The Effects of 4 Different Recovery Strategies on Repeat Sprint-Cycling Performance

**Christos K. Argus, Matthew W. Driller, Tammie R. Ebert,
David T. Martin, and Shona L. Halson**

Purpose: To evaluate the effectiveness of different recovery strategies on repeat cycling performance where a short duration between exercise bouts is required. *Methods:* Eleven highly trained cyclists (mean ± SD; age = 31 ± 6 y, mass = 74.6 ± 10.6 kg, height = 180.5 ± 8.1 cm) completed 4 trials each consisting of three 30-s maximal sprints (S1, S2, S3) on a cycle ergometer, separated by 20-min recovery periods. In a counterbalanced, crossover design, each trial involved subjects performing 1 of 4 recovery strategies: compression garments (COMP), electronic muscle stimulation (EMS), humidification therapy (HUM), and a passive control (CON). The sprint tests implemented a 60-s preload (at an intensity of 4.5 W/kg) before a 30-s maximal sprint. Mean power outputs (W) for the 3 sprints, in combination with perceived recovery and blood lactate concentration, were used to examine the effect of each recovery strategy. *Results:* In CON, S2 and S3 were (mean ± SD) –2.1% ± 3.9% and –3.1% ± 4.2% lower than S1, respectively. Compared with CON, COMP resulted in a higher mean power output from S1 to S2 (mean ± 90%CL: 0.8% ± 1.2%; possibly beneficial) and from S1 to S3 (1.2% ± 1.9%; possibly beneficial), while HUM showed a higher mean power output from S1 to S3 (2.2% ± 2.5%; likely beneficial) relative to CON. *Conclusion:* The authors suggest that both COMP and HUM may be effective strategies to enhance recovery between repeated sprint-cycling bouts separated by ~30 min.

Keywords: compression, electronic muscle stimulation, humidification, blood lactate, fatigue

Enhancing recovery from training and competition has become an integral aspect of improving athletic performance. Incorporating appropriate recovery strategies after exercise is believed to enhance subsequent performance[1] and may minimize the risk of injury.[2] There are a growing number of publications describing various strategies implemented to improve recovery after exercise. Competitive events in which athletes are required to perform repeated bouts of maximal effort separated by brief periods of recovery (<30 min), such as certain track-cycling events, may pose an even greater demand for athletes and coaches to ensure that recovery is optimized. The scheduling of some of these events at major competitions such as the Olympic Games creates a significant challenge for athletes and coaches. For example, the women's keirin at the London Olympics had only 30 minutes between the end of the first round and the start of the first-round repechage, and only 45 minutes to the start of the second round (after the repechage). These and similar challenges have prompted development of novel recovery strategies and techniques to improve performance and gain an edge over the competition.

Compression garments have been suggested as a method to promote recovery from exercise, with their use becoming increasingly popular in athletic populations. The use of compression garments and compression bandaging has been well established as a common method of treatment for patients with various venous insufficiencies.[3] Compression garments are thought to improve venous return through application of graduated compression to the limbs from proximal to distal.[4,5] The promotion of venous return after exercise is suggested to be an effective method in removing the metabolic waste products that accumulate during exercise and, therefore, enhance recovery.[6] Furthermore, the external pressure created by compression garments may reduce the intramuscular space available for swelling, attenuating the inflammatory response and reducing muscle soreness.[4,6] The effect of compression garments on recovery from exercise remains equivocal, with studies that both support[7,9] and show no benefit of compression garments for recovery.[9,11] Furthermore, no studies have investigated the use of compression garments between exercise bouts where a short turnaround time (<30 min) is required.

