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Effects of recovery using contrast water therapy or compression stockings on subsequent 5-min cycling performance

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Abstract

Many researchers have investigated the effectiveness of contrast water therapy (CWT) or compression stockings (CS) during recovery, using subsequent performance as the principal outcome measure. However, data in the literature are contradictory, mainly because of the methodology used. Purpose: Based on well-controlled performance measures, this study aimed to compare the effects of CWT, CS or passive recovery (PR) on subsequent performance. Methods: After inclusion based on reproducibility criteria (intra-participant variability in performance test lower than the expected differences between the recovery interventions, i.e. 1.5%), 12 competitive male cyclists (peak power output: 5.0 ± 0.2 W/kg; cycling practice: 4.9 ± 0.4 times/week; intra-participant variability: 1.2 ± 0.2%) came to the laboratory three times in a random crossover design. Each time visit, they performed a tiring exercise on a cycle ergometer, followed by a 5-min performance test during which the mean power output was recorded, separated by a 15-min recovery period during which a 12-min PR, CWT (1:2 (cold: 10-12°C to warm: 36-38°C) min ratio) or CS (~20 mmHg) was implemented. Results: Compared with PR (353.8 ± 13.1 W), performance was significantly higher after CWT (368.1 ± 12.3 W) and CS (360.5 ± 14.8 W). Moreover, performance was significantly higher after CWT than after CS. Conclusion: Athletes can use this information as a way of improving their performance in competition format using repeated high-intensity exercises in a short period of time, such as in mountain bike, track or BMX races. Moreover, these data reinforce interest for researchers to consider performance tests with high test-retest reproducibility, especially when small but real benefits are expected.

Keywords: recovery methods, water immersion, elastic compression, exercise reproducibility

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Introduction

In recent years, recovery interventions between repeated bouts of exhaustive exercise have become a major focus in the field of sports science (Barnett 2006). In order to remain efficient at a high level for subsequent performances, it is of fundamental importance to put the interspersed recovery period to good use. It is the case in competition format using subsequent bouts of high-intensity exercise in a short period of time (series and final). In cycling, races from many disciplines take place in the form of tournament with several phases competed on a single day. Some races of mountain bike (cross-country eliminator), track (pursuits, points race, scratch, omnium...) and BMX consist in sequence of series, qualifying rounds and finals with short recovery times.

Nowadays, athletes therefore use a wide variety of passive strategies to accelerate short-term recovery. These passive strategies present the advantage to result in a greater amount of muscle glycogen resynthesis than active strategies (as active recovery) over the same duration (Choi et al. 1994). Compression garments and water immersion (including hot, cold and contrast water) are examples of passive strategies often studied and reviewed (Barnett 2006). Hot water immersion (>36°C) has contraindications and cold water immersion (<15°C) is assumed to be more beneficial in treatment of exercise-induced muscle damage following unaccustomed or eccentric (Bleakley et al. 2012) than between repeated high-intensity exercises (Parouty et al. 2010). Conversely, there is a growing body of evidence to support the use of compression stocking (CS) and contrast water therapy (CWT: alternation of brief exposures of contrasted temperatures: ≤15°C to ≥35°C) between repeated high-intensity exercises (Chatard et al. 2004; Crampton et al.

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2011; Versey et al. 2011). These recovery strategies are thought to increase blood flow and venous return through application of pressure to the limbs (Ménétrier et al. 2013). The promotion of blood circulation is suggested to be an effective method in removing the metabolic waste products that accumulate during this kind of exercise and, therefore, enhance recovery (Barnett 2006). Furthermore, the external pressure created by the water or the compression garments and the cold application may improve perceptions of recovery or 'wellbeing' reducing muscle soreness (Washington et al. 2000; Weiss and Duffy 1999).

