in the biceps femoris and rectus femoris. Maximal radial displacement of the muscle belly (DM) Contraction time (TC), Sustained time (TS), Relaxation time (TR) and Delay time (TD) were collected according to the procedures described by Sánchez-Sánchez et al. [37]. Two self-adhesive electrodes (TMG electrodes, Ljubljana, Slovenia) were used to induce the electric stimulus at 20 mAp during 1 ms with 10 mAp increases each time until 110 mAp. To measure muscle response a digital Dc-Dc transducer Trans-Tek (GK 40, Ljubljana, Slovenia) was positioned perpendicular to the muscle belly. All participants were provided with 15 s rest between measurement to prevent from fatigue.

Statistical analyses

Statistical analyses were conducted utilizing Jamovi, version 2.4.10 (The Jamovi Project, 2020). Descriptive measures, including mean and standard deviation, were calculated. To assess the assumption of normality, Shapiro–Wilk test was performed whereas Levene's test was utilized to evaluate the homogeneity of variance. The effects of the three different recovery strategies were examined using a two-way repeated-measures ANOVA, with Time (six levels: pre, post, 0, 24, 48, and 72 h) and Condition (3 levels: Control, CWI, IPC) as within-subject factors. Bonferroni's post-hoc tests were calculated to allocate significant main effects. The effect size was assessed using partial eta squared (η^2p) for variance analysis, and Cohen's d (ES) was used to analyze the standardized difference between two means. An η^2p within the range of 0.1–0.24 indicated a small effect, 0.25–0.36 a medium effect, and ≥ 0.37 a large effect, following criteria adapted from [38]. Cohen's d scale considered small effect size when values ranged between 0.2 and 0.5, moderate between 0.5 and 0.8, and large when values exceed 0.8, according to Cohen [39]. The alpha level of statistical significance was set up at $\alpha \leq 0.05$.

Results

The effects of three different recovery methods on CK values and physical fitness performance after a KSAT are presented in Table 1. No significant differences were detected at baseline for any condition (Fig. 2). The time effect analysis revealed that all variables, except for hand grip, changed significantly over time across all conditions ($p < 0.001$), whereas only CMJ showed a significant time × condition interaction effect ($p < 0.001$). In the post-hoc analysis, better performances in CMJ ($p = 0.04$; $d = 0.98$) and push-ups ($p = 0.03$; $d = 1.03$) were identified after the CWI treatment compared to the IPC method, but only at the 0 h time point.

Table 2 summarizes the results of TMG analysis in the biceps and rectus femoris depending on the recovery method used after a KSAT. At baseline no differences were observed between recovery strategies. However, significant improvements were observed in almost all tensiomyographic variables over the time, especially in the biceps femoris

Table 1 Main effects and inter-condition differences in CK and physical fitness parameters according to three recovery strategies

	ANOVA (F. p)													Pre−training test		
	Baseline		Time			Condition			Time*condition					MD	p	ES
	Mean	SD	F	p	η2p	F	p	η2p	F	p	η2p					
CK (units)																
Control (A)	362.0	225	5.91	< .001	0.50	2.06	0.17	0.26	1.10	0.38	0.16	A vs.B		166.00 (240.63)	1.00	0.98
CWI (B)	196.0	85.3										A vs.C		135.00 (270.97)	1.00	0.70
IPC (C)	227.0	151.0										B vs. C		−31.00 (173.43)	1.00	−0.25
CMJ (cm)																
Control (A)	42.50	3.46	16.53	< .001	0.38	0.04	0.96	0.00	3.43	< .001	0.20	A vs.B		0.10 (5.74)	0.98	0.02
CWI (B)	42.40	4.58										A vs.C		0.86 (6.06)	0.67	0.21
IPC (C)	41.60	4.98										B vs. C		0.80 (6.77)	0.68	0.17
Push−ups (cm)																
Control (A)	14.10	4.55	4.64	< .001	0.15	1.61	0.11	0.11	0.57	0.57	0.04	A vs.B		−0.99 (6.39)	0.60	−0.22
CWI (B)	15.10	4.49										A vs.C		−1.30 (5.64)	0.48	−0.33
IPC (C)	15.40	3.33										B vs. C		−0.34 (5.59)	0.86	−0.08
Sprint (s)																
Control (A)	0.75	0.10	6.04	< 0.001	0.40	1.54	0.24	0.15	1.09	0.38	0.11	A vs.B		0.02 (0.11)	1.00	0.25
CWI (B)	0.73	0.05										A vs.C		0.05 (0.13)	1.00	−0.53
IPC (C)	0.80	0.09										B vs. C		0.07 (0.10)	0.79	−0.96
Hand grip (kg)																
Control (A)	48.60	10.10	2.37	0.05	0.21	1.74	0.20	0.16	1.02	0.43	0.10	A vs.B		1.05 (14.43)	1.00	0.10
CWI (B)	47.60	10.30										A vs.C		2.21 (13.70)	1.00	0.22
IPC (C)	46.50	9.25										B vs. C		1.15 (13.84)	1.00	0.11

