

Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables

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The purpose of this study was to compare the effectiveness of three different recovery modalities – active (ACT), passive (PAS) and contrast temperature water immersion (CTW) – on the performance of repeated treadmill running, lactate concentration and pH. Fourteen males performed two pairs of treadmill runs to exhaustion at 120% and 90% of peak running speed (PRS) over a 4-hour period. ACT, PAS or CTW was performed for 15-min after the first pair of treadmill runs. ACT consisted of running at 40% PRS, PAS consisted of standing stationary and CTW consisted of alternating between 60-s cold (10°C) and 120-s hot (42°C) water immersion. Run times were converted to time to cover set distance using critical power. Type of recovery modality did not have a significant effect on change in time to cover 400 m (Mean±SD; ACT 2.7±3.6 s, PAS 2.9±4.2 s, CTW 4.2±6.9 s), 1000 m (ACT 2.2±4.0 s, PAS 4.8±8.6 s, CTW 2.1±7.2 s) or 5000 m (ACT 1.4±29.0 s, PAS 16.7±58.5 s, CTW 11.7±33.0 s). Post exercise blood lactate concentration was lower in ACT and CTW compared with PAS. Participants reported an increased perception of recovery in the CTW compared with ACT and PAS. Blood pH was not significantly influenced by recovery modality. Data suggest both ACT and CTW reduce lactate accumulation after high intensity running, but high intensity treadmill running performance is returned to baseline 4-hours after the initial exercise bout regardless of the recovery strategy employed.

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Introduction

Athletes training for competitive sports, particularly at the elite level, are often exposed to very demanding training two or three times a day¹. Large volumes of intense training can have a negative effect on performance if the body does not adequately recover between training sessions. Therefore, recovery can be considered a significant component of athletic training and performance. An adequate recovery decreases fatigue, accelerates the rate of physiological regeneration, facilitates overload, may decrease the risk of injury and enhances supercompensation¹. Acknowledging recovery as an important principle of training has led to research investigating a variety of recovery strategies. Numerous studies have investigated active (light exercise) and passive (resting) recovery modalities^{2,3,4}. Present knowledge overwhelmingly supports the superiority of active recovery methods over passive recovery for lactate removal from the circulation⁵. While most studies support the consensus that active recovery reduces lactate accumulation, its relationship with recovery and subsequent performance remains unclear^{6,7}.

Other recovery modalities include sports massage and various water therapies⁸. Viitasalo et al⁹ suggest that warm water immersion may enhance maintenance of performance capacity and reduce delayed onset muscle soreness. Hudson, Loy, Vincent and Yaspelkis⁴ found that active treadmill and active water recovery are equally effective in enhancing blood lactate removal and that active water recovery may provide a greater perception of recovery after high intensity exercise. Many athletes and coaches are currently utilising hot- and cold-water immersion as a post-exercise strategy with the intention of enhancing recovery. However, very little research has been conducted to substantiate the effectiveness of contrast temperature water immersion as a recovery strategy.

The purpose of this study was to compare the effectiveness of three different recovery modalities - active, passive and contrast temperature water immersion - on the performance of repeated treadmill running, blood lactate concentration and pH. Our hypothesis was that both active recovery and contrast temperature water immersion would be more effective in restoring performance, removing lactate and maintaining pH than passive recovery.

Method

Participants

Fourteen male volunteers participated for the completion of the study. Volunteers were highly active individuals including runners, multisport athletes, team sport players and recreational athletes (Table 1). Participants volunteered after being informed of the potential risks, giving their written informed consent and following completion of a health-screening questionnaire. The study received ethical approval from the Waikato Institute of Technology Research Ethics Committee.

Participants refrained from consuming caffeine or alcohol and performed no strenuous exercise for 24-hours, and no lower body resistance training for 48-hours, prior to testing.

Preliminary testing

A test to establish peak running speed (PRS) and two familiarisation sessions of the testing protocol were performed on a motorised treadmill (Powerjog JM200, England) prior to the commencement of the study. Familiarisation sessions were performed to enhance intra-subject reliability¹⁰ and to allow participants to become familiar with the test protocol. Participant details including mass, height, mid-thigh skinfold, calf skinfold and girth measurements were recorded prior to all preliminary testing following International Society for the Advancement of Kinanthropometry (ISAK) guidelines.