However to date, no study has yet compared CS and CWT directly, between exercise bouts where a short turnaround time (15-30 min) is required. This comparison could provide direction for athletic trainers, as a way of potentially improving the recovery of their athletes during subsequent bouts of exercise. Results of research into the effectiveness of CS (Chatard et al. 2004; Ménétrier et al. 2011) and CWT (Crampton et al. 2011; Stanley et al. 2012) using subsequent performance as the principal outcome measure are contradictory, whereas this outcome is of major importance. Compared with passive recovery (PR), only one study has reported significant effects of CS on subsequent performance (Chatard et al. 2004), while many studies have reported no change (Ali et al. 2007; Ménétrier et al. 2011; Scanlan et al. 2008). With regard to CWT, some studies have reported significant positive effects on subsequent performance (Crampton et al. 2011; Versey et al. 2011). Beyond differences in study design (involving different recovery period (Crampton et al. 2011; Stanley et al. 2012)), studied population (untrained or elite athletes (Chatard et al. 2004; Ménétrier et al. 2011)) or in application modalities of the recovery intervention (Crampton et al. 2011; Stanley et al. 2012); the main reason that could explain the contradictory results may be linked to the test-retest reproducibility of the performance test (Hopkins 2004). Indeed, the variability, expressed as a coefficient of variation (Hopkins et al. 2001), is often greater than the expected benefits of the studied recovery interventions and may confuse the interpretation of the results. When small benefits are expected (~2% after CS (Chatard et al. 2004) and ~3-8% after CWT (Crampton et al. 2011; Versey et al. 2011)) it seems warranted that more controlled studies are needed to ensure that differences are real. Thus, the intra-participant variability within repeated performance tests must be a key consideration for making pragmatic assumptions about the effectiveness of recovery interventions and must be lower than the expected effects of those (Hopkins et al. 2001).

Therefore, the aim of our study was to compare with PR, the effects on subsequent performance of CWT and CS. We intended to detect small but real benefits, using a sensitive methodology based on a well-controlled performance test with high test-retest reproducibility. Our hypothesis was that CWT and CS would significantly increase the cycling performance after a previous fatiguing exercise. Although no study has yet compared them directly, in light of results in the literature (Crampton et al. 2011; Ménétrier et al. 2011; Versey et al. 2011), we also hypothesized that this improvement would be greater after CWT. To provide more complete information for athletic trainers, we also compared the effects of CWT and CS on recovery parameters usually studied in the literature, such as blood lactate concentrations and muscular soreness perceptions.

Materials and methods

Design

We used a 5-min cycle ergometer test, during which the mean power output was registered (Chatard et al. 2004), to assess the effects of CWT and CS on the subsequent performance. This kind of exercise was chosen because of its strong reproducibility (Chatard et al. 2004). Based on the literature, the expected improvement in this performance test after CWT and

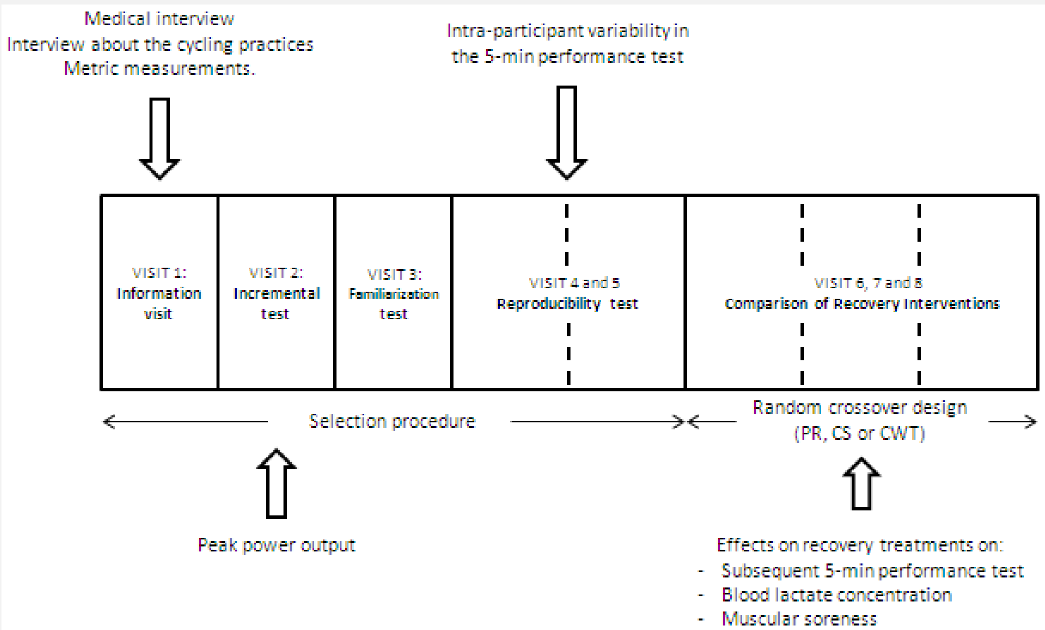

Figure 1. Experimental design.

