Eur J Appl Physiol (2008) 102:447–455
DOI 10.1007/s00421-007-0605-6

ORIGINAL ARTICLE

Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness

Joanna Vaile · Shona Halson · Nicholas Gill · Brian Dawson

Accepted: 19 October 2007 / Published online: 3 November 2007

Abstract This study independently examined the effects of three hydrotherapy interventions on the physiological and functional symptoms of delayed onset muscle soreness (DOMS). Strength trained males ($n = 38$) completed two experimental trials separated by 8 months in a randomised crossover design; one trial involved passive recovery (PAS, control), the other a specific hydrotherapy protocol for 72 h post-exercise; either: (1) cold water immersion (CWI: $n = 12$), (2) hot water immersion (HWI: $n = 11$) or (3) contrast water therapy (CWT: $n = 15$). For each trial, subjects performed a DOMS-inducing leg press protocol followed by PAS or one of the hydrotherapy interventions for 14 min. Weighted squat jump, isometric squat, perceived pain, thigh girths and blood variables were measured prior to, immediately after, and at 24, 48 and 72 h post-exercise. Squat jump performance and isometric force recovery were significantly enhanced ($P < 0.05$) at 24, 48 and 72 h post-exercise following CWT and at 48 and 72 h post-exercise following CWI when compared to PAS. Isometric force recovery was also greater ($P < 0.05$) at 24, 48, and 72 h post-exercise following HWI when compared to PAS. Perceived pain improved ($P < 0.01$) following CWT at 24, 48 and 72 h post-exercise. Overall, CWI and CWT were found to be effective in reducing the physiological and functional deficits associated with DOMS, including improved recovery of isometric force and dynamic power and a reduction in localised oedema. While HWI was effective in the recovery of isometric force, it was ineffective for recovery of all other markers compared to PAS.

Keywords Recovery · Eccentric exercise · Water immersion · Performance

Introduction

Delayed onset muscle soreness (DOMS) is a well-documented phenomenon, often occurring as the result of unaccustomed or high intensity eccentric exercise (Connolly et al. 2003; MacIntyre et al. 1995). Associated symptoms include muscle shortening, increased passive stiffness, swelling, decreases in strength and power, localised soreness, and disturbed proprioception (Proske and Morgan 2001). Symptoms will often present within 24 h post-exercise and typically subside after 3–4 days (Clarkson and Sayers 1999). Elite athletes are often susceptible to muscle damage due to muscles being regularly subjected to repetitive, high intensity contractions (Allen et al. 2004).

Recently, the use of various forms of hydrotherapy such as cold water immersion (CWI), hot water immersion (HWI), and contrast water therapy (CWT) as post-exercise recovery interventions have gained popularity and are now a common practice within the elite sporting environments (Cochrane 2004; Vaile et al. 2007). However, such recovery interventions are being employed despite lack of scientific

J. Vaile (✉) · S. Halson
Department of Physiology, Australian Institute of Sport,
PO Box 176, Belconnen, ACT, Australia
e-mail: jo.vaile@ausport.gov.au

N. Gill
School of Sport and Exercise Science,
Waikato Institute of Technology, Hamilton, New Zealand

N. Gill
Division of Sport and Recreation,
Auckland University of Technology, Auckland, New Zealand

B. Dawson
School of Human Movement and Exercise Science,
University of Western Australia, Perth, Australia

investigation and evidence regarding their potential benefits and/or mechanisms by which they may work.

Various forms of cryotherapy have been shown to produce multiple physiological responses, including decreased swelling (Yanagisawa et al. 2004), tissue temperatures (Enwemeka et al. 2002), heart rate (HR) and cardiac output (Sramek et al. 2000), enhanced creatine kinase clearance (Eston and Peters 1999) and analgesic effects, resulting in altered perceptions of pain and discomfort (Bailey et al. 2007). However, there appear to be conflicting conclusions regarding the effect of CWI on performance, with some studies suggesting beneficial effects (Bailey et al. 2007; Burke et al. 2000; Lane and Wenger 2004) and others indicating negligible changes (Isabell et al. 1992; Paddon-Jones and Quigley 1997; Sellwood et al. 2007; Yamane et al. 2006). In contrast, despite limited research in the area, HWI affects the body differently resulting in increased HR, cardiac output and tissue temperatures and may enhance the inflammatory response (Wilcock et al. 2006). Contrast water therapy (CWT) incorporates the combined effect of both CWI and HWI with athletes alternating between them for a set period of time. While there is a limited research investigating the physiological effects of CWT and its role on return/ maintenance of performance following damage or exercise-induced fatigue, current knowledge suggests CWT to be a promising recovery intervention (Coffey et al. 2004; Gill et al. 2006; Vaile et al. 2007). However, the use of CWT has previously been criticised due to the unknown effects of exposure to both hot and cold water as well as the effect of CWT on tissue oedema accumulation.