	Post−training test			0 h−treatment			24 h−treatment			48 h−treatment			72 h−treatment		
	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES
CK (units)															
Control (A)	181.00 (264.20)	1.00	0.97	209.00 (348.81)	1.00	0.85	450.000 (1171.76)	1.00	0.54	−18.00 (248.73)	1.00	−0.07	40.00 (13.61)	1.00	0.46
CWI (B)	156.00 (292.98)	1.00	0.75	227.00 (360.85)	1.00	0.89	459.00 (1158.15)	1.00	0.56	−10.00 (357.87)	1.00	−0.07	44.00 (119.23)	1.00	0.52
IPC (C)	−25.00 (180.65)	1.00	−0.20	18.00 (184.62)	1.00	0.14	75.00 (303.77)	1.00	0.35	8.00 (370.57)	1.00	4.00	4.00 (88.66)	1.00	0.06
CMJ (cm)															
Control (A)	0.61 (7.53)	0.81	0.11	4.20 (6.04)	0.05	0.98	−0.99 (6.50)	0.65	−0.22	0.20 (6.00)	0.92	0	−0.69 (6.85)	0.74	−0.14
CWI (B)	0.17 (8.00)	0.95	0.04	−0.24 (6.99)	0.91	−0.06	0.45 (6.56)	0.84	0.09	0.41 (58.55)	0.84	0.09	−0.09 (6.02)	0.97	−0.02
IPC (C)	−0.44 (8.67)	0.87	−0.07	−4.40 (6.42)	0.04	−0.99	−0.07 (7.57)	0.52	−0.01	0.21 (58.41)	0.92	0	0.60 (6.84)	0.78	0.12
Push−ups (cm)															
Control (A)	0.11 (8.45)	0.97	0.02	2.90 (6.31)	0.20	0.65	0.13 (6.20)	0.95	0.02	−0.17 (6.64)	0.94	−0.01	1.43 (6.00)	0.51	0.35
CWI (B)	−2.41 (9.26)	0.38	−0.37	−2.21 (7.65)	0.32	−0.41	−1.79 (7.19)	0.40	−0.35	−1.01 (20.38)	0.65	−0.20	−0.27 (7.18)	0.90	−0.04

Table 1 (continued)

	Post−training test			0 h−treatment			24 h−treatment			48 h−treatment			72 h−treatment		
	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES
IPC (C)	−2.60 (7.69)	0.36	−0.46	−5.22 (6.97)	0.03	−1.03	−1.52 (6.25)	0.37	−0.34	−0.84 (20.51)	0.71	−0.06	−1.70 (7.28)	0.44	−0.33
Sprint (s)															
Control (A)	−0.02 (0.11)	1.00	−0.27	−0.04 (0.13)	0.99	−0.54	−0.02 (0.09)	1.00	−0.45	−0.03 (0.09)	0.94	−0.03	−0.07 (0.11)	1.00	−0.92
CWI (B)	−0.05 (0.11)	0.97	−0.50	−0.05 (0.14)	1.00	−0.50	−0.08 (0.11)	0.61	−1.14	−0.04 (1.04)	0.99	−0.60	0.00 (0.07)	1.00	0
IPC (C)	−0.02 (0.11)	1.00	−0.27	0.00 (0.11)	1.00	0	−0.06 (0.13)	1.00	−0.22	−0.01 (1.05	1.00	−0.01	0.07 (0.10)	1.00	1.01
Hand grip (kg)															
Control (A)	−0.75 (15.46)	1.00	−0.06	−1.18	1.00		−3.25 (14.16)	0.72	−0.32	−2.60 (14.01)	0.09	−0.05	−2.14 (13.21	0.98	−0.22
CWI (B)	1.35 (14.50)	1.00	0.14	−0.09	1.00		0.85 (12.85)	1.00	−0.1	−1.00 (66.61	1.00	−0.11	−0.24 (12.57)	1.00	−0.02
IPC (C)	2.10 (15.65)	1.00	0.19	1.19	1.00		2.40 (12.98)	0.76	0.21	1.60 (68.46)	1.00	0.03	1.90 (12.03)	0.91	0.22