Characteristic	Mean (\pm SD)
Mass	77.8 \pm 11.1 kg
Height	180.3 \pm 8.8 cm
Age	26.4 \pm 6.6 yr
Number of exercise sessions per week	5.5 \pm 1.8

Table 1: Participant characteristics represented as means \pm standard deviations (SD).

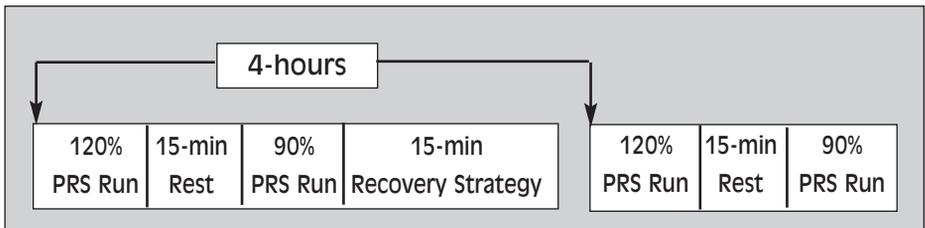


Figure 1: Research design completed by participants on three separate occasions including a different recovery strategy in randomised order (PRS= peak running speed).

Following an initial 5-minute warm up at $10 \text{ km}\cdot\text{h}^{-1}$ participants made an immediate transition to begin the PRS test. The PRS test was performed with the treadmill set at 1% gradient and an initial velocity of $10 \text{ km}\cdot\text{h}^{-1}$. Treadmill velocity was increased $0.5 \text{ km}\cdot\text{h}^{-1}$ every 30-seconds until the participant reached volitional exhaustion. Participants' PRS was recorded as the velocity of the last 30-second period fully completed prior to dismounting the treadmill.

Research design

Following the PRS test and familiarisation trials, participants completed the same testing protocol on three separate occasions in a block randomised multiple cross-over design. The test protocol consisted of two treadmill runs to exhaustion (at 120% and 90% PRS) separated by a 15-minute standardised rest period. Upon completion of the second run to exhaustion, participants were exposed to either active (ACT), passive (PAS) or contrast temperature water immersion (CTW) recovery strategies. Four hours after the start of the test protocol, participants then completed an additional two treadmill runs to exhaustion (at 120% and 90% PRS). Heart rate (HR), rating perceived exertion recovery (RPE_{rec}), blood lactate (BLa), and pH were recorded before each test protocol and during and after each recovery strategy.

Test protocol

The test protocol consisted of repeated performance of a 120% and 90% of peak running speed (PRS) treadmill run to exhaustion. The treadmill was set at 1% gradient throughout all test procedures. Test performance was preceded by a 5-minute standardised treadmill warm-up at 40% PRS followed by a 1-minute rest period, straddling the treadmill belt. On completion of this initial 6-minute warm-up period the participant performed a run to exhaustion at 120% PRS. The participant then had 15-minutes before performing the 90% of



Figure 2: Protocol details of the 15-minutes between participants 120% and 90% PRS treadmill run to exhaustion.

PRS run to exhaustion. The 15-minutes between tests included a cooldown and passive rest (Figure 2). Time to exhaustion in each treadmill run was manually recorded using an electronic stopwatch. Time to exhaustion was defined as the time from initial releasing of the hands from the handrail to commence running until the subject dismounted from the treadmill belt.

Immediately following completion of the 90% PRS run to exhaustion, the participant performed either ACT, PAS or CTW recovery for 15-minutes followed by 5-minutes of seated rest. After a 4-hour interval from the commencement of the initial testing the test procedure was repeated. Subject food and fluid intake between 4-hour test sessions was recorded in the first trial and matched in subsequent trials. Each trial day was separated by a minimum of 72-hours.

Recovery strategies

Active recovery (ACT)

Participants ran at 40% PRS on the treadmill for 15-minutes as soon as was practicable following volitional exhaustion for the 90% PRS run.

Passive recovery (PAS)

Each participant stood upright for 15-minutes confined within an 80 cm diameter circle.

