Water Immersion Recovery for Swimmers in Hot Environments

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Abstract**—**This study recognized the effectiveness of cold-water immersion recovery post short-term exhaustive exercise. The purpose of this study was to understand if 16-20 °C of cold-water immersion would be beneficial in a tropical environment to achieve an optimal recovery in sprint swim performance in comparison to 10-15 °C of water immersion. Two 100 m-sprint swim performance times were measured along with blood lactate (BLa), heart rate (HR) and rate of perceived exertion (RPE) in a 25 m swimming pool with full body head out horizontal water immersions of 10-15 °C, 16-20 °C and 29-32 °C (pool temperature) for 10 minutes followed by 5 minutes of seated passive rest outside; in between the two swim performances. 10 well-trained adult swimmers (5 male and 5 female) within the top twenty in the Sri Lankan nationals swimming championships in 100m Butterfly and Freestyle in the years 2020 & 2021 volunteered for this study. One-way ANOVA analysis ($p < 0.05$) suggested performance time, BLa and HR had no significant differences between the three conditions after the second sprint, however RPE was significantly different with $p = 0.034$ between 10-15 °C and 16-20 °C immersion conditions. The study suggested that the recovery post the two cold-water immersion conditions were similar in terms of performance and physiological factors however the 16-20 °C temperature had a better "feel good" factor post sprint 2. Further study is recommended as there was participant bias with the swimmers not reaching optimal levels in sprint 1. Therefore, they might have been possibly fully recovered before sprint 2 invalidating the physiological effect of recovery.

Keywords**—**Hydrotherapy, blood lactate, fatigue, recovery, sprint-performance, sprint-swimming.

I. Introduction

SWIMMING is a high intensity sport that is energetically supported by the phosphocreatine, glycolytic and the aerobic combustion of carbohydrate, fats and proteins [1]. Competitive swimmers might have to swim multiple high intensity swimming events with a short period (60 min – 24 hours) of rest [2], [3]. Whilst there is very little data in swimmers itself, the duration and intensity of a 100 m swim is similar to a 400 m run. During such events the athlete sprint utilizes phosphocreatine in the first 5 to 10 seconds [4], then followed by a gradual increase of glycolysis until the event is primarily dependent of glycolysis [5]. Likewise, in a 100m swim the contribution of the glycolytic energy system is around 60-70%. The high dependence on the glycolytic system can result in the elevation of plasma lactate levels and other metabolic and physiological changes which can affect performance [2], while changing the muscle and blood homeostasis [6]. Therefore, measuring the levels of BLa after a sprint swim and after recovery is a common practice to understand the level of performance in competitive swimming [7] and recovery in maximal and submaximal exercise [8].

Fatigue has been defined in many ways in sports science; for biochemists, fatigue is seen as the reduction of force out of the muscle, for psychologists it is the sensation of tiredness, and for physiologists it may be the failure of a particular physiological system [9]. Fatigue has also been viewed as either central fatigue, where the central nervous system (CNS) stops the muscle from exerting extraordinary effort to protect the muscle from injury, or peripheral fatigue, where the muscles homeostasis has been disturbed due to physical muscle damage and biochemical changes [10]. In swimming the level of BLa can be as high as 12.6 $mmol/L^{-1}$ [11], [12] and the main problem with lactate increase and the subsequent accumulation is the prevention of muscle contraction [13]. The increase of BLa leads to the increase in hydrogen ions which as a result increases the level of Adenosine diphosphate (ADP) and impairs the function of the muscle by creating a sodium-potassium-ATPase (Na-K-ATPase) imbalance [12]. Apart from this direct impact to performance, the increase in lactate and hydrogen ions inhibit the rate-limiting enzymes phosphofructokinase (PFK) and lactate dehydrogenase of glycolysis [12], thus affecting the subsequent high intensity exercise (sprint) bout. However, it is debatable whether lactate alone can be attributed to the onset of fatigue [14], but it is used widely as an indicator of fatigue.