CK Creatine Kinase, *CWI* Cold Water Immersion, *IP* Intermittent Pneumatic Compression. Statistically significant p-values (<0.05) are presented in bold

($p < 0.01$). Although time x condition interaction only exhibited significant differences in rectus femoris TS ($p = 0.001$) meaningful tendencies were observed for biceps femoris TR and TD ($p = 0.05$ and $p = 0.09$, respectively). The analysis of post-hoc revealed significant lower rectus femoris TS at 0 h-treatment when CWI was applied respect to both, Control ($p = 0.02$; $d = 1.19$) and IPC ($p < 0.01$; $d = 1.41$). Conversely, no other parameter presented significant condition interaction at any post-treatment time.

Discussion

The most significant finding emerging from the results was the absence of significant differences between recovery therapies observed at the physiological level and in most physical fitness capacities within 72 h after treatment in karate players. Similarly, the biceps and rectus femoris seemed to experience no significant tensiomyographic changes during the testing period regardless of the strategy used. Nevertheless, an interesting tendency towards an improved recovery with the application of IPC and CWI methods respect to passive recovery supported by moderate effect size values can be identified from these parameters. Thus, the hypothesis of the current investigation of the faster and more efficient recovery associated with IPC and CWI treatments after a high-intensity muscle-damage training session was not entirely supported by the results. The significant differences observed in most parameters over time in each condition suggested that the recovery protocols and procedures followed in this study were appropriately executed. Since this study appears to be the first to analyze different recovery methods in elite karate athletes, these results may help elite athletes with high-demand training and competition programs select an appropriate recovery strategy in order to guarantee an effective restoration in muscle function and physical performance.

Muscle damage

Prior studies in mixed martial arts have reported increasing CK values post-combat or post-training, significantly peaking 24 h following a passive recovery [20, 21]. Although similar results were observed in the current research, no significant differences were identified in serum CK between recovery strategies at any time analyzed. However, a tendency towards lower levels was detected in CWI and IPC than the control condition, especially at post and 24 h after treatment. While the CIs around the between-condition differences were wide (supplementary tables), they included values that may indicate potentially relevant effects. This suggests that CWI and IPC might still offer physiological benefits despite the lack of statistical significance. The