Electronic muscle stimulation (EMS) is another practical recovery strategy used by many athletic populations and, like compression garments, is based on the premise of increased blood flow and venous return to

Argus, Driller, and Halson are with Performance Recovery, and Martin, the Physiology Dept, Australian Inst of Sport, Belconnen, ACT, Australia. Ebert is with the Australian Inst of Sport Track Cycling Program, Australian Inst of Sport, Adelaide, SA, Australia.

enhance recovery from exercise. The method consists of attaching electrodes to the skin, allowing an electrical current to be delivered to the muscle belly or muscle nerve (depending on the device). The electrical current delivered typically results in small muscle contractions and has been shown to increase blood flow and alleviate pain.[11] A recent review on EMS included 13 articles examining the effects on recovery from exercise, with 10 articles including a performance measure.[12] However, only 1 article reported a significant improvement in subsequent performance.[11] Ii is interesting that none of the studies reviewed incorporated a short anaerobic explosive test as the fatiguing exercise. Instead, all investigations used either a resistance exercise or an aerobic-based activity to create fatigue. Therefore, the effect of EMS on a sprint-performance task is unknown.

Humidification therapy has been suggested as a potential method to enhance recovery from exercise.[13] Humidification therapy involves the delivery of high flow rates (5–50 L/min) of warm (37°C) humidified air (100%) through a nasal cannula, causing a low level of positive airway pressure[14] similar to that used in continuous positive airway pressure to treat obstructive sleep apnea and improve mucociliary and general airway clearance.[15] It has been suggested that humidification may enhance recovery through improvement in the efficiency of respiratory muscles via reversal of dynamic hyperinflation.[13] An unpublished pilot study reported higher levels of blood lactate clearance and enhanced perceptions of recovery in 8 well-trained subjects when using humidification therapy as a recovery strategy after running 1500 m.[13] The researchers stated that when dynamic hyperinflation is reversed, respiratory muscles become more efficient and oxygen consumption decreases, as does oxygen requirement.[13] However, this possible mechanism is only speculative. It is also possible that humidification therapy assists psychological recovery due to its soothing sensation. While the possible mechanisms for humidification therapy improving performance or recovery remain unclear, based on the pilot study we felt that further research assessing the effects on recovery was warranted.

Given the need for repeated bouts of exercise interspersed with short recovery periods in numerous sporting events, many athletes and coaches are continuously seeking new and novel techniques to enhance recovery and prevent a decrement in performance. Therefore, the aim of the current study was to evaluate the use of 3 relatively novel recovery strategies compared with a passive control on repeated sprint-cycling performance in highly trained cyclists.

Methods

Subjects

Eleven highly trained cyclists (mean ± SD; age = 31 ± 6 y, mass = 74.6 ± 10.6 kg, height = 180.5 ± 8.1 cm) volunteered to take part in the current study. All testing took place during the competition phase of the cycling season, where all subjects were racing at either A- or B-grade level in their respective states. Subjects provided informed consent before any testing taking place. The study was approved by the Australian Institute of Sport research ethics committee.

Design

The current study involved subjects' attending 5 separate testing sessions at our laboratory over a 3-week period. To minimize any learning effect, subjects initially attended a familiarization session of the testing protocol that was to be used in the experimental trials. After the familiarization trial, in a counterbalanced crossover design, subjects performed 4 trials separated by >48 hours within a maximum of 14 days. Trials differed only in the recovery strategy used between cycling bouts: compression garments (COMP), EMS, humidification therapy (HUM), and a passive control (CON). To control any dietary variables, subjects completed a 24-hour food diary before their first trial and were instructed to replicate their diet as closely as possible before the subsequent trials. Training was also controlled for, with subjects keeping all training the same for the 48 hours before testing on all occasions. Subjects were asked to refrain from strenuous exercise (<24 h) and caffeine (<12 h) and to arrive in a fully rested, hydrated state. All testing was performed at the same time of day (± 1 h), to minimize diurnal variation, and on the same cycle ergometer.