CS was 1.5% or more (Chatard et al. 2004; Crampton et al. 2011; Versey et al. 2011). Therefore participants able to reproduce a 5-min cycle ergometer test with a variability <1.5% were recruited (Hopkins et al. 2001). We calculated that 12 participants would be sufficient to show a difference of 1.5% or more between interventions in the cycle ergometer performance, with a beta risk of 10% and an alpha risk of 5%.

Our protocol comprised two parts:

-A selection procedure (5 visits) to recruit participants able to able to reproduce the 5-min maximal cycling exercise with a variability < 1.5%,

-3 other visits in a random crossover design to compare the effects of the recovery interventions on the subsequent performance. These visits were designed to simulate a competition format using subsequent bouts of high-intensity exercise in a short period of time (series and final). Each time visit, the participants performed a tiring exercise on a cycle ergometer followed by the 5-min performance test, separated by a 15-min recovery period during which PR, CWT or CS was implemented.

Participants

After verbal and written explanation, volunteer participants underwent the selection procedure for potential inclusion (visits 1 to 5). The inclusion criteria were: (a) competitive male cyclists recruited in the regional cycling team (with an experience in competitive cycling of more than 5 years); (b) peak power output comprised between 4.5 and 6 W/Kg and cycling training between 4 and 6 times sessions/week (6 and 12 hours/week); elaborate on (c) context of competitive period (to minimize the possible training or habituation effect) (Sassi et al. 2008); (d) ability to reproduce the performance test used to compare the recovery interventions with a variability <1.5%, since as, based on the literature the expected improvement after CWT and CS was 1.5% or more (Chatard et al. 2004); (e) not familiarized with CS and CWT; (f) no history of systemic disease; and (f) no ongoing medication.

The first 12 competitive male cyclists (mean ± SEM age: 20.7 ± 0.6 years (19.0-23.0); height: 179.4 ± 1.4 cm (172.0-188.0); weight: 71.8 ± 1.6 kg (66.4-88.2); experience in cycling: 6.25 ± 0.4 (5.0-9.0); peak power output: 5.0 ± 0.2 W (4.5-6.0); cycling practice: 4.9 ± 0.4 times/week (4.0-6.0) (8.7 ± 0.7 hours/week (6.0-12.0)); intra-participant variability: 1.2 ± 0.2% (0.5-1.5)) who met the inclusion criteria were included, and performed the study protocol of the comparison of recovery interventions (visits 6 to 8). The results of the selection procedure are presented in Table 1.

Participants were provided verbal and written information of experimental procedures and signed informed consent statements and medical history forms before study initiation. The study protocol was approved by the local ethics committee, and the study was in accordance with the Declaration of Helsinki (Harriss and Atkinson 2009).

Testing Conditions

This study was performed in spring (context of competitive period) (Sassi et al. 2008). Participants were requested to abstain from competition and maintain constant life habits (nutrition, sleep, etc.). Only light training was tolerated.

Laboratory visits for the study purposes were performed at the same time of the day (between 6:00 and 9:00 PM) and in similar environmental conditions (temperature: ~21°C, humidity: ~30%), at intervals of 48 to 96 hours. Food was prohibited during the visits, but although participants had to drink 50 cl of water each time.

Selection Procedures

The selection procedure comprised five visits to the laboratory (visits 1, 2, 3, 4 and 5) to verify the inclusion criteria, as follows:

Visit 1 – Information Visit: The participants received verbal and written explanations before signing an informed consent document. Participants then had a medical interview; an interview about their cycling