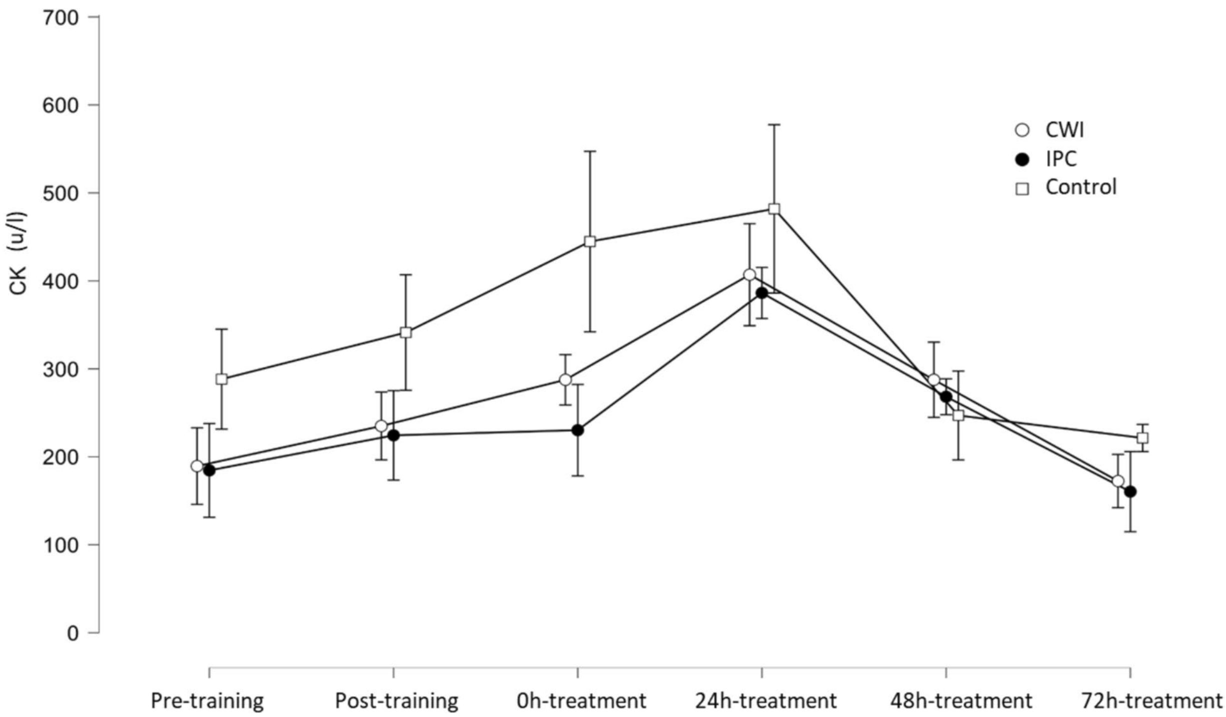

Fig. 2 Evolution of CK values (mean ± SD) over time following a karate training session under three different recovery conditions. *CWI* cold water immersion, *CK* creatine kinase, *IPC* intermittent pneumatic compression

collected data were consistent with previous investigations that determined a significantly decrease of muscle damage biomarkers when CWI treatment was applied compared to passive recovery in trained combat athletes immediately post-training or competition and 24 h after [29, 30]. Additionally, the evidence of CWI as an efficient recovery intervention in martial arts was also supported by the lower DOMS and perceived soreness recently reported when compared to other methods [30, 40]. Perhaps, the absence of significant physiological effects observed in the present study might be related to the lower time of exposure to cold water (10 min) experienced by the participants in comparison to the mentioned investigations [41].

In relation to massage and compression interventions, previous studies have speculated that vibration and IPC might promote recovery by improving metabolites removal, increasing the local blood flow, and stimulating sensory receptors [31, 32]. However, the uncertain effects on muscle damage-related biomarkers have been detected after IPC utilization in endurance athletes [33] while specifically in karate only positive results in DOMS seemed to be associated with the application of deep tissue massage therapy [42]. Recently, Patra et al., [43] determined significantly lower RPE values in the post-karate training after a 15-min massage treatment. Unfortunately, to date, no combat sport research about the influence of IPC or other compression therapy on physiological parameters of recovery has been undertaken.

Functional capacity

The restoration of physical attributes to normal levels after effort is especially important in an individual sport such as karate where performance is dependent on fitness level [2, 3]. The functional capacity in karate actions after high intensity training without the sufficient recovery might be compromised. In this regard, Ghoul et al., [19] identified a significant decrease of countermovement jump height 30 min after an MMA combat compared to baseline levels ($p = 0.02$) following a passive recovery. The analysis of alternative recovery strategies in combat sports has been limited to a few studies. Contradictory results have been identified in CMJ and upper body strength when CWI under 10 °C for 15 min was used in comparison to passive recovery [29, 30]. In any case, best recovery effects of CWI are often observed after 24 h of application as revealed by Tabben et al., [40] when determined a significant improvement in 10 m sprint time in martial arts players. Accordingly, a recent meta-analysis conducted by Moore et al., [27] identified that CWI had moderate to no effect on power and strength compared to other recovery interventions such as warm-water immersion, contrast water or massage therapy. In the current investigation, only the 0 h time point reached statistical significance

Table 2 Main effects and inter-condition differences of tensiomyography parameters in biceps femoris and rectus femoris according to three recovery strategies