Consequently, the present studies set out to examine the effect of the three hydrotherapy interventions (CWI, HWI, and CWT) in comparison to a passive rest recovery following a controlled exercise task, ensuring identical durations of recovery, water exposure and temperatures were maintained. Functional and physical symptoms of DOMS and the recovery of performance were assessed.

Methods

Subjects

A total of 38 strength trained males completed two experimental trials separated by 8 months in a randomised crossover design; one trial involved passive recovery (PAS, control), the other a specific hydrotherapy protocol. Subjects were randomly assigned to one of the three groups differing only in recovery hydrotherapy intervention: (1) cold water immersion (CWI, 15°C, $n = 12$), (2) hot water immersion (HWI, 38°C, $n = 11$) or (3) contrast water therapy (CWT, 15°C/38°C, $n = 15$). These interventions were selected using water temperatures and durations similar to those used in common practice and to ensure identical durations of water exposure. The physical and functional symptoms of DOMS were monitored throughout a 72 h follow-up period and compared to pre-exercise values. After an 8 month washout period, the subjects completed the exercise task with the alternate (hydrotherapy or PAS) recovery protocol.

Experimental design

On two separate occasions (8 months apart; hydrotherapy vs. PAS), subjects completed a muscle-damaging protocol (MDP) consisting of seven sets of ten eccentric repetitions on a leg press machine. Previously it has been demonstrated that a single bout of eccentric exercise can have a prophylactic effect not only on muscle soreness, but also on blood responses and performance capabilities after a second bout of eccentric exercise performed within a few weeks (Brown et al. 1997; Byrnes and Clarkson 1986; Mair et al. 1995; Nosaka et al. 2001). Therefore, it was important to consider this effect and control it by utilising a crossover design and selecting athletes who were both familiar and accustomed to resistance training (Viitasalo et al. 1995). A substantial washout period of 8 months was chosen to minimise the effect of the first session of eccentric exercise. Nosaka et al. (2001) investigated the duration of the protective effect of eccentric exercise-induced muscle damage, concluding that the repeated bout effect for most measures appeared to last at least 6 months.

Two weeks prior to both the trials (separated by 8 months), subjects completed a comprehensive familiarisation session to determine maximal strength in the form of one repetition maximum (1RM) on the leg press machine and isometric squat 1RM to establish squat jump load (30% isometric squat) (Nosaka and Newton 2002). Additionally, subjects were familiarised with squat jump and isometric squat protocols until no further learning/ improvement was apparent (this was achieved by a maximum of three independent familiarisation sessions). Following each testing session, and once a day for 72 h post-exercise, subjects performed one of the two recovery interventions (hydrotherapy or PAS). Prior to participation, all subjects were informed of the requirement and risks associated with the study and provided informed written consent. The study was approved by the Australian Institute of Sport Research Ethics Committee.

Procedures

The DOMS-inducing exercise protocol consisted of 5×10 eccentric bi-lateral leg press contractions with a load of 120% of one repetition maximum [1-RM (concentric)] followed by 2×10 at a load of 100% 1-RM. The aforementioned protocol was chosen as eccentric strength has been shown to be approximately 20–60% greater than concentric strength and similar protocols have been successfully employed to induce DOMS (Hortobagyi and Katch 1990). During each eccentric contraction, the load was resisted with both legs from full knee extension to a 90° knee angle (Vaile et al. 2007) with contractions lasting for 3–5 s duration. After the completion of each eccentric repetition, the load was raised by an electrical winch. Subjects completed one contraction every 15 s and had a 3 min rest period between sets (Nosaka and Newton 2002; Vaile et al. 2007).

Recovery interventions

Following each testing session, and once a day for 72 h post-exercise, subjects performed one of two recovery interventions (hydrotherapy or PAS). All subjects completed PAS recovery and one of the other three hydrotherapy interventions (subjects wore shorts during the hydrotherapy intervention and shorts/t-shirt during PAS). These were: (1) passive recovery/control (PAS) whereby subjects were seated with minimal movement for 14 min. (2) Cold water immersion (CWI) where subjects immersed their entire body (excluding head and neck) in 15°C water for 14 min. (3) Hot water immersion (HWI) where subjects immersed their entire body (excluding head and neck) in 38°C water for 14 min. (4) Contrast water therapy (CWT) where subjects immersed their entire body (excluding head and neck) and alternated between cold water exposure (15°C 1 min) and hot water exposure (38°C 1 min) water for a total of 14 min (seven cycles). Subjects were required to transfer between the hot and cold baths in less than 5 s to ensure maximal duration of water exposure. Recovery was performed immediately following the post-exercise testing session, and at 24, 48, and 72 h post-exercise.

Outcome measures

The effects of the exercise task and subsequent recovery were assessed through the measurement of isometric squat force, squat jump performance, blood markers [creatine kinase (CK), myoglobin (Mb), interleukin-6 (IL-6), lactate dehydrogenase (LDH)], thigh circumference and perceived muscle soreness. Measures were recorded pre-exercise, and immediately post-exercise, as well as at 24, 48 and 72 h post-exercise.