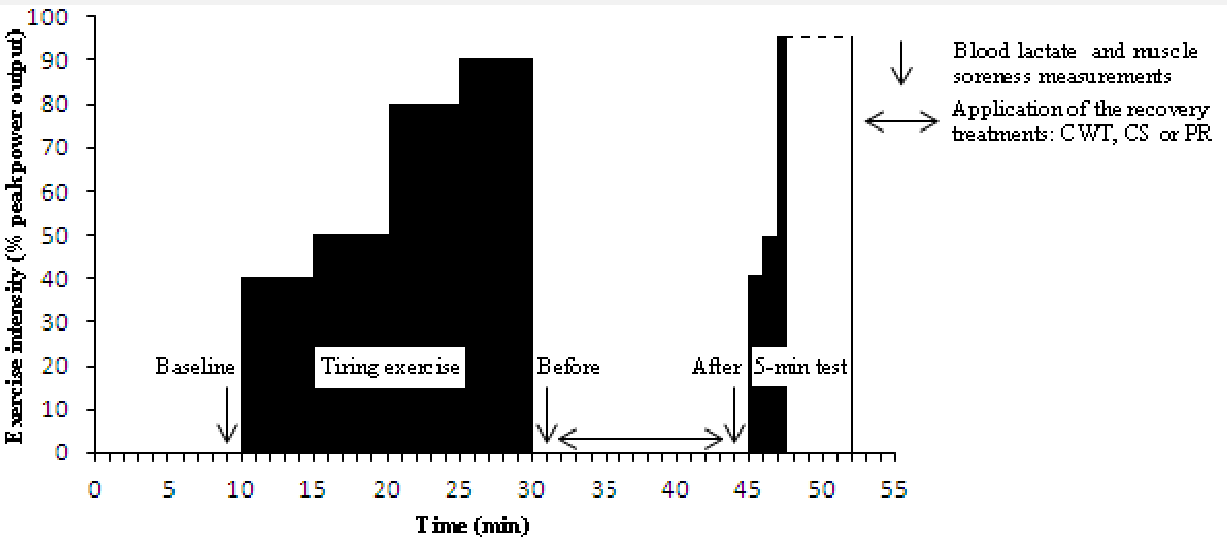

Figure 2. Design of the recovery interventions comparison.

practices; and metric measurements.

Visit 2 - Incremental Test: The second visit included an incremental test to exhaustion (start: 100 W, increments: 30 W/2 min) on a cycle ergometer (Wattbike, Nottingham, UK). Peak power output was recorded (Faria et al. 2005). Heart rate was recorded with a heart rate monitor (Suunto t6, Suunto, Oy, Finland). Peak heart rate during the incremental test was considered as the average value observed over the 15 sec period where heart rate was highest. Difficulty and exertion perceived by the participants at the end of the exercise were quantified using the CR10 Borg-scale (Borg et al. 1985). The state of exhaustion was validated by the achievement of the theoretical maximal heart rate (220 – age) and the maximal rating of perceived exertion (CR10 = 10).

Visit 3 – Familiarization Test: Participants underwent a familiarization trial in laboratory (same exercise bout proposed in visits 4 and 5) in order to get used to the experiment and to eliminate the training effect (Abbiss et al. 2008).

Visits 4 and 5 - Reproducibility Test: The participants' ability to reproduce the exercise used to compare the recovery interventions was tested. The two visits to establish the reproducibility comprised the same 5-min exercise bout on cycle ergometer preceded by a standardized warm-up (5 min at 40%, 5 min at 50% and 5 min at 60% of peak power output). Braking force was constant during the exercise and was calculated to obtain a pedaling frequency around 90–100 rpm. The mean power output developed by the participant during the trial was registered throughout via an interface between the cycloergometer and the computer and expressed in watts for 5 min. The only way to increase or reduce the power was to increase or reduce the pedaling frequency. During the protocol, participants were not informed about any performance results. In order to guide the participants, intensity was fixed at 95% of peak power output during the first 30 sec. After that, the time countdown was the only information communicated to the participants. Peak heart rate during reproducibility test was considered as the average value observed over the 15 sec period where heart rate was highest. Difficulty and exertion perceived by the participants at the end of the exercise were quantified to verify that the fatigue criteria were identical from one visit to the next.

Comparison of Recovery Interventions

Participants who were included in the study performed the laboratory protocol comprising three test visits (visits 6, 7 and 8), in a randomized order, to compare the three recovery interventions.