Methodology

All cycle testing was performed on an air-braked cycle ergometer (Wattbike Ltd, Nottingham, UK). Before the start of the study, the ergometer was calibrated by technicians at the Australian Institute of Sport using a dynamic calibration rig based on first principles. The reliability of the Wattbike cycle ergometer has been reported previously over a range of power outputs (50–300 W), with a CV of 2.6% (95% CI 0.7–2.0%) in trained cyclists.[16]

The experimental trials involved subjects performing 3 maximal cycling sprints separated by 30-minute recovery periods that included a 1-minute setup and removal of the recovery device or garment, a 3-minute warm-down, a 20-minute recovery intervention, and a subsequent warm-up. The cycling sprints (S1, S2, and S3) consisted of an incremental warm-up that included 2 short (3-s) sprints and easy pedaling (see Figure 1 for test protocol). The sprint test implemented a rolling start that consisted of a 60-second preload (at an intensity of 4.5 W/kg) before the 30-second maximal sprint.[17] During the 30-second sprint, subjects could only see time and were required to produce as much work as possible. The gearing and cadence were self-selected by subjects on the ergometer during the familiarization trial, and this gearing was then replicated during the preload and 30-second sprint in the experimental trials.

The computer attached to the cycle ergometer was used to record mean 30-second power output during the
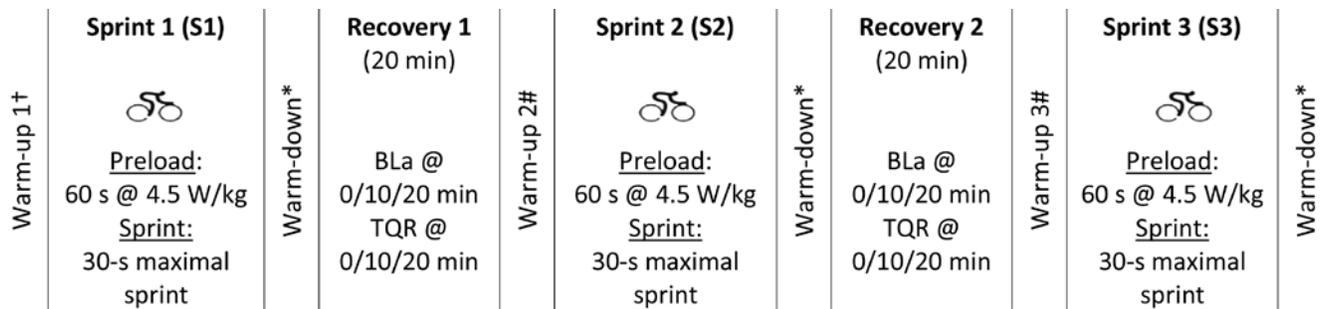
Figure 1 — Experimental testing protocol. Abbreviations: BLa, blood lactate; TQR, perceived total quality recovery. †Warm-up 1: 3 min at 2.5 W/kg, 3.0 W/kg, and 4.0 W/kg; 60 s of passive rest; 2 short sprints (3-s max sprints with 20 s of easy pedaling between); 5 min at 2.5 W/kg; 60 s of passive rest (and BLa sample). #Warm-ups 2 and 3: 1-min removal of recovery device/garment, 1 min at 3.0 W/kg and 4.0 W/kg, 2 short sprints (3-s max sprints with 20 s of easy pedaling between), 90 s at 2.5 W/kg, 60 s of passive rest. *Warm-down: 3 min at 2.0 W/kg followed by 1 min setup of recovery device/garment (after S1 and S2 only).

sprint test. Immediately after the sprint test, a standardized cooldown was completed (3 min at 2.0 W/kg). S1 was followed by a 20-minute period of recovery where 1 of 4 recovery interventions was implemented. During recovery subjects remained seated in a semireclined position in a temperature-controlled environment (20.7°C ± 0.3°C). Twenty minutes after the cessation of S1, subjects were required to repeat the initial exercise task with a shortened warm-up (S2), before another recovery period and, finally, S3. The sprint-test protocol implemented in the current study was designed to closely mimic certain track-cycling events that involve a period of preload followed by a maximal sprint effort and also require multiple races with short recovery periods (eg, keirin track-cycling event). Furthermore, the protocol used in the current study is one that has been implemented to test and monitor some of the Australian cyclists in the lead-up to the 2012 Olympic Games.