Contrast temperature water immersion (CTW)

Participants immersed the lower body to the level of the anterior superior iliac spine while standing upright in a 260L plastic container, alternating between 60-seconds cold (10°C) and 120-seconds hot (42°C) water immersion for 15-minutes. The recovery modality began with cold water and finished with hot water immersion.

Physiological variables

HR, RPE_{rec} and BL_a were recorded at rest, immediately and 4-, 8-, 12-, 16- and 20-minutes after the first pair of treadmill runs to exhaustion, and at rest before and immediately after the last pair of treadmill runs to exhaustion in each trial. Blood pH was recorded at rest, 20-minutes after the first pair of treadmill runs to exhaustion, and at rest immediately before the last pair of treadmill runs to exhaustion in each trial. Heart rate was measured via telemetry (Polar, Finland). All blood samples utilised whole blood from the fingertip site. Punctures for blood samples were made with a monojector lancette device (Kendall-LTP, Massachusetts). BL_a was taken from the fingertip site using 25 µL capillary tubes and analysed via immobilised enzyme membrane sensor technology using a fluid system YSI 1500 lactate analyser (Yellow Springs, Ohio). Additional blood was collected with a 300 µL lithium-heparin lined microvette (Sarstedt, Germany). Blood pH was analysed using EC8+ cartridges for the microprocessor-controlled electromechanical i-STAT portable clinical analyser (Princeton, New Jersey).

Rating perceived exertion recovery (RPE_{rec})

RPE_{rec} was recorded using the methods of Robertson et al¹¹ and Hudson et al⁴. Subjects were instructed to rate stress, discomfort and/or fatigue that remained in their legs at that moment.

Critical power model

A critical power model was used to reduce performance variation associated with exercise time to exhaustion. Time to exhaustion (seconds) and running velocity ($\text{m}\cdot\text{s}^{-1}$) were used to calculate the distance covered during each treadmill run. The trendline between the two data points for each pair of runs (120% and 90% PRS) represents critical power. The critical power model was used to calculate mean time to cover set distances of 400 m, 1000 m, and 5000 m for each individual; hence:

$$\text{Time} = y - b/a$$

where y = set distance, b = y axis intercept of the line and a = slope of the line.

Performance variation

Estimates of variability in performance were calculated for all participants. Times to cover set distances were log transformed and allowed within participant variation to be calculated and presented as coefficients of variation (CV). The within participant CV represents the typical percent variation in performance of the first pair of treadmill runs (120% and 90% PRS) from test to test (derived as the square root of the sum of within participant variances for the three experimental trials).

Statistical analysis

Data were analysed using repeated measures analysis of variance. Pairwise comparisons were conducted to determine significant differences between selected means. Bonferroni correction was applied to reduce the likelihood of Type I error. Statistical significance was set at $p < 0.05$. In addition, 95% confidence intervals (CI) for mean scores and selected differences between means were calculated and are presented where appropriate. All statistical analyses were conducted using SPSS computer software.

Results

Significant effects of recovery modality were not found for any of the performance variables (Table 2 and 3). Predicted times to cover set distance of 5000 m were lower for ACT and CTW compared with PAS but were not significant at $p < 0.05$ (Table 3). Within participant variation for times to cover set distances were 3.3% (400 m), 2.2% (1000 m) and 2.1% (5000 m).

Modality	120% PRS ¹	120% PRS ²	90% PRS ¹	90% PRS ²
ACT	70.4 ± 19.9	65.6 ± 18.4	301.9 ± 83.1	289.3 ± 81.8
PAS	68.2 ± 20.7	63.4 ± 20.5	302.8 ± 93.2	281.8 ± 120.6
CTW	71.2 ± 18.3	64.6 ± 18.9	296.3 ± 89.5	295.0 ± 123.9

PRS¹ = first pair of treadmill runs, PRS² = second pair of treadmill runs.

Table 2: Time to exhaustion (Mean ± SD) for the initial and repeated pairs of treadmill runs to exhaustion for each recovery modality (in seconds).

Effect of recovery modality on 4-hour repeated...