Recovery assessment

Isometric squat (peak force)

The production of vertical ground reaction forces were measured via force platform (Kistler Instrumenté, Switzerland) and assessed though an isometric squat performed against an immovable bar on a Smith Machine. On each occasion, subjects performed thee trials, each separated by 3 min, with the best effort (indicated by peak vertical force) used to represent the subject's isometric squat force. The squat was performed in an identical position each time, with foot placement recorded for each individual and maintained throughout all testing sessions to ensure a straight line from the temporo-mandibular joint to the lateral malleolus with the subject in a standing position (Blazevich et al. 2002; Vaile et al. 2007). The protocol used to assess the isometric force was found to have ICC = 0.97 and TEM = 2.9%.

Squat jump (peak power)

Subjects were required to perform squat jumps (separated by 2 min) on a Smith machine, which was loaded, to a combined weight equivalent of 30% of their isometric squat force. The best of the three attempts was recorded for analysis. Subjects were instructed to lower the weighted bar to a 90° knee angle, pause for 2 s, and then jump upward for maximum height (Vaile et al. 2007). Peak power was measured using a GymAware system (Kinetic Performance, Australia). When assessed on ten subjects, this peak power protocol was acceptably reliable (ICC = 0.94, TEM = 6.1%).

Blood markers

Venous blood samples were collected pre-exercise and at each of the four post-exercise time-points. Each blood sample (8 mL) was collected from a superficial forearm vein using standard venipuncture techniques. All samples were collected directly into serum separator collection tubes (Greiner Bio-one; Frickenhausen, Germany) and serum separated by centrifugation at 4,000 rpm for 5 min. Serum samples were stored frozen at −80°C until analysis. Creatine kinase (CV 0.6%) and LDH (CV 0.8%) concentrations were determined using a Hitachi 911 automated clinical chemistry analyser (Roche Diagnostics Corporation; Indianapolis, IN, USA) and commercially available reagents (Roche Diagnostics Corporation; IN, USA). Myoglobin (CV 2.6%) and IL-6 (CV 3.5%) concentrations were determined using an Immulite 1000 (Diagnostics Products Corporation, CA, USA) solid-phase chemiluminescent enzyme immunoassay system and commercially available assay kits (Diagnostics Products Corporation, CA, USA).

Thigh circumference

A non-stretch anthropometric measuring tape (Lufkin, USA) was used to measure circumference at three sites on the upper leg: above-knee, mid-thigh and sub-gluteal. Measurement sites were marked with a permanent marker to ensure re-test reliability (0, 24, 48 and 72 h). Circumference measurements were taken as an indicator of acute changes in thigh volume (Brown et al. 1997; Chen and Hsieh 2000; Chleboun et al. 1998; Eston and Peters 1999), likely to occur from osmotic fluid shifts or inflammation, which has often been associated with muscle-damage and eccentric exercise (Fielding et al. 2000). For the purposes of presentation, mid-thigh girth was selected for representation of all upper leg measurements (above-knee, mid-thigh, and sub-gluteal) as it closely resembled changes throughout all the measured sites. When ten subjects were tested and re-tested using identical methodology as used in the present study the reliability of these measurements was ICC = 1.00 and TEM = 0.1%.

Perceived soreness

A visual analogue scale (VAS; 1–10) was used to assess the subjects perceived soreness whereby they were required to rank their perception of soreness on a scale of 0 to 10, with 0 being "normal" and 10 being "extremely sore". This method has been used previously as a non-invasive way to monitor changes in perceived pain following muscle-damaging protocols (Cleak and Eston 1992; Harrison et al. 2001; Vaile et al. 2007). Prior to reporting their VAS ranking, subjects were required to perform a standardised half squat to ensure all subjects were experiencing the same movement/sensation.

Statistical analysis

Each part of the present study (CWI vs. PAS; HWI vs. PAS; CWT vs. PAS) was independently analysed. Mean effects were calculated using a spreadsheet via the unequal-variances t statistic computed for change scores between pre- and post-tests of the two groups (Batterham and Hopkins 2005). Each subject's change score was expressed as a percentage of baseline score via analysis of log-transformed values, in order to reduce bias arising from non-uniformity of error. Baseline values (for all variables) from the two trials, 8 months apart were also compared, with no significant difference observed over time.

Results

Isometric squat

No differences were observed between any interventions at baseline or immediately post-exercise ($P > 1.3$) (Table 1). However, change in isometric squat performance (% change from baseline) was significantly less at 24, 48, and 72 h post exercise following both HWI (−12.8, −10.1, −3.2%; $P < 0.05$; Fig. 1b) compared to PAS (−17.0, −16.0, −9.8%) and CWT (−10.3, −7.4, −2.8%; $P < 0.01$; Fig. 1c) compared to PAS (−17.3, −14.0, −11.5). Additionally at 48 and 72 h post-exercise, change in isometric squat performance from baseline was significantly less following CWI (−7.3, −4.3%; $P < 0.05$; Fig. 1a) when compared to PAS (−15.7, −11.7%).