	ANOVA (F, p)												Pre−training test		
	Baseline		Time			Condition			Time*condition				MD	p	ES
	Mean	SD	F	p	η2p	F	p	η2p	F	p	η2p				
Biceps femoris DM (mm)															
Control (A)	6,7	2,44	5,85	<.001	0,18	0,01	0,99	0	1,6	0,14	0,11	A vs.B	−0.06 (3.66)	1,000	−0.02
CWI (B)	6,75	2,73										A vs.C	0.81 (3.65)	1,000	0,31
IPC (C)	5.89	2,72										B vs. C	0.87 (3.85)	1,000	0.32
Biceps femoris TC (ms)															
Control (A)	24,52	6,19	3,6	0,004	0,12	0,81	0,45	0,06	0,91	0,53	0,06	A vs.B	−0.26 (8.38)	1,000	−0,04
CWI (B)	24,78	5,65										A vs.C	−0.71 (9.36)	1,000	−0,11
IPC (C)	25,23	7,02										B vs. C	−0.45 (9.01)	1,000	−0,07
Biceps femoris TS (ms)															
Control (A)	211,74	46,08	4,12	0,004	0,13	0,29	0,75	0,02	1,7	0,11	0,11	A vs.B	−10.1 (76.30)	1,000	−0,19
CWI (B)	221,83	60,82										A vs.C	−18.28 (68.47)	1,000	−0,38
IPC (C)	230,02	50,64										B vs. C	−8.18 (79.14)	1,000	−0,15
Biceps femoris TR (ms)															
Control (A)	47,09	12,6	3,03	0,01	0,1	0,49	0,62	0,04	1,88	0,05	0,12	A vs.B	−17.38 (32.41)	0,250	−0,76
CWI (B)	64,46	29,86										A vs.C	−1.47 (22.79)	1,000	−0,09
IPC (C)	48,56	18,99										B vs. C	15.91 (35.39)	0,340	0,64
Biceps femoris TD (ms)															
Control (A)	22,25	2,37	10,34	<.001	0,28	0,17	0,85	0,01	1,75	0,09	0,12	A vs.B	−0.05 (4.99)	1,000	−0,02
CWI (B)	22,3	2,33										A vs.C	1.15 (3.02)	0,760	0,54
IPC (C)	21,1	1,87										B vs. C	1.2 (2.99)	0,700	0,57
Rectus femoris DM (mm)															
Control (A)	10,49	3,59	3,58	0,01	0,12	0,17	0,84	0,01	0,1	1	0,01	A vs.B	0.06 (4.99)	1,000	0,01
CWI (B)	10,44	3,47										A vs.C	−0.31 (4.21)	1,000	−0,1
IPC (C)	10,8	2,2										B vs. C	−0.36 (4.11)	1,000	−0,12
Rectus femoris TC (ms)															
Control (A)	39,95	8,65	1,02	0,41	0,04	0,23	0,79	0,02	1,38	0,2	0,09	A vs.B	−2.71 (10.39)	1,000	−0,37
CWI (B)	42,66	5,76										A vs.C	−1.08 (11.08)	1,000	−0,14
IPC (C)	41,03	6,92										B vs. C	1.63 (9.00)	1,000	0,26
Rectus femoris TS (ms)															
Control (A)	143,3	20,24	11,81	<.001	0,3	0,66	0,53	0,05	3,3	0,001	0,2	A vs.B	9.20 (29.31)	1,000	0,44
CWI (B)	134,1	21,2										A vs.C	6.27 (30.56)	1,000	0,29
IPC (C)	137,02	22,89										B vs. C	−2.92 (31.20)	1,000	−0,13
Rectus femoris TR (ms)															
Control (A)	58,37	23,12	1,93	0,13	0,07	0,15	0,86	0,01	1,46	0,16	0,1	A vs.B	3.65 (26.73)	1,000	0,19
CWI (B)	54,72	13,41										A vs.C	−3.48 (28.60)	1,000	−0,17
IPC (C)	61,85	16,84										B vs. C	−7.13 (21.53)	1,000	−0,47

Table 2 (continued)

	ANOVA (F, p)													Pre−training test		
	Baseline		Time			Condition			Time*condition					MD	p	ES
	Mean	SD	F	p	η2p	F	p	η2p	F	p	η2p					
Rectus femoris TD (ms)																
Control (A)	25,03	2,6	5,33	< .001	0,17	0,28	0,76	0,02	1,31	0,23	0,09		A vs.B	−0.34 (3.30)	1,000	−0,15
CWI (B)	25,37	2,04											A vs.C	−0.43 (3.28)	1,000	−0,19
IPC (C)	25,46	2											B vs. C	−0.09 (2.86)	1,000	−0,04