Modality	400 m	1000 m	5000 m
ACT	2.74 ± 3.63	2.21 ± 4.03	-1.36 ± 29.02
PAS	2.99 ± 4.21	4.78 ± 8.63	16.72 ± 58.53
CTW	4.18 ± 6.85	2.10 ± 7.17	-11.72 ± 33.00

Table 3: Predicted changes in time to cover set distances (Mean ± SD) between each pair of treadmill runs. Values calculated from critical power for each recovery modality (in seconds).

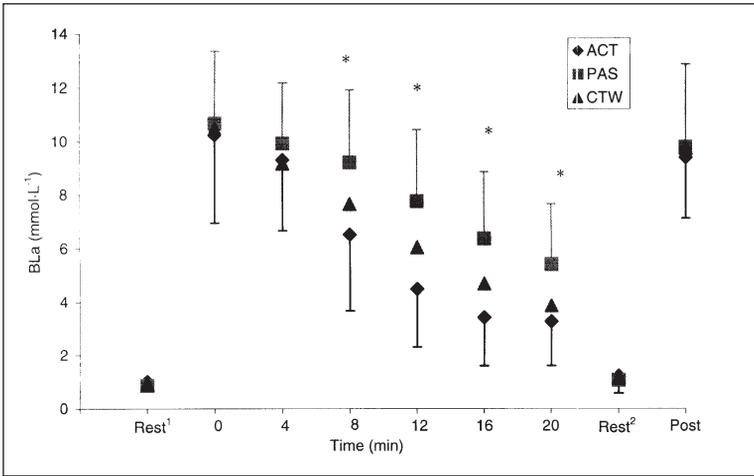


Figure 3: Blood lactate values (Mean±SD) recorded at rest prior to each pair of treadmill runs and post exercise for all participants. * indicates significant difference between ACT and PAS ($p < 0.05$). Rest¹ = resting values prior to first pair of treadmill runs, Rest² = resting values prior to second pair of treadmill runs.

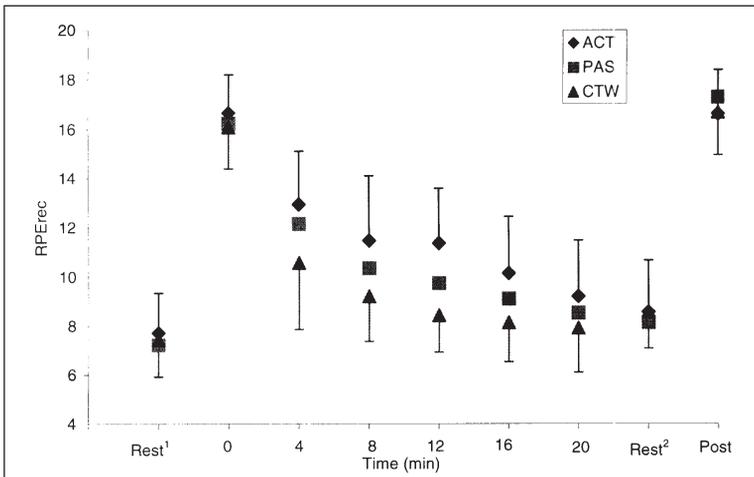


Figure 4: RPE recovery values (Mean±SD) recorded at rest prior to each pair of treadmill runs and post exercise for all participants.

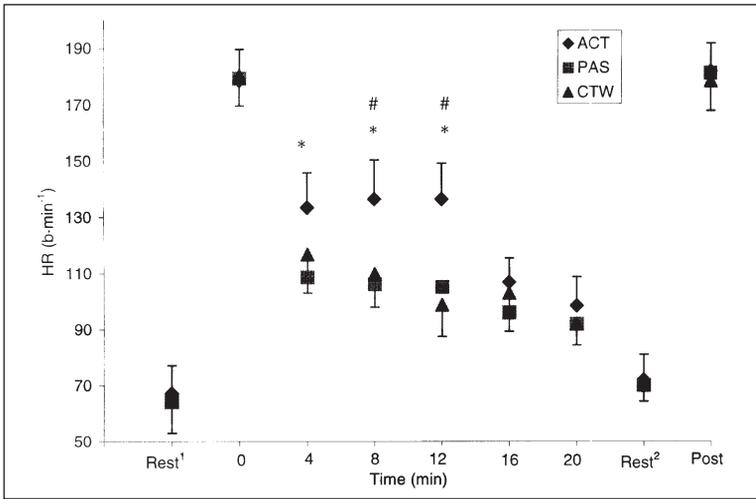


Figure 5: Heart rate values (Mean±SD) recorded at rest prior to each pair of treadmill runs and post exercise for all participants. * indicates significant difference between ACT and PAS and # indicates significant difference between ACT and CTW ($p < 0.05$).