Weighted squat jump

Compared to PAS, change in peak power performance (% change from baseline) was significantly less at 48 ($P = 0.01$) and 72 ($P = 0.03$) h post-exercise following CWI (Fig. 2a) and at 24, 48, and 72 h post-exercise following CWT ($P < 0.01$; Fig. 2c). However, HWI did not positively influence the recovery of squat jump performance compared to PAS (Table 1). Production of peak power, 72 h post-exercise was significantly reduced below baseline by 8.2 ± 4.1% following HWI and 7.7 ± 3.2% following PAS; no differences were observed between HWI and PAS ($P > 0.05$; Fig. 2b) at any time point.

Mid-thigh girth

Mid-thigh girth was significantly reduced at 24, 48 and 72 h post-exercise following CWI ($P < 0.03$; Fig. 3a) and CWT interventions ($P < 0.01$; Fig. 3c) compared to PAS (Table 1). However, HWI was not effective ($P > 0.05$; Fig. 3b) in reducing post-exercise thigh volume compared to PAS.

Blood variables

Significant reductions in [CK] were observed 24 h ($P = 0.03$) and 72 h ($P = 0.04$) post-exercise following CWI, and 48 h ($P = 0.04$) post-exercise following HWI when compared to PAS. However, none of the three hydrotherapy interventions influenced post-exercise changes of Mb, IL-6, or LDH.

Perceived pain (VAS)

Perception of pain was reduced only at 24, 48, and 72 h post-exercise following CWT ($P < 0.01$) compared to PAS (Fig. 4c). Both CWI and HWI ($P > 0.05$) were ineffective in reducing perceptions of pain following intense eccentric exercise (Fig. 4a/b).

Discussion

The main findings of the present studies were that following DOMS-inducing exercise; all the three hydrotherapy

Table 1 Descriptive statistics (mean ± SD) for dependent variables for each intervention and its independent control (CWT vs. PAS, CWI vs. PAS, and HWI vs. PAS)

Variable	CWT	vs.	PAS	CWT	vs.	PAS	CWT	vs.	PAS
Jump squat (peak power W)									
Baseline	3,938 ± 871		3,969 ± 879	4,158 ± 945		4,170 ± 947	3,902 ± 303		3,900 ± 277
0 h post ex	3,328 ± 806		3,479 ± 792	3,547 ± 1033		3,564 ± 878	3,446 ± 351		3,382 ± 278
24 h post ex	3,675 ± 741 *		3,389 ± 750	3,735 ± 872		3,577 ± 878	3,459 ± 389		3,401 ± 416
48 h post ex	3,805 ± 821 *		3,473 ± 755	3,939 ± 877 *		3,507 ± 795	3,487 ± 455		3,460 ± 370
72 h post ex	3,937 ± 808 *		3,659 ± 795	4,080 ± 914 *		3,857 ± 846	4,593 ± 409		3,606 ± 356
Isometric squat (peak force N)									
Baseline	2,068 ± 446		2,066 ± 469	2,110 ± 472		2,089 ± 443	1,929 ± 295		1,916 ± 350
0 h post ex	1,733 ± 320		1,750 ± 389	1,748 ± 424		1,734 ± 420	1,592 ± 262		1,597 ± 271
24 h post ex	1,857 ± 405 *		1,711 ± 396	1,877 ± 418		1,792 ± 401	1,685 ± 286 *		1,598 ± 342
48 h post ex	1,923 ± 457 *		1,783 ± 424	2,077 ± 465 *		1,769 ± 412	1,735 ± 272 *		1,617 ± 329
72 h post ex	2,018 ± 477 *		1,833 ± 436	2,074 ± 487 *		1,859 ± 463	1,868 ± 291 *		1,724 ± 290
Mid-thigh circumference (cm)									
Baseline	56.2 ± 4.5		56.1 ± 4.5	56.7 ± 3.7		56.6 ± 3.4	57.3 ± 3.8		57.4 ± 3.7
0 h post ex	56.8 ± 4.6		56.7 ± 4.6	57.4 ± 3.8		57.1 ± 3.3	57.8 ± 3.8		57.9 ± 3.7
24 h post ex	56.4 ± 4.5 *		56.9 ± 4.7	57.1 ± 3.8 *		57.6 ± 3.2	58.1 ± 3.9		58.1 ± 3.8
48 h post ex	56.3 ± 4.6 *		56.9 ± 4.7	56.9 ± 3.8 *		57.4 ± 3.3	57.9 ± 3.9		58.0 ± 3.7
72 h post ex	56.3 ± 4.5 *		56.7 ± 4.7	56.9 ± 3.8 *		57.1 ± 3.3	57.6 ± 3.8		57.8 ± 3.8
Creatine kinase (U/L)									
Baseline	176 ± 76		218 ± 168	223 ± 222		189 ± 45	199 ± 241		143 ± 105
0 h post ex	229 ± 147		245 ± 220	203 ± 175		193 ± 156	269 ± 411		165 ± 105
24 h post ex	736 ± 1115		737 ± 361	231 ± 182 *		570 ± 263	312 ± 242		402 ± 255
48 h post ex	416 ± 589		361 ± 318	211 ± 259		263 ± 174	225 ± 221 *		748 ± 1694
72 h post ex	359 ± 433		271 ± 234	204 ± 343 *		296 ± 290	151 ± 57		169 ± 86
Lactate dehydrogenase (U/L)									
Baseline	271 ± 72		218 ± 107	236 ± 82		207 ± 61	261 ± 87		256 ± 93
0 h post ex	280 ± 87		246 ± 98	227 ± 95		208 ± 52	278 ± 85		272 ± 103
24 h post ex	291 ± 132		270 ± 123	194 ± 65		194 ± 69	271 ± 90		269 ± 97
48 h post ex	264 ± 117		230 ± 92	177 ± 71		204 ± 89	260 ± 69		280 ± 68
72 h post ex	254 ± 109		247 ± 112	183 ± 68		219 ± 75	254 ± 83		267 ± 77
Myoglobin (ng/mL)									
Baseline	44.1 ± 22.3		47.8 ± 38.4	36.4 ± 17.8		27.2 ± 7.71	35.6 ± 22.8		27.3 ± 7.7
0 h post ex	95.4 ± 76.6		116.2 ± 101.1	60.7 ± 30.1		67.5 ± 24.9	65.1 ± 44.3		74.8 ± 68.1
24 h post ex	67.2 ± 51.1		69.5 ± 54.9	44.9 ± 25.4		38.5 ± 13.3	39.8 ± 23.2		47.3 ± 22.7
Interleukin-6 (pg/mL)									
Baseline	1.5 ± 0.6		1.7 ± 0.7	3.6 ± 3.9		2.6 ± 2.3	1.7 ± 1.1		2.6 ± 2.7
0 h post ex	2.2 ± 0.7		2.6 ± 1.1	4.5 ± 6.8		3.4 ± 3.2	2.3 ± 1.3		2.7 ± 2.8
24 h post ex	1.5 ± 0.9		1.9 ± 1.0	3.7 ± 6.3		2.8 ± 2.5	1.7 ± 0.9		2.4 ± 2.1