Experimental trials differed only in the recovery interventions. Recovery interventions were performed twice for each experimental trial—between S1 and S2 and between S2 and S3. All interventions were performed for 20 minutes during the recovery period. The 4 recovery interventions were as follows:

- COMP: Compression leg sleeves were used (2XU, Victoria, Australia), which were composed of 250/70 denier Lycra fiber material. The garment covered the proximal aspect of the medial malleolus to the inguinal crease. The level of compression was assessed in our laboratory using a Kikuhime pressure-monitoring device (MediGroup, Melbourne, Australia), which has an accuracy (expressed as a coefficient of variation) of ~1% (unpublished observations). The garments provided a pressure gradient of 27 (± 6) mmHg at the lower calf and 18 (± 2) mmHg at the upper thigh.
- EMS: An electrical current was delivered to the leg muscles using a commercially available EMS device (Bodyflow, Victoria, Australia). Four electrodes were

placed on the gastrocnemius and vastus lateralis/vastus medialis muscles (vastus lateralis first 10 min, vastus medialis second 10 min). Frequency was set at the lowest setting required to invoke a muscle twitch (15.7 ± 2.8 Hz). The manufacturer's Web site suggests that Bodyflow therapy promotes the flow of body fluids such as blood and lymph by its ability to stimulate smooth muscle in veins, arteries, and lymphatic vessels.

- HUM: Subjects received warm humidified air (38°C/100% relative humidity at a flow rate of 45 L/min) delivered via nasal cannula using an Airvo humidifier (Fisher & Paykel, Auckland, New Zealand).
- CON: Subjects sat in a temperature-controlled room for the recovery period with no recovery intervention.

Blood lactate concentration was measured via a capillary fingertip sample and was analyzed with a Lactate-Pro analyzer (Shiga, Japan). Measurements were taken at standardized intervals throughout the study (Figure 1). The test–retest reliability of the Lactate Pro has been previously reported, with technical error of measurement ranging from 0.1 to 0.4 mmol/L at blood lactate concentrations of 1.0 to 18.0 mmol/L.[18] Subjects were required to give ratings of their perceived total quality recovery (TQR) on a modified Borg scale of 6 (*very poorly recovered*) to 20 (*fully recovered*) at standardized time points (Figure 1).

Subjects were asked to rank in order (1 being the most effective, 4 the least effective) which strategy they thought would optimize their recovery. The ranking was performed at the completion of the familiarization session. Eight of the 11 participants completed this aspect of the methodology. Three of 8 subjects ranked COMP as anticipated most effective, 3 ranked HUM the most effective, and 2 ranked EMS the most effective. No subject ranked CON as the most effective. Conversely, 5 of the 8 ranked CON as anticipated least effective, and 3

ranked HUM the least effective. No subjects ranked EMS or COM as anticipated least effective.

Statistical Analysis

Data are presented as mean ± SD or mean ± 90% confidence limits (±90%CL). Excluding TQR, data were log-transformed to reduce nonuniformity of error and presented as percentage changes.[19] To make inferences about the true effect of each recovery strategy on change in performance (from baseline, sprint 1) relative to control, the uncertainty in the effect was expressed as 90%CL. The likelihoods that the true value of the effect represented a substantial change (harm or benefit) were calculated[20] using the following thresholds for assigning qualitative terms: <1%, *almost certainly not;* <5%, *very unlikely;* <25%, *unlikely or probably not;* <50%, *possibly not;* >50%, *possibly;* >75%, *likely or probable;* >95%, *very likely;* >99% almost certain.*[21] An effect was deemed unclear if its confidence limits overlapped the thresholds for both the smallest beneficial and the smallest harmful effect, that is, if the effect could be substantially positive and negative.[22] The smallest substantial change in mean

power output was estimated to be 0.75% based on variability in performance of athletes between interday trials in our laboratory.

Results

Absolute power outputs for S1, S2, and S3 for each intervention are presented in Table 1. There was approximately a 3- to 4-W difference between the mean baseline (S1) power outputs in 3 of the 4 interventions (Table 1).