	Post−training test			0 h−treatment			24 h−treatment			48 h−treatment			72 h−treatment		
	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES
Biceps femoris DM (mm)															
Control (A)	−0.32 (3.10)	1,000	−0,15	0.11 (4.00)	1,000	0,04	−0.22 (3.98)	1,000	−0,08	0.18 (4.00)	1,000	0,03	0.74 (4.17)	1,000	0,25
CWI (B)	−0.04 (3.06)	1,000	−0,02	−0.76 (3.72)	1,000	0,29	−0.47 (4.1)	1,000	−0,16	0.78 (9.46)	1,000	0,27	0.68 (4.14)	1,000	0,23
IPC (C)	0.28 (3.39)	1,000	0,12	−0.87 (4.19)	1,000	−0,29	−0.25 (4.22)	1,000	−0,08	0.59 (9.32)	1,000	0,09	−0.06 (3.92)	1,000	−0,02
Biceps femoris TC (ms)															
Control (A)	−1.63 (8.03)	1,000	−0,29	−2.11 (8.63	1,000	−0,35	−2.01 (9.42)	1,000	−0,30	1.22 (12.46)	1,000	0,04	2.85 (11.60)	1,000	0,35
CWI (B)	−7.42 (19.84)	0,560	−0,53	−8.33 (19.11)	0,380	−0,62	−8.18 (19.01)	0,400	−0,61	−3.1 (43.37)	1,000	−0,20	−3.17 (19.67)	1,000	−0,23
IPC (C)	−5.79 (19.82)	0,780	−0,41	−6.22 (19.97)	0,750	−0,44	−10.66 (19.58)	0,760	−0,77	−4.32 (42.56)	1,000	−0,14	−6.02 (19.34)	0,840	−0,44
Biceps femoris TS (ms)															
Control (A)	6.06 (40.43)	1,000	0,210	−3.79 (75.02)	1,000	−0,07	12.8 (41.35)	1,000	0,44	24.54 (42.25)	1,000	0,11	8.93 (57.17)	1,000	0,22
CWI (B)	8.35 (50.19)	1,000	0,240	33.72 (45.44)	0,400	1,05	40.2 (75.31)	0,200	0,76	−18.13 (334.59)	1,000	−0,24	21.93 (69.01)	0,880	0,45
IPC (C)	2.29 (40.92)	1,000	0,080	37.51 (81.28)	0,290	0,65	−38.56 (77.61)	0,620	−0,70	−42.67 (318.42)	0,440	−0,19	13 (67.77)	1,000	0,27
Biceps femoris TR (ms)															
Control (A)	−24.63 (50.83)	0,310	−0,69	3.35 (48.23)	1,000	0,10	4.88 (48.73)	1,000	0,14	17.2 (54.08)	1,000	0,26	−0.49 (74.73)	1,000	−0,01
CWI (B)	−6.59 (40.31)	1,000	−0,23	20.78 (35.76)	0,350	0,82	27.06 (42.43)	0,190	0,80	−15.85 (117.33)	1,000	−0,26	21.07 (69.93)	0,930	0,43
IPC (C)	18.04 (47.43)	0,690	0,54	17.43 (36.03)	0,550	0,68	22.18 (40.42)	0,370	0,36	−33.05 (107.20)	0,480	−0,44	21.56 (44.33)	0,900	0,69
Biceps femoris TD (ms)															
Control (A)	−0.08 (3.16)	1,000	−0,04	−1.72 (3.17)	0,280	−0,77	−0.39 (3.54)	1,000	−0,16	−0.28 (3.17)	1,000	−0,01	0.55 (3.25)	1,000	0,24
CWI (B)	0.24 (2.64)	1,000	0,13	−0.57 (2.62)	1,000	−0,30	−0.49 (3.85)	1,000	−0,18	0.39 (31.40)	1,000	0,18	0.38 (2.86)	1,000	0,19
IPC (C)	0.32 (3.07)	1,000	0,15	1.16 (3.56)	0,760	0,46	−0.44 (3.68)	1,000	−0,17	0.67 (31.60)	1,000	0,03	−0.18 (3.44)	1,000	−0,07
Rectus femoris DM (mm)															
Control (A)	0.45 (3.33)	1,000	0,19	0.63 (5.00)	1,000	0,18	0.29 (4.83)	1,000	0,08	0.45 (4.57)	1,000	0,04	0.45 (4.33)	1,000	0,15
CWI (B)	−0.34 (3.71)	1,000	−0,13	−0.4 (4.45)	1,000	−0,12	−0.23 (4.04)	1,000	−0,08	−0.08 (15.27)	1,000	−0,03	−0.42 (3.86)	1,000	−0,15
IPC (C)	−0.79 (3.42)	1,000	−0,33	−1.03 (3.95)	1,000	−0,37	−0.52 (3.60)	1,000	0,56	−0.54 (14.96)	1,000	−0,05	−0.86 (3.95)	1,000	−0,31
Rectus femoris TC (ms)															
Control (A)	−0.46 (8.80)	1,000	−0,07	−3.86 (7.54)	0,660	−0,73	−5.51 (9.20)	0,290	−0,80	1.42 (9.77)	1,000	0,03	2.65 (7.16)	0,940	0,52
CWI (B)	1.67 (9.50)	1,000	0,25	−4.83 (10.68)	0,380	−0,64	−5.21 (10.02)	0,290	−0,74	2.26 (58.90)	1,000	0,36	1.04 (8.75)	1,000	0,17
IPC (C)	2.13 (10.42)	1,000	0,29	−0.97 (10.61)	1,000	−0,13	−1.16 (9.54)	1,000	−0,17	0.84 (57.87)	1,000	0,02	−1.61 (8.45)	1,000	−0,27