Appropriate statistics were completed using log transformed values

* $P < 0.05$

interventions (CWI, HWI, and CWT) improved the recovery of isometric force compared to PAS througout the 72 h post-exercise data collection period. However, compared to PAS, only CWI and CWT significantly enhanced the recovery of dynamic power (squat jump), while HWI appeared to have no effect on the return of power, following a similar trend to PAS. In addition to enhancing the recovery of athletic performance, CWI and CWT (but not HWI) significantly reduced the degree of post-exercise swelling when compared to PAS.

To the authors knowledge, the present studies are the first to independently investigate three commonly prescribed post-exercise hydrotherapy interventions ensuring identical exercise mode and intensity, duration of water

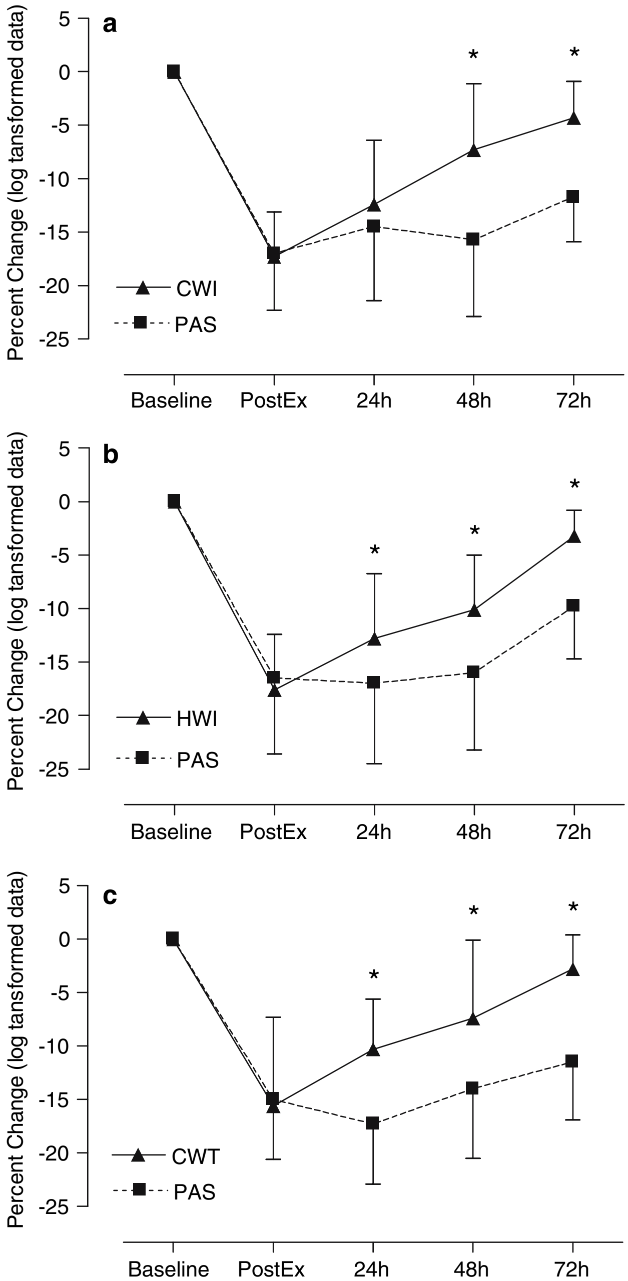

Fig. 1 Percent change in isometric squat performance (peak force) following CWI (**a**), HWI (**b**), and CWT (**c**). Performance was assessed pre and post muscle-damaging exercise as well as at 24, 48, and 72 h post-exercise. *Significant difference between hydrotherapy intervention and PAS

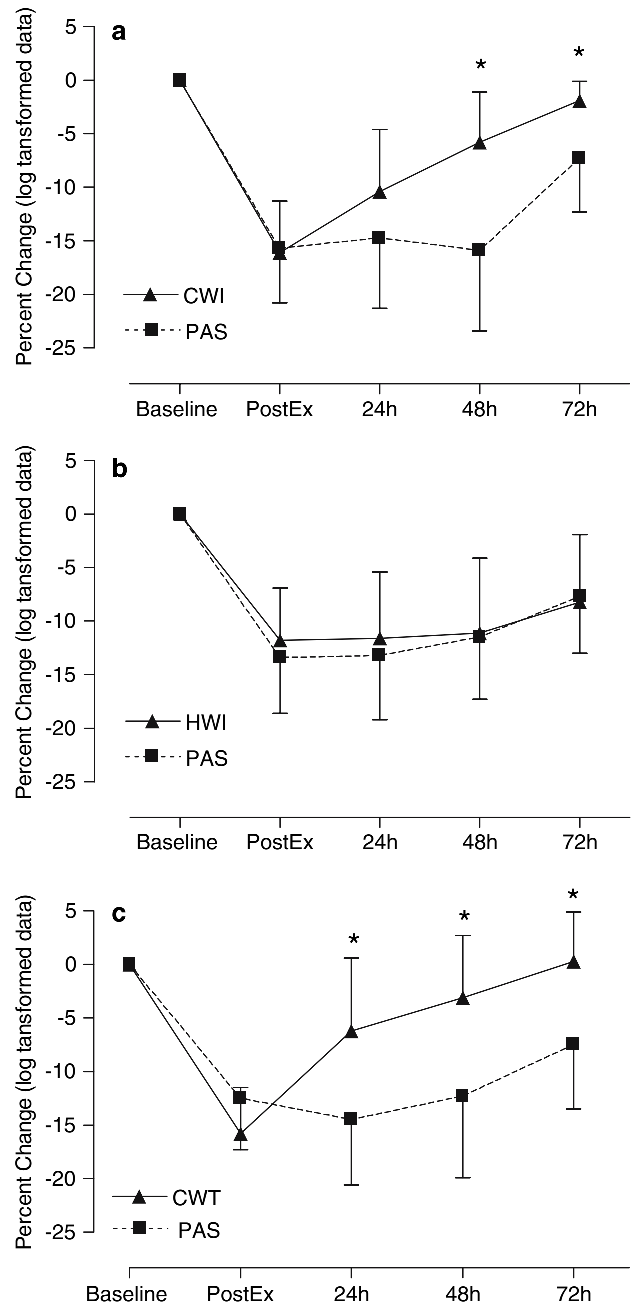

Fig. 2 Percent change in squat jump performance (peak power) following CWI (**a**), HWI (**b**), and CWT (**c**). Performance was assessed pre and post muscle-damaging exercise as well as at 24, 48, and 72 h post-exercise. *Significant difference between hydrotherapy intervention and PAS

exposure and water temperature (CWI 15°C, HWI 38°C, CWT 38°C/15°C). The mechanism by which such interventions may be effective remains largely unknown. However, there are multiple theories surrounding the effectiveness of water immersion.

The effect of hydrostatic pressure exerted on the body during water immersion is becoming more defined. The compressive effect of immersion in water is thought to create a displacement of fluids from the periphery to the central cavity. This results in multiple physiological changes, including increases in substrate transport and cardiac output as well as a reduction in peripheral resistance (Hinghofer-Szalkay et al. 1987; Wilcock et al. 2006). Full body (head out) water immersion, as prescribed in the present studies, has been shown to increase central blood volume (Hinghofer-Szalkay et al. 1987; Johansen et al. 1997; Wilcock et al. 2006) and extracellular fluid volume via