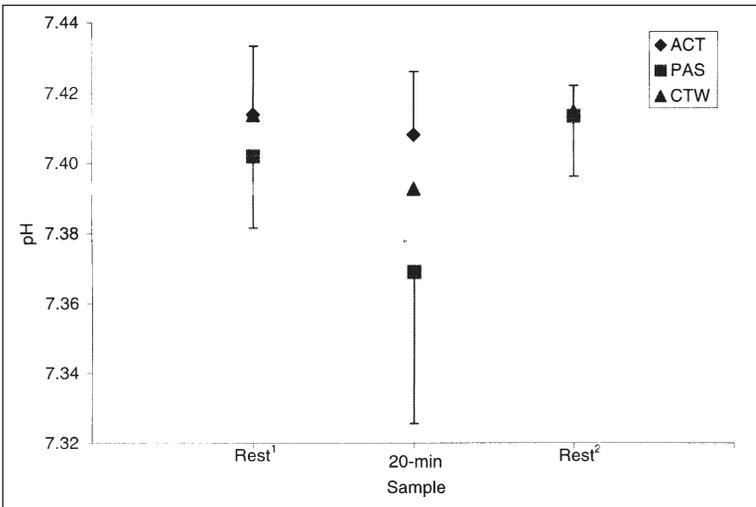


Figure 6: Blood pH values (Mean±SD) recorded at rest, 20-minutes post exercise and 4-hours after initial resting values.

Significant differences ($p < 0.05$) were found between ACT and PAS, but not ACT and CTW, for BLa concentration at 8-, 12-, 16- and 20-minutes post exercise (Figure 3). While BLa was lower at these time points for CTW compared with PAS, these differences were not statistically significant. However, the 95% confidence intervals for the difference between PAS and CTW are close to no overlap of zero at 8-, 12-, 16- and 20-minutes post exercise (95% CI: 8-min -0.28 -3.50 $\text{mmol}\cdot\text{L}^{-1}$, 12-min -0.40 -3.88 $\text{mmol}\cdot\text{L}^{-1}$, 16-min -0.12 -3.55 $\text{mmol}\cdot\text{L}^{-1}$, 20 min -3.29 -5.66 $\text{mmol}\cdot\text{L}^{-1}$).

Values recorded for RPE_{rec} during CTW were lower than both ACT and PAS but these differences were not statistically significant at $p < 0.05$ (Figure 4). In contrast, significant differences in HR were found at 8- and 12-minutes post exercise between ACT and both PAS and CTW (Figure 5). HR at 4-minutes post exercise during ACT was significantly higher than PAS but not CTW (ACT-CTW 95% CI -4.5 - 34.7 $b \cdot \text{min}^{-1}$).

Blood pH was lower at 20-minutes post exercise with PAS when compared with ACT and CTW. However, no significant differences between modalities were apparent for blood pH (Figure 6).

Discussion

The aim of the present study was to compare the effectiveness of the three different recovery modalities - active, passive and contrast temperature water immersion - on the performance of repeated treadmill running, blood lactate concentration and pH. It was found that both active recovery and contrast temperature water immersion reduced blood lactate concentration after high intensity running, but high intensity treadmill running performance is returned to baseline 4-hours after the initial exercise bout regardless of the recovery strategy employed.

Our finding that active recovery reduces post exercise blood lactate concentration is in accordance with a number of other studies^{3,12,13}. Findings from previous research indicate that it may be reasonable to assume that this reduction in blood lactate concentration is likely to be associated with enhanced lactate clearance^{14,15}. The main metabolic pathway for lactate elimination is oxidation in the tricarboxylic acid cycle to end products CO_2 and H_2O ¹⁶. Lactate oxidation predominantly occurs in active skeletal muscle. In addition, a secondary pathway for lactate elimination is reconversion to glycogen via gluconeogenesis. It has been reported that 13-27% of lactate may be converted to glycogen during recovery¹⁴. Hence, enhanced lactate elimination with active recovery is primarily attributed to increased blood flow to active muscle. However, the present study was restricted to the measurement of blood lactate concentration. Therefore it is not possible to determine the exact fate of lactate in our subjects.