During the CON trials, the average change in power from S1 to S2 was –2.1% (± 3.9%), and the change in power from S1 to S3 was –3.1% (± 4.2%). All recovery interventions were then compared with this standard sprint-performance profile. Of particular interest was whether the change in power (S1–S2 and S1–S3) after recovery interventions was better. COMP had an attenuation of power decrement (ie, a better recovery) from S1 to S2 relative to CONT (possibly beneficial), while both COMP and HUM showed a better recovery of power from S1 to S3 (possibly beneficial and likely beneficial, respectively; Figure 2, Table 1).

Table 1   Power Produced (Mean ± SD) in Each 30 s Cycle Sprint and Change in Sprint Performance (±90% CL and Qualitative Inference) Relative to Control Using 3 Separate Recovery Strategies in 11 Highly Trained Male Cyclists

Condition	Sprint 1 (W)	Sprint 2 (W)	Sprint 3 (W)	Δ sprint 2 to sprint 1 relative to control (%)	Δ sprint 3 to sprint 1 relative to control (%)
Control	758 ± 132	742 ± 129	735 ± 128	—	—
Compression	757 ± 125	747 ± 130	742 ± 122	0.8 ± 1.2 (possibly beneficial)	1.2 ± 1.9 (possibly beneficial)
Humidification	754 ± 133	751 ± 141	747 ± 133	1.6 ± 3.2 (unclear)	2.2 ± 2.5 (likely beneficial)
EMS	774 ± 152	739 ± 124	739 ± 124	– 1.8 ± 2.8 (unclear)	–0.6 ± 2.7 (unclear)

Abbreviations: CL, confidence limits; EMS, electronic muscle stimulation.
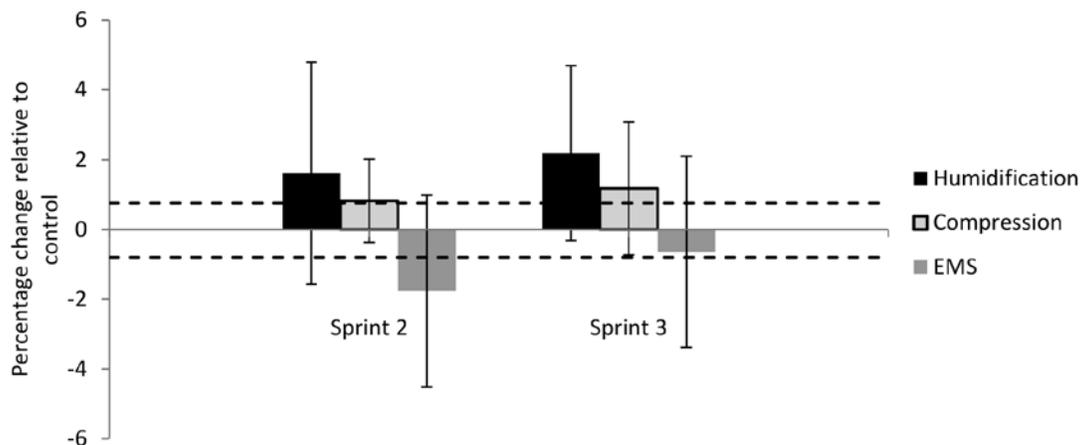
Figure 2 — Percentage change in mean 30-s cycle power output from baseline, relative to control, in 11 highly trained cyclists after 3 separate recovery strategies (humidification, compression, and EMS). Abbreviations: EMS, electronic muscle stimulation. Error bars represent 90% confidence limits. Error bars that overlap both the smallest positive and smallest negative effect (shown by the perforated lines) represent an unclear effect.