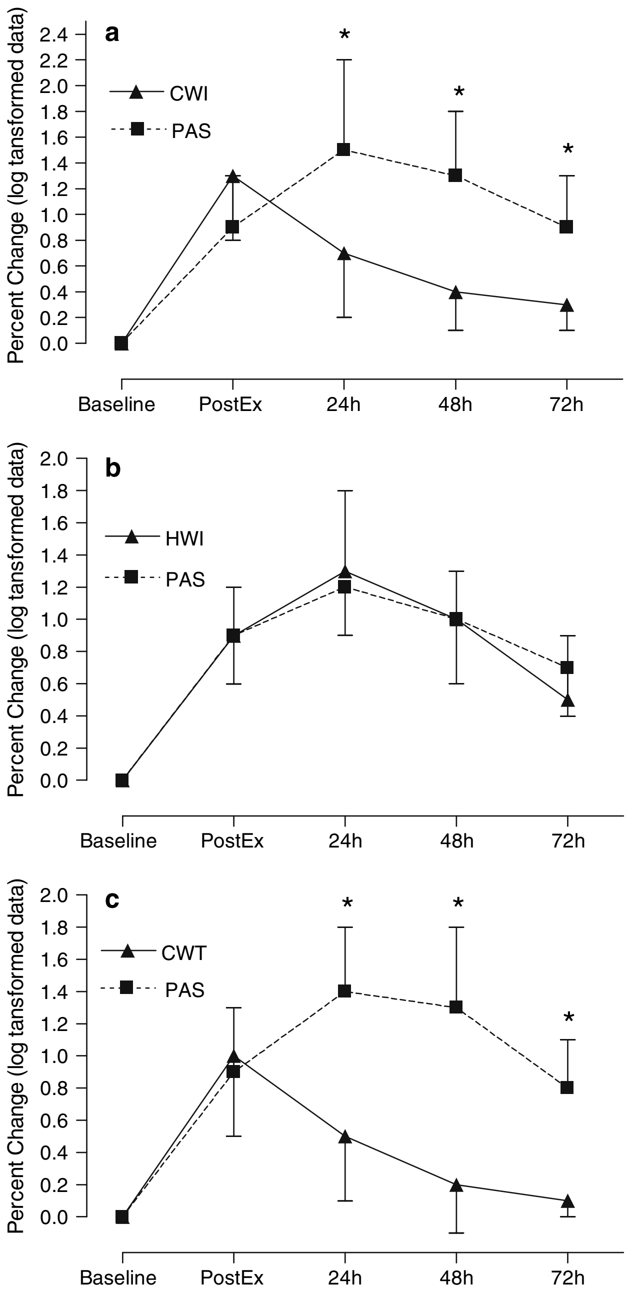

Fig. 3 Percent change in mid-thigh circumference following CWI (**a**), HWI (**b**), and CWT (**c**). Circumference was assessed pre and post muscle-damaging exercise as well as at 24, 48, and 72 h post-exercise. *Significant difference between hydrotherapy intervention and PAS

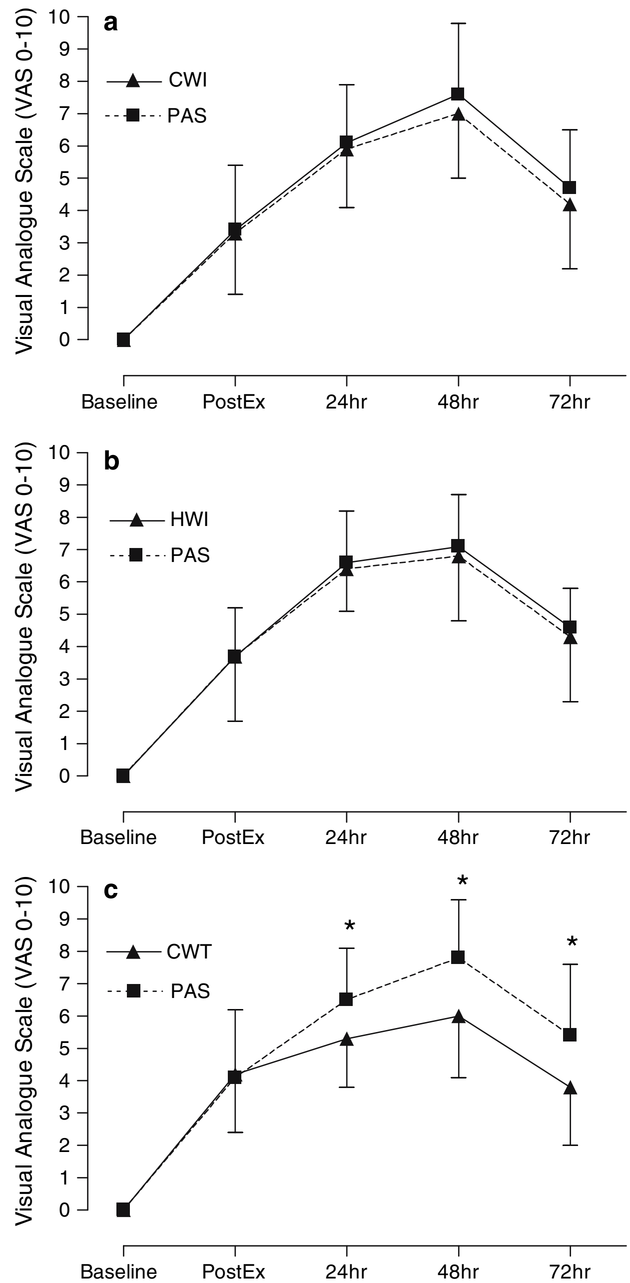

Fig. 4 Perception of pain CWI (**a**), HWI (**b**), and CWT (**c**). The visual analogue scale was completed immediately post muscle-damaging exercise as well as at 24, 48, and 72 h post-exercise. *Significant difference between hydrotherapy intervention and PAS