Visits 6, 7 and 8: These visits included 10 min at rest, a 10-min warm up (5 min each at 30% and 40% of peak power output) followed by a tiring exercise (5 min each at 80% and 90% of peak power output), then a 15-min recovery period during which one of the three 12-min recovery interventions was implemented, and finally a standardized warm up (40 sec each at 40%, 50% and 60% of peak power output) followed by a 5-min test on cycle ergometer (Figure 1). During the 5-min test, the participants had to produce the greatest mean possible power output for the whole 5-min exercise. Braking force, pedaling frequency modalities and any other procedures were the same that as during the reproducibility test. The mean power output sustained by the participants over the 5-min test was registered to compare the performances achieved after each recovery intervention (Chatard et al. 2004). Blood samples (5 µL) were taken at the earlobe before tiring exercise (baseline), and before and after the application of the recovery interventions in a sitting position. The blood samples were immediately analyzed with the Lactate Pro device (Arkray, Kyoto, Japan) to measure blood lactate concentrations. The average value observed over the 15-sec period where heart rate was highest during both tiring exercise and 5-min test and difficulty and exertion as perceived by the participants at the end of the both exercises were quantified to assess fatigue criteria. A visual analogue pain scale (1-10) was used to assess muscular soreness whereby participants were required to rank their perception of soreness on a scale, with 0 being 'normal' and 10 being 'extremely sore' (Vaile et al. 2008). Pain ranking was reported at baseline and before and after the application of the recovery interventions.

Recovery Interventions

Recovery period included 1.5 min in a sitting position before and after the 12 min of recovery interventions, which consisted in resting in vertical position with garments used for cycling. For PR, the participants wore garments used for cycling only. For CS, the participants also wore full leg compression stockings from the ankle to the groin (Full Leg, Compressport, Geneva, Switzerland). According to the size chart provided by the manufacturer, the pressure applied by the CS is estimated to be 14, 27, and 15 mmHg at the thigh, calf and ankle respectively. For CWT, participants underwent 4 cycles of 3 minutes each, comprising immersion to the top of the thigh (~75 cm of water for a height of 180 cm) in a cold bath (10-12°C) for 1 min, followed by 2 min in a hot bath (36-38°C) with a 5-s changeover (Wilcock et al. 2006). With ~60 cm of water above the ankle, ~45 cm above the calf and ~15 cm above the thigh, the mean pressure applied by CWT is ~45 mmHg at the ankle, ~34 mmHg at the calf and 11 mmHg at the thigh.

Statistical Analyses

Statistical analyses were performed using SigmaStat for Windows 3.5 (Systat Software Inc., San Jose, CA, USA). Data are presented as mean ± standard error of the mean (SEM). A p-value < 0.05 was considered statistically significant. Normality was tested using the Kolmogorov-Smirnov Test. Appropriate parametric or non-parametric tests were used. To assess the reproducibility of the participants (visits 4 and 5), mean power output and peak heart rate were analyzed using the paired Student t-Test and CR10 was analyzed using the Wilcoxon Signed Rank Test. To check that the state of exhaustion achieved during tiring exercise was identical between visits 6, 7 and 8, heart rate and CR10 were analyzed using One Way Repeated Measures ANOVA. To assess the effects of the recovery interventions, performance in 5-min test was also analyzed using One Way Repeated Measures ANOVA. Heart rate and CR10 during 5-min test were analyzed using Friedman's Repeated Measures ANOVA on Ranks. Blood lactate concentrations and muscular soreness data were analyzed using Two Way Repeated Measures ANOVA. Fisher's LSD Test was used for pairwise comparisons. Intra-participant variability is defined as the ratio of the standard deviation to the mean, which is known as the absolute value of the coefficient of variation, expressed as a percentage. We assessed the reliability of these data with the intraclass correlation coefficient: using a 2-way random effects model with single-measure reliability in which variance over the repeated session is considered. The ICC indicates the error in measurements as a proportion of the total variance in scores. As a general rule, we considered an intraclass correlation coefficient over 0.90 as high, between 0.80 and 0.90 as moderate, and below 0.80 as insufficient.

Results

Performance: After CWT (+4.1 ± 0.7%, $p < 0.001$) and CS (+1.8 ± 1.0%, $p < 0.05$), 5-min test performance (mean power output sustained over the 5-min) was higher than after PR. Moreover, performance was greater after CWT than after CS (+2.2 ± 0.8%; $p < 0.05$) (Figure 2A).