There were no significant differences in blood lactate between groups before S1 (mean ± SD; COMP, 2.3 ± 2.0 mmol/L; EMS, 2.3 ± 1.5 mmol/L; HUM, 2.3 ± 1.4 mmol/L; CON, 2.4 ± 1.6 mmol/L). The change in lactate concentrations in recovery period 1 resulted in unclear effects for all interventions. However, in recovery period 2, there was a reduced lactate concentration compared with CONT in the HUM (4.3% ±7.9%; possibly beneficial) and EMS groups (4.9 ± 6.9; possibly beneficial; Table 2). Only 1 comparison of TQR (EMS to CONT, recovery 2, 0.7 ± 0.9 arbitrary units) resulted in a clear finding and suggested that the change in TQR was likely beneficial (better perceived recovery) in the EMS group than in CONT in the second recovery period (Table 2). Only 2 of the 8 subjects who completed the belief ranking accurately predicted which recovery strategy would optimize their individual recovery (from S1 to S3), while none of the subjects accurately predicted which strategy would result in the least effective recovery.

Discussion

Findings from this study support the use of compression garments and humidification therapy for improving recovery when there is only a short turnaround time between high-intensity cycling bouts. These findings may be particularly important in sports where multiple exercise bouts are performed with limited recovery time between bouts, as in multiple track-cycling events. For example, in the track sprint-cycling finals (best of 3 races) at the 2012 Olympic Games, there was approximately 20 to 30 minutes separating the start times between sprints.

It should be highlighted that S1 in the EMS intervention was approximately 15 to 20 W higher than baseline in the other 3 interventions. While the difference was unclear between interventions, there was a trend for most subjects to be higher on the EMS S1. Subjects were told which intervention they were participating in before the first trial; however, as only 2 (of 8) subjects ranked EMS as their perceived best recovery intervention, it is

unlikely that it was due to a placebo effect. In addition, the sequence of treatments was counterbalanced using a Latin-square design, eliminating a possible order effect. As such, at this time we are unable to explain this difference. Therefore, it is important to interpret the recovery profile of EMS accordingly, especially the change from S1 to S2.

The current study supports previous literature reporting positive effects of compression garments as a recovery aid and further adds to the literature regarding the use of compression garments during recovery between cycling bouts.[8,23] Two previous studies investigated the use of compression garments between 2 endurance-cycling bouts (5-min test and 40-km time trial) and reported a 2.1% and a 3.3% improvement in the compression garment trial (compared with control) when the garments were worn for 80 minutes and 24 hours between bouts, respectively.[8,23] While the magnitude of improvement in the current study was not as large as these previous cycling studies, our results indicated that compression was a possibly beneficial recovery strategy, with improvements of 0.8% and 1.2% compared with control between S1 and S2 and between S1 and S3, respectively. The short performance test (30 s) and recovery period (20 min) used make the current study the first to show improvements in recovery between repeated exercise bouts when using compression garments in this type of exercise protocol.

Mechanisms associated with improved recovery when wearing compression garments remain unclear.[24] It has been suggested that wearing graduated compression garments acts to increase venous blood flow, thereby enhancing stroke volume and cardiac output.[23] The increase in stroke volume and cardiac output may enhance muscle blood flow and oxidation, subsequently aiding in the removal of metabolic waste that accumulates during high-intensity exercise. While blood flow was not measured in the current study, as a somewhat crude surrogate measure we evaluated changes in blood lactate concentration during the recovery period, which can indirectly reflect changes in venous return.[25] Our results indicated that there were no substantial differences

Table 2   Postsprint Blood Lactate and TQR and Change in Lactate and TQR Over Two 20-min Recovery Periods Using Different Recovery Strategies in 11 Highly Trained Cyclists, Mean ± SD