intracellular-intravascular osmotic gradients. Such changes may increase the removal of waste products with the potential of enhancing recovery from exercise. Although the present studies observed post-exercise increases in the blood markers analysed, the only post-exercise reduction observed between interventions was in CK response at 24 and 72 h post-exercise following CWI and 48 h post HWI compared to PAS. In the present study, compared to PAS, CWI and CWT were effective in reducing swelling of the thigh following muscle-damaging exercise. This result indicates a possible increase in the re-absorption of interstitial fluid resulting in reduced oedema (Vaile et al. 2007). Similar to the effects of compression garments (Bernhardt and Anderson 2005; Doan et al. 2003; Kraemer et al. 2001), hydrostatic pressure has been shown to increase the pressure gradient between the interstitial compartment of the legs and the intravascular space (Wilcock et al. 2006). In addition, the reduction of post-exercise oedema may not only improve the contractile functions within the muscle but also decreases the chances of secondary damage to the tissues that may result from cellular infiltration (Wilcock et al. 2006). However, immersion in hot water did not have the same effect despite identical exposure time and water depth. Therefore, in addition to hydrostatic pressure, water temperature appears to play a role in overall recovery following damaging exercise.

Main physiological effects resulting from immersion in cold water appear to be localised vasoconstriction and decreased blood flow that may reduce oedema (Meeusen and Lievens 1986). The effect of cold application through various mediums has been shown to stimulate an analgesic effect, resulting in a decreased perception of pain (Cheung et al. 2003; Meeusen and Lievens 1986). While the results of the present study do not indicate an altered perception of pain compared to PAS, it must be noted that pain ratings were taken prior to immersion on each of the testing occasions. Therefore, while subjects may have experienced an acute analgesic effect immediately post-CWI, any such effect had diminished 24 h post-recovery.

Not surprisingly, immersion in hot water has been shown to demonstrate opposite physiological effects on the body; including an increase in blood flow, HR, and cardiac output, and a decrease in peripheral resistance (Wilcock et al. 2006). Benefits such as decreased muscle spasm, stiffness and increased range of motion have also been reported following the application of heat (Kaul and Herring 1994; Prentice 1999). However, to the author's knowledge, no study has investigated the isolated effects of hot water immersion on the recovery of muscle damage in a controlled environment. The present study found HWI to be beneficial only through enhanced recovery of isometric force in comparison to PAS. When a specific movement (squat jump) was performed requiring dynamic power HWI did not appear to provide any improvement in return of performance to baseline levels. However, in comparison to PAS, CWT enhanced the recovery of both isometric force production and squat jump performance. The combined effects of alternating between hot and CWI appears to be more beneficial than when the interventions are prescribed as an isolated exposure. However, despite a growing body of knowledge, the physiological effects arising from CWT remain largely unknown. Contrast water therapy has been suggested to be an effective post-exercise intervention due to increased lactate clearance (Cochrane 2004), decreased oedema (Vaile et al. 2007), increased blood flow (Cochrane 2004), increased stimulation of the central nervous system and reduced metabolic rate (Coffey et al. 2004; Hamlin 2007; Vaile et al. 2007). Myrer et al. (1994) and Higgins and Kaminski (1998) proposed one of the main effects of CWT to be a pumping action stimulated by vasodilation and vasoconstriction of the blood vessels. No study has observed any form of vasodilation or vasoconstriction during or following CWT (Higgins and Kaminski 1998; Myrer et al. 1994), however, this has only been assessed via intramuscular temperature measures, with results indicating no significant changes following various applications of CWT. Measures of blood flow using Doppler ultrasound (or similar) procedures may help to improve knowledge regarding the potential effects of CWT on muscle blood flow.

The present series of studies has contributed to the limited knowledge base investigating the effects and mechanisms underlying the three popular hydrotherapy interventions. The findings indicate CWI and CWT to be effective in minimising the physiological and functional deficits associated with DOMS, when compared to PAS. While HWI was effective in the recovery of isometric force, it was ineffective for recovery of all other markers compared to PAS.

Acknowledgments The authors would like to acknowledge the Australian Institute of Sport and Waikato Institute of Technology for funding the aforementioned studies. In addition, Professor Will Hopkins is acknowledged for his assistance with the statistical analysis.

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