Blood Lactate Concentrations: No significant difference was observed in blood lactate concentrations before the recovery interventions. At baseline, blood lactate concentrations were 1.4 ± 0.2 mmol.L^{-1}, 1.2 ± 0.1 mmol.L^{-1} and 1.3 ± 0.1 mmol.L-1 and before the application of the recovery interventions, blood lactate concentrations were 13.0 ± 0.8 mmol.L-1, 12.8 ± 1.0 mmol.L^{-1} and 12.3 ± 1.0 mmol.L-1 for PR, CS and CWT conditions respectively. After CWT (5.7 ± 1.0 mmol.L^{-1}, $p < 0.001$) and CS (7.3 ± 1.2 mmol.L^{-1}, $p < 0.05$), blood lactate concentrations were lower than after PR; and (8.4 ± 1.0 mmol.L^{-1}). Moreover, blood lactate concentrations were lower after CWT than after CS ($p < 0.05$) (Figure 2B).

Perceived Muscular Soreness: No significant difference was observed in muscular soreness before the recovery interventions. At baseline, muscular soreness were 0.0 au for the three visits and before the application of the recovery interventions, muscular soreness were 7.0 ± 0.3 au, 6.5 ± 0.3 au and 6.5 ± 0.3 au for PR, CS and

Table 1. Incremental and reproducibility tests results (n = 12). * In Mean Power Output.

Visit 2: Incremental Test	
Peak power output (W.kg^{-1})	5.0 ± 0.2
Peak heart rate (beats.min^{-1})	193.1 ± 2.7
CR10 (au)	10.0 ± 0.0
Reproducibility Test	
Visit 4:	
Mean Power Output (W)	360.1 ± 11.0
Peak heart rate (beats.min^{-1})	193.1 ± 2.8
CR10 (au)	10.0 ± 0.0
Visit 5:	
Mean Power Output (W)	362.2 ± 10.9
Peak heart rate (beats.min^{-1})	192.4 ± 2.6
CR10 (au)	10.0 ± 0.0
Intra-participant variability*	1.2 ± 0.2% (0.5-1.5)
Intraclass correlation coefficient*	0.99