Recovery has been defined as the return of muscle to its pre-existing state after an exercise bout [15]. Reference [10] divided recovery into immediate recovery, short-term recovery and training recovery. Immediate is the rapid recovery you get in a stroke cycle in swimming between the left and right arm or between the left leg and right leg during walking. Short-term recovery is the recovery time between two interval sprints and training recovery is the recovery between two successive workouts or competitions. Recovery through completely restoring homeostasis (i.e. bring back BLa to the pre-exercise level) can be achieved with long-term passive rest (approximately 72 hours) [16]. However, during competition, the natural recovery process of 72 hours [15] is not possible. Therefore, in sports such as cycling, swimming and running other recovery modalities such as active recovery, passive and hydrotherapy are commonly used. Active-recovery can double the rate of lactate removal in comparison to passive recovery [12]. In the study conducted on female college students by Felix et al. [2], there were three recovery modalities, two being active (swimming and rowing) and one passive rest was compared. It

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was observed that after 15 minutes of recovery, lactate was lower in active recovery and the rate of reduction was faster in comparison to passive recovery.

Hydrotherapy is similar to actively recovery excluding the energy expenditure component [17]. The added advantage is that the body temperature which is high during exercise can be lowered with cold water or thermo-neutral temperatures [14]. The pressure exerted due to immersion causes displacement of bodily fluids from the periphery to the central cavity, this displacement increases cardiac output and transportation of substrates [14]. Reference [18], in the study of active recovery, passive recovery and water immersion, suggests that CWI lowers core temperature. Reference [19] conducted a study on well-trained 5 km runners, where a graded exercise test was performed to obtain the baseline measurements of VO_2max, HR and rate or perceived exertion (RPE). The results suggested that the measurements obtained from the CWI recovery were similar to baseline, while passive rest measurements were slower. Reference [17] compared three immersion temperatures on sprint swimming. CWI temperature was 16-23 °C; hot water immersion (HWT) and contrast water immersion (CWT) temperatures were 40 °C and 40/23 °C respectively. The participants were fully immersed and only their head was out of the water and periodic measurements of HR, BLa and skin temperature were taken. The results suggested that the highest HR reduction was after CWI; both CWI and CWT had a significant skin temperature reduction, CWT had the best BLa removal ability and CWI and CWT were associated with a better performance. In reviewing 214 articles on water immersion, [20] states that CWI can enhance recovery and the temperature can vary from 10-15 °C while the immersion duration can range from 5-15 minutes. The immersion too can vary from immersing multiple times, i.e. 5 minutes x 3 with a minute break or immersing for 10 minutes without a break.

Water immersion protocols vary based on duration, temperature and immersion depth; as all these variables play a key role in training recovery [21], [10]. There is a substantial difference between the temperature used in CWI in the literature and this temperature is as low as 10 °C and as high as 23 °C. In some studies, thermo-neutral temperature has been between 23-25 °C, whereas in tropical countries the ambient temperature ranges between 35-38 °C. The temperature used in water immersion recovery has been uncertain, more so there is a limited study conducted in tropical countries where the ambient temperature is approximately 8-10 °C higher. The current study would be to test the performance difference between two CWI temperatures along with a control (TWI) to understand which temperature might be more suited for sprint swimmers in a tropical environment. The hypothesis is that water temperature between 16-20 °C will provide a reduced time in the sprint post recovery in comparison to the temperatures of 10-15 °C and 29-32 °C, further the HR and BLa will be lower in the 16-20 °C before the sprint, in comparison to the other two water immersion temperatures.