	After Sprint 1		Δ Recovery 1		After Sprint 2		Δ Recovery 2	
Condition	Lactate (mmol/L)	TQR (au)	Δ lactate (mmol/L)	Δ TQR (au)	Lactate (mmol/L)	TQR (au)	Δ lactate (mmol/L)	Δ TQR (au)
Compression	11.1 ± 1.9	11.6 ± 1.9	−5.1 ± 0.7	3.5 ± 1.3	11.1 ± 2.1	11.8 ± 1.9	−4.6 ± 1.0	2.4 ± 1.1
Control	11.2 ± 2.0	11.2 ± 2.0	−5.1 ± 1.2	3.4 ± 2.4	11.5 ± 2.2	11.5 ± 2.4	−4.6 ± 0.9	2.4 ± 1.8
EMS	11.4 ± 2.2	11.5 ± 1.9	−4.8 ± 0.9	3.2 ± 1.5	11.3 ± 2.2	11.6 ± 2.2	−4.9 ± 1.0†	3.2 ± 1.6*
Humidification	11.0 ± 2.2	12.1 ± 2.0	−4.9 ± 1.3	2.8 ± 1.4	11.4 ± 2.3	12.5 ± 2.6	−5.0 ± 1.0†	2.8 ± 1.5

Abbreviations: TQR, total quality recovery; au, arbitrary units; EMS, electronic muscle stimulation.

†Likely beneficial compared with control. *Possibly beneficial compared with control.

between COMP and CON for blood lactate or perceived recovery at any time point, making it difficult to attribute the enhanced recovery to these variables.

Humidification therapy is a novel method that has been proposed to improve exercise recovery. Apart from a single pilot study, this was the first study to investigate the effects of humidification therapy on recovery. Findings from the current study showed that, although not statistically different from compression, humidification therapy resulted in the best recovery of performance from S1 to S3 (2.2%, relative to control). It has been suggested that humidification may enhance recovery through improvement in the efficiency of respiratory muscles via reversal of dynamic hyperinflation[13]; however, this is purely speculative. The identification of the mechanisms for improved recovery is beyond the scope of this study. As such, future research should aim to investigate potential factors leading to enhanced recovery.

There was a substantial decrement in blood lactate concentration throughout the second recovery period with humidification and EMS relative to CON. However, only the humidification strategy led to enhanced performance. Therefore, it may be the mechanism for lactate removal that is providing the performance benefit rather than the removal itself. EMS is proposed to improve lactate clearance through invoked muscle contractions increasing blood flow throughout the musculature.[11] However, it is unlikely that humidification therapy would result in increased blood flow, so other mechanisms are likely responsible for clearance of lactate after humidification therapy that may also be in part responsible for the improved performance observed.

EMS did not improve recovery between bouts, even though there was enhanced lactate clearance and perceived recovery benefits. These findings are in line with previous research that has failed to report any short-term performance benefits in a range of exercises modes.[12] Based on past research and the current study, it may be unlikely that a short bout of EMS improves recovery and subsequent performances. It may be that a longer duration of EMS is required to promote recovery. Indeed, Beaven et al[26] reported improvements in creatine kinase and perceptions of recovery when an EMS device was worn for approximately 8.4 hours overnight during a preseason training phase in professional rugby union athletes. However, no performance data were reported.[26]

We acknowledge the lack of a placebo for each of the 3 recovery interventions (COMP, HUM, and EMS) in the current study. While it remains possible that a placebo effect may have contributed to performance, results from the belief questionnaire at the beginning of the study may help clarify some of the psychological contribution. The results from the questionnaire suggest that only 2 subjects correctly anticipated which treatment would work best for them before testing took place. Subjects also predicted HUM as being the least effective recovery intervention (excluding CON); however, results indicated that it was the most effective from S1 to S3. Furthermore, the ability to correctly predict the effectiveness of each recovery

treatment may have been compromised by some of the relatively novel treatment strategies.

Practical Applications

Humidification therapy and lower-body compression garments can be implemented between repeated high-intensity cycling bouts and may assist in the recovery process where a short turnaround time is required (~30 min). These results can be applied to athletes and coaches looking to improve recovery between exercise bouts to allow for better quality or quantity of training or where subsequent performance is critical. In an applied sport setting, both of these modalities are easy to administer and therefore are more likely to be embraced by athletes and coaches.

Conclusion

Findings from this study suggest that both compression and humidification therapy are effective strategies for enhancing recovery between bouts where there is only a limited recovery period (ie, less than 30 min).

Acknowledgments

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