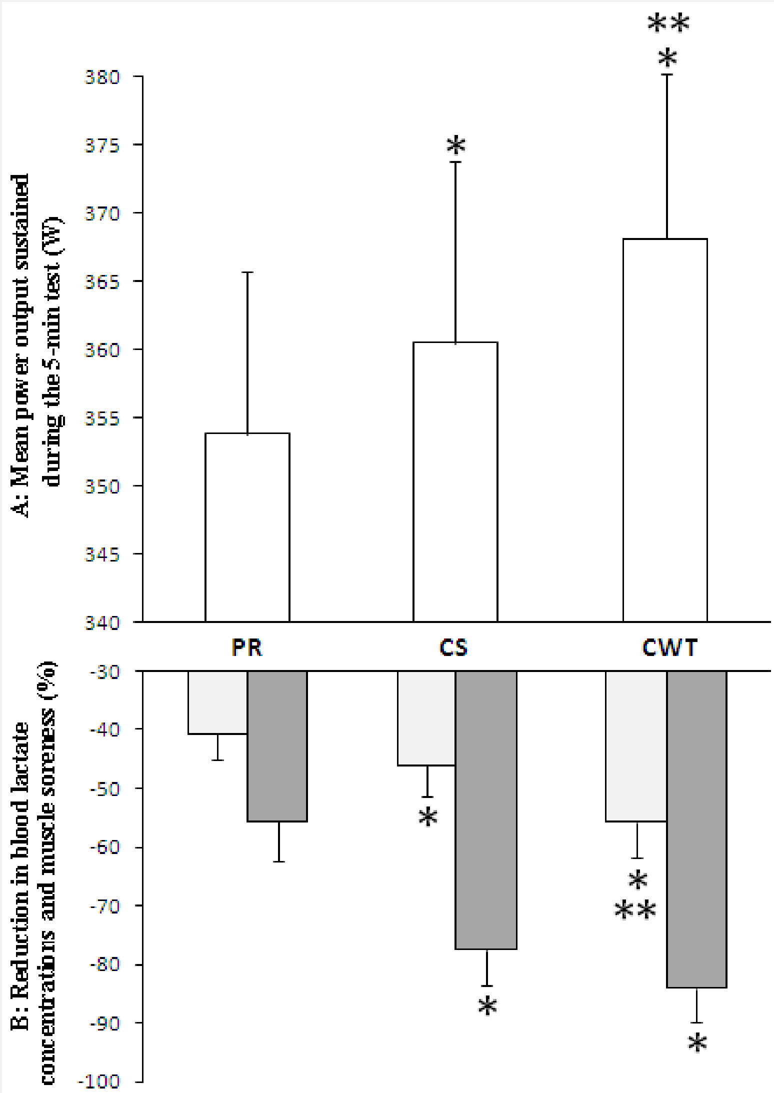

Figure 2. panel A: mean power output sustained over the 5-min test and panel B: reduction in ▨ blood lactate concentrations and ☐ muscular soreness (%) (Corresponding to: [(after the application of the recovery interventions data - before the application of the recovery interventions data) / before the application of the recovery interventions data * 100]) during the three visits of the recovery interventions comparison. *: Indicates a significant difference between CWT or CS and PR. **: Indicates a significant difference between CWT and CS.

CWT conditions respectively. After CWT (1.1 ± 0.4 au, $p < 0.001$) and CS (1.6 ± 0.4 au, $p < 0.001$), muscular soreness were lower than after PR (3.2 ± 0.5 au). Moreover, muscular soreness were lower after CWT than after CS without attaining the significance threshold (-29.2 ± 12.2%; $p = 0.08$) (Figure 2B).

Heart Rate: Heat rates during tiring exercise (184.1 ± 1.6 beats.min-1, 183.6 ± 2.2 beats.min-1 and 182.1 ± 2.3 beats.min-1 for PR, CS and CWT conditions respectively) and 5-min test (188.6 ± 2.3 beats.min-1, 189.4 ± 1.9 beats.min-1 and 190.2 ± 2.0 beats.min-1 for PR, CS and CWT conditions respectively) were not statistically different for the three visits.

CR10: CR10 during tiring exercise (9.1 ± 0.3 au, 8.6 ± 0.2 au and 8.7 ± 0.2 au for PR, CS and CWT conditions respectively) and 5-min test (10.0 ± 0.0 au for the three visits) were not statistically different for the three visits.

Discussion

The present study aimed at testing the hypothesis that CWT and CS would significantly increase the subsequent cycling performance. We also hypothesized that this improvement would be greater after CWT. Contrary to most of the previous studies; this was done with a study design based a on well controlled performance test with high test-retest reproducibility.

Our results are in accordance with previous studies and confirm that CWT (Crampton et al. 2011; Versey et al. 2011) and CS (Chatard et al. 2004) significantly increased subsequent performance compared with PR, by increasing the mean power output sustained over the 5-min test by 14.2 ± 2.3 W and 6.7 ± 3.6 W, respectively. Moreover, greater benefits were apparent after CWT compared with CS (7.6 ± 2.7 W). However, our results also contrast with the findings of other authors, who have reported unchanged performance following CWT (Stanley et al. 2012) or CS (Ménétrier et al. 2011; Scanlan et al. 2008) when compared with PR. Discrepancies between results may depend on several factors, such as the period between the intervention and the tiring exercise, the duration of the recovery period (Stanley et al. 2012), or the application modalities of the recovery intervention. For example, when the pressure applied by the compression garments is too high, the blood flow may be decreased, while the main rational to use CS during recovery is based on the blood flow increase (Sperlich et al. 2013). It also appears that more controlled, reliable and repeatable performance measures are needed to highlight potential differences between recovery interventions, especially when small benefits are expected (Hopkins 2004). These considerations justify the major focus of our study, since as such data are lacking in the literature. Any error in measurement may mask the effect of the recovery interventions (Ménétrier et al. 2011). Therefore it is necessary to measure the variability between repeated performance tests and to ensure that it is lower than the expected changes induced by the recovery interventions (Thomas et al. 2012). In order to reach this goal, several methodological aspects were considered. Firstly, performing tests with a constant workload until exhaustion may yield individual performances with variations of more than 25% (Billat et al. 1994; Ménétrier et al. 2011). Therefore, given the strong reproducibility (~1.5%) observed with maximal cycling exercise for a fixed duration (Chatard et al. 2004), we used this exercise to assess the efficacy of the recovery interventions. Secondly, since with the expected improvement after CWT and CS was reported to be 1.5% or more (Chatard et al. 2004), we included only participants able to reproduce the 5-min maximal cycling exercise with a variability < 1.5%. After a familiarization test, the intra-participant variability was 1.2 ± 0.2% and the ICC was 0.99. This high reproducibility was obtained by including only well trained cyclists, based on a high peak power output (4.5-6 W/kg) and cycling training (4-6 sessions/week, 6-12 hours/week). Elite cyclists were not recruited because they are often justifiably reluctant to participate in controlled studies. The included participants had to be in a cycling phase (to minimize the possible training or habituation effect), but they were requested to cease competition participation during the study period (so as to not accumulate too much excessive fatigue). Additionally, all participants were previously accustomed to performing 5-min maximal exercise in training programs and competitions. With particular regard to the lack of improvements in subsequent performance most often observed with CS, this reproducible testing method with a low variability is able to detect small, but real, differences between CWT, CS and PR.