Table 2 (continued)

	Post–training test			0 h–treatment			24 h–treatment			48 h–treatment			72 h–treatment		
	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES	MD	p	ES
Rectus femoris TS (ms)															
Control (A)	2.99 (20.13)	1,000	0,21	−41.49 (49.38)	0,020	−1,19	−3.27 (42.44)	1,000	−0,11	7.93 (36.55)	1,000	0,06	−7.9 (43.22)	1,000	−0,26
CWI (B)	0.89 (20.10)	1,000	0,06	7.62 (29.33)	1,000	0,37	7.21 (30.97)	1,000	0,33	1.8 (201.83)	1,000	0,08	−1.78 (40.31)	1,000	−0,06
IPC (C)	−2.1 (20.89)	1,000	−0,14	49.11 (49.11)	<.01	1,41	14.42 (42.52)	1,000	0,48	−6.13 (196.26)	1,000	−0,04	6.12 (45.73)	1,000	0,19
Rectus femoris TR (ms)															
Control (A)	2.11 (21.78)	1,000	0,14	−17.15 (50.47)	0,630	−0,48	4.48 (29.76)	1,000	−0,21	9.29 (33.78)	0,960	0,16	1.31 (30.51)	1,000	0,06
CWI (B)	−4.57 (22.40)	1,000	−0,29	7.7 (27.35)	1,000	0,40	5.45 (17.04)	1,000	0,45	8.26 (81.61)	1,000	0,38	0.25 (23.89)	1,000	0,01
IPC (C)	−6.68 (21.94)	1,000	−0,43	24.85 (44.98)	0,220	0,78	16.04 (28.58)	0,700	0,79	−1.03 (74.84)	1,000	−0,02	−1.06 (25.68)	1,000	−0,06
Rectus femoris TD (ms)															
Control (A)	−0.29 (3.95)	1,000	−0,10	−1.53 (4.54)	0,750	−0,48	−0.18 (2.84)	1,000	−0,09	1.12 (3.39)	0,820	0,04	0.62 (3.25)	1,000	0,27
CWI (B)	−0.51 (3.91)	1,000	−0,18	−1.55 (3.41)	0,730	−0,64	−1.24 (3.03)	1,000	−0,58	0.25 (36.99)	1,000	0,12	−0.32 (2.69)	1,000	−0,17
IPC (C)	−0.23 (3.75)	1,000	−0,08	−0.15 (4.30)	1,000	0	−0.31 (2.45)	0,720	−0,18	−0.87 (36.20)	1,000	−0,03	−0.94 (3.33)	1,000	−0,40

CWI Cold Water Immersion, *IPC* Intermittent pneumatic compression, *TC* Contraction time, *TS* Sustained time, *TR* Relaxation time, *TD* Delay time. Statistically significant p-values (<0.05) are presented in bold

in favor of CWI, but the associated 95% CIs and large effect size for CMJ and push-ups suggest a range of possible effects from small to large. These intervals indicate a level of uncertainty but also point toward possible practical relevance, particularly in the acute recovery phase. Therefore, the observed trends and effect sizes suggest that CWI may provide short-term functional benefits, and future studies with larger samples are needed to confirm these preliminary indications.

The effectiveness of pneumatic compression on physical fitness attributes has not been analyzed in martial arts yet. Previous research in active males only identified significant better performance after 30 min of treatment in CMJ and SJ compared to passive recovery measured 24 h and 48 h after intense exercise [44]. The absence of relevant effects of IPC and other massage therapies observed in literature [32] might be explained by the limited doses of treatment or the delayed positive effects. Furthermore, the high training status could also favor the recovery process and mask the effects of the intervention itself. Another possible explanation could be that the level of muscular damage was not significant enough to generate an interaction effect with the applied interventions.