A novel finding of the present study is that contrast temperature water immersion appears to provide similar effects for removing lactate from the circulation as active recovery and is more effective compared with passive recovery. It is difficult to speculate upon the mechanism responsible for reduced lactate concentration after contrast temperature water immersion. However, it is likely that this recovery modality changes intra-muscular hydrostatic pressure and produces alternating vasoconstriction and vasodilation, which is likely to alter blood flow to the immersed musculature. Increased muscle perfusion may improve lactate removal^{17,18}. Clearly, further research is necessary to investigate the mechanism responsible for causing reduced lactate accumulation in the CTW condition.

Despite reduced lactate concentration in the ACT and CTW conditions, treadmill run performance was similar regardless of recovery condition. While some researchers have demonstrated a relationship between lactate clearance and performance of a subsequent exercise task^{2,19}, others have found that improved performance and recovery with active modalities was not associated

with a lower blood lactate concentration^{20,6}. Uncertainty remains with regard to the exact relationship between blood lactate disappearance and subsequent performance. Acidosis as a result of lactic acid accumulation may alter the ability of the muscle to produce force²¹. Though the effects of H⁺ are controversial, there is evidence to suggest that increased H⁺ concentration in muscle reduces the force and velocity of contraction²². Our data show a lower, but not significantly different, pH 20-minutes post exercise following PAS recovery when compared with ACT or CTW. Low pH has been implicated as a contributor to metabolic fatigue and may also influence subsequent recovery. Therefore, attenuated lactate build up may result in enhanced recovery.

The reason for the type of recovery not having an influence on performance in the present study is probably due to the timing of the two pairs of treadmill runs. The second pair of treadmill runs were performed four hours after the commencement of the first pair. During this period blood lactate and pH had returned to resting levels in all three recovery conditions. Therefore, the intensity of exercise in the present study was such that participants had recovered fully within the 4-hour time period between exercise bouts. Clearly, with active and contrast temperature water immersion recovery strategies reducing post exercise lactate concentration, the potential remains that the type of recovery modality may have influenced performance if the second exercise bout had been performed closer to the first bout. Time to exhaustion has a large coefficient of variation. However, critical power (a series of constant power tests) has been shown to be more reliable¹⁰. Analysis of our data shows a within participant variation of 3.3% (400 m), 2.2% (1000 m) and 2.1% (5000 m). The critical power calculations of changes in time to cover set distances show a trend toward improved repeated performance with ACT and CTW recovery modalities (Table 3). Therefore, this may indicate a relative enhanced recovery when compared with the passive modality. Nevertheless, no significant difference in running performance was apparent. Further research is required to ascertain the influence of contrast temperature water immersion on the time course for recovery of treadmill running performance.

The results of the present study indicate that both active recovery and contrast temperature water immersion appear to be similar in reducing lactate accumulation. However, participants in the CTW condition had a lower heart rate and reported a lower perception of fatigue, discomfort or stress during recovery. Therefore, contrast temperature water immersion may be a better recovery strategy for athletes after high intensity exercise because it appears to have similar effects in reducing blood lactate concentration as active recovery, but the athlete achieves these effects with less exertion and increased perceptions of recovery. Clearly, further research is required to examine the effects of the different recovery modalities on other physiological processes in the post exercise recovery period before a definitive conclusion can be made on the relative merits of active recovery versus contrast temperature water immersion.

In conclusion, the present study has shown that both active recovery and contrast temperature water immersion reduces blood lactate concentration after high intensity running, but high intensity treadmill running performance is returned to baseline four hours after the initial exercise bout regardless of the recovery strategy employed. Contrast temperature water immersion may be

a more appropriate recovery strategy than active recovery for some athletes, because similar physiological changes are achieved with reduced exertion and increased perceptions of recovery.

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