The current study also aimed to compare the effects of CWT and CS on recovery parameters usually studied in the literature, such as blood lactate concentrations and muscular soreness. Our finding of lower blood lactate concentrations following CWT and CS supports previous studies' reports of more pronounced lactate removal after CWT (Hamlin 2007; Morton 2007) and CS (Chatard et al. 2004). For an active recovery, it is well accepted that persistent low-intensity activity primarily increases blood lactate clearance by increasing muscle blood flow (Ahmaidi et al. 1996). Remaining in an upright position without moving during PR may limit the muscle pump and hence the blood lactate removal; thus, the effects of pressure caused by water and CS on the blood circulation may contribute to these changes. Studies conducted on the leg and forearm have shown that external compression may increase both venous return (Charles et al. 2011) and arterial flow rate (Bochmann et al. 2005). In addition, blood lactate removal was more pronounced after CWT compared with CS. The most probable explanations for this result are the differences in pressure gradient with CWT and CS (direction of the graduated compression: decreasing from ankle with CWT and progressive with CS; and level of compression: ~45 mmHg to the ankle with CWT (i.e. ~60 cm of water above ankle) and 15 mmHg with CS), but the current study was not designed to provide precise information on this point. The possible alternation of local vasoconstriction and vasodilatation during CWT may contribute to blood lactate removal. Results in the literature suggest that such an alternation exists but at subcutaneous level only (Fiscus et al. 2005; Myrer et al. 1994). To aid intramuscular blood lactate removal more effectively, temperature changes would surely be required at a deeper tissue level.

Our findings of improved perceived recovery, characterized by lower muscular soreness, following CWT (Crampton et al. 2011; Stanley et al. 2012) and CS (Chatard et al. 2004) support previous findings reporting heightened perceptions of recovery or wellbeing following both CWT and CS. The pressure applied by CWT and CS may improve perceptions of recovery or ‘wellbeing’ (Weiss and Duffy 1999). Moreover, cold immersion during CWT may reinforce the effects of this type of recovery on muscular soreness (Washington et al. 2000) and explain the trend toward greater benefits compared with CS.

Finally, although CWT and CS induce physiological and perceptive changes which may have a role in facilitating recovery from exercice, studies investigating the mechanisms concomitant with functional outcomes are needed to substantiate whether CWT and CS have an effect greater than simply a placebo or subjective improvement in recovery.

Practical applications

This study illustrates that when exhaustive physical exercises bouts must be repeated in a short period, the application of CWT or CS immediately after the first exercise bout improves subsequent performance. Moreover, if CWT is an available intervention, it should be used in priority compared with CS as additional performance benefits are offered. Coaches can use this information as a way of potentially improving performance of their athletes in competition format using subsequent bouts of high-intensity exercise. In cycling, these recommendations can be applied between each competition phases of mountain bike (cross-country eliminator), track (pursuits, points race, scratch, omnium...) and BMX races.

Furthermore, the results of this study reinforce interest for researchers in sports science to consider performance tests with high test-retest reproducibility, especially when small but real benefits are expected between the interventions.

In summary, this study showed a positive impact of 12-min recovery using CWT or CS on subsequent 5-min cycling performance compared with PR (+14.2 ± 2.3 W and +6.7 ± 3.6 W, respectively). Moreover, greater benefits were apparent after CWT compared with CS (+7.6 ± 2.7 W).

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