TMG

The analysis of tensiomyography in the current study revealed inconsistent results. Although, significant better TS and relatively high upper CI bounds were observed in the rectus femoris when CWI were applied at post-treatment, the undetermined tendency of the remaining TMG variables suggested no clear evidence of the superiority of any of recovery strategy used. Thus, the use of different treatments has apparently limited effects on muscle function and contractile velocity after a high-intensity training session in karate. Associations between muscle damage markers and TMG after high intensity exercise have been previously reported [14, 45]. Particularly, in concentric contraction such as the most repeated in karate, significant decreases in velocity contractions of the vastus lateralis have been observed after fatiguing leg extension exercises [46]. These results are consistent with those from the current investigation since significantly lower CK and greater TMG variables were observed over time suggesting a recovery from exercise-induced muscle damage.

Limitations

In addition, the findings on physical performance observed in the current investigation are in agreement with the previously reported inconsistent effects of cryotherapy and IPC. Similar conclusions were drowned by Reilly et al., [23] who determined that the optimal recovery relies on an efficient combination of factors taking into consideration the individual differences and lifestyle determinants. Furthermore, the results obtained here, and especially the comparisons with other studies, must be treated with caution due to the utilization of different protocols, durations and the diverse timing of exposure/doses of treatments. Regarding the relatively small sample size, it may affect the statistical power and generalizability of the findings. However, the use of a randomized crossover design, in which each participant served as his own control, helped mitigate inter-individual variability and strengthen the internal validity of the results. Another potential limitation of the study is related to the CK measurement. As previously reported by Bishop et al., [24], the difficulty of serum CK collection seemed to result in unstable measures. Additionally, the levels of muscle damage might not have been sufficient, as the CK values did not reach a minimum threshold typically associated with significant muscle damage. As a result, the intensity of the muscle damage may not have been high enough to allow the recovery systems (CWI, IPC, and passive recovery) to demonstrate their potential differences in effectiveness. Since the current investigation did not take into account the individual differences in training responses and specific recovery adaptations of athletes, future studies might consider the performance level of karate players as an adaptation variable to recovery. This approach would allow an optimal identification of the most effective recovery interventions attending the individual characteristics of the athletes.

Practical applications

The findings of this study offer valuable insights for coaches and elite karate athletes managing high-demand training and competition schedules. While no significant differences were observed among recovery strategies (CWI, IPC, and passive recovery) in CK levels, physical fitness performance, or tensiomyographic variables within 72 h post-exercise, a notable trend toward enhanced recovery with CWI and IPC was detected. These results suggest that alternative recovery methods may benefit elite athletes, particularly when experiencing significant levels of DOMS or diminished functional capacity following high-intensity training.

The data emphasize that no single recovery approach demonstrates clear superiority. Coaches and athletes should consider individual needs, resource availability, and practical factors such as time and accessibility when selecting recovery strategies. Additionally, it may be beneficial to explore personalized or combined recovery protocols over longer periods, as individual responses can vary depending on physiological characteristics and training demands. Integrating recovery interventions like CWI and IPC may be particularly beneficial under conditions of significant muscle damage, but their application should be personalized to optimize performance restoration.

Although the present study focused on isolated recovery methods, it is important to recognize that recovery is influenced by broader factors such as sleep quality, nutrition, hydration, and psychological stress. Moreover, combining recovery strategies may produce greater benefits and future studies should explore the effectiveness of such integrative approaches in high performance athletes.

Conclusions

In conclusion, karate players appeared to recover CK levels similarly, regardless of the recovery therapy employed (CWI, IPC, or passive recovery) within 72 h after a high-intensity training session. Furthermore, no substantial differences in physical performance or TMG variables were identified among treatments. However, a trend indicating enhanced recovery with IPC and CWI compared to passive recovery was observed. While these results suggest potential benefits of alternative recovery strategies, their application should consider individual athlete needs and situational constraints. Thus, considering the lack of strong evidence regarding the superiority of one particular treatment over others, coaches and athletes should choose the most appropriate strategy, taking into account factors such as their resources, time constraints or accessibility to recovery tools.

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Author contributions AR-M and JR-A conceived and designed research, all authors contributed to data collection process and performed experiments. LA-C and DR-C analyzed data and interpreted results of experiments while DL-P prepared figures and drafted manuscript. JR-A supervised the project and all authors revised and approved final version of manuscript.

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Data availability No datasets were generated or analyzed during the current study.

Declarations

Conflict of interest The authors declare that there are no competing interests.

Ethics approval The University Institutional Review Board (nº UA-2019-04-09) approved the experimental design and procedures of the investigation which was conducted in accordance with the latest Declaration of Helsinki.

Participant consent All participants were fully informed of the experimental procedures and the risks involved and provided their written consent before the experiments.

Permission to reproduce material from other sources No material from other sources was included in this work.

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