II. Literature Review

The study was on performances and physiological changes after cold-water immersion recovery between two freestyle sprint swims. The resources were all online-based journals from databases such as PubMed, Google Scholar, ERIC-Institute of Education and Sciences, JSTOR, Academia.edu, Journal of sports science and medicine. The strategy was to perform multiple searches on the mentioned data bases using key words such as, fatigue, recovery, hydrotherapy, cold-water immersion, sprint swimming recovery, sprint exercise recovery, lactate recovery, HR recovery, anaerobic energy systems and glycolytic energy systems to identify the literature online. 85 peer reviewed original articles and systematic review articles were identified during the key word search; the abstracts of these journal articles were read followed by the selection of 40 articles based on the hypothesis. Further the bibliography, key words of the selected research articles and the systematic review articles were examined for authors and cold-water immersion sprint performance studies. The literature was then assessed on following;

- The methodology of the journal articles.
- Objectivity of the research.
- If the arguments are supported by evidence.
- The institute location and affiliation of the study.

Finally, the selected journals were used to formulate the method and the objectives of the present study.

III. Methods

A. Subjects

Ten participants were recruited for this research project. They were within the top 20 at the Sri Lankan national swimming championships for the 50 m and 100 m freestyle and butterfly events within the past 3 years (2019-2021). The Medical Ethics Committee of the University of Glasgow approved the study. All swimmers were informed of the purposes and method of the study and a written informed consent was obtained from the swimmers before participation.

B. Design

Three tests were performed and all athletes were tested at each of the three different water immersion temperatures. The testing temperatures were randomly selected in the first test, then randomly selected between the remaining two temperatures and finally with the untested temperature. The recovery modalities were passive water immersion at three different temperatures. The control temperature was 29-32 °C, and the two cold-water immersions were 10-15 °C and 16-20 °C. The test procedure started with an initial measurement of HR and BLa. This was followed by a warm up and a sprint maximal effort of 100 m freestyle swim. Immediately after the first sprint (S1) measurements of the sprint time, BLa, HR and the RPE were measured, followed by a water immersion for 10 minutes at either 10-15 °C, 16-20 °C or 29-32 °C. At the end of the 10 minutes HR and Bla were recorded. The swimmers then rested passively for 5 minutes outside the water and at the end of the hour HR and Bla was recorded. A 5-minute warm up was performed and followed by a 100 m maximal effort freestyle sprint (S2). Immediately after the sprint HR, BLa, and RPE were recorded again as presented by Table I. Each recovery temperature was tested on 3 different days with a minimum of 48 hours between each day.

C. Measurements

BLa was measured with an ear prick capillary blood sample (5 µL) and analysed using a Lactate pro-2 analyser. The samples were gathered at rest, post S1, water immersion recovery, passive rest and S2. HR was measured using a water-resistant Garmin forerunner 735. Measurements were taken at rest, post S1, water immersion recovery, passive rest and S2. The two 100 m sprints (S1 and S2) were separated by 15 minutes of recovery and a very minimal warm up. Time was measured using a Casio recorder. RPE was recorded using a Borg scale of 6-20 where 6 was rated as the exertion level is very light and 20 being the exertion level is extremely high. This was recorded immediately after the two sprint swims (S1 & S2).

D. Statistical Analysis

All experimental and calculated values are presented as mean +/- standard deviation. One-way ANOVA was performed on all measurements (Bla, RPE, HR & S2) to understand if there is a statistical significance in performance and if there is a difference between the means of the three immersion temperatures. Levene's Homogeneity test and Welch's ANOVA were performed to understand the meaningful significance. The threshold for significance was set at $p \leq 0.05$. All data were analysed using SPSS 20.0.0.

IV. Results

There were 10 participants (n = 10) with a mean age of 19.17 ± 1.80 years, weight of 63.83 ± 12.16 kg and height of 1.69 ± 0.884 meters.

TABLE I
MEANS AND SD OF SPRINT TIME AND RPE FROM POST SPRINT 1 (S1) TO POST SPRINT 2 (S2)

N = 12	Factor	10-15 °C	16-20 °C	29-31 °C
Sprint Time	S1	1:00.0 ± 0:04.5	1:00.2 ± 0:04.6	0:59.9 ± 0:04.6
± SD	S2	0:59.9 ± 0;04.7	0:59.9 ± 0:04.7	1:00.0 ± 0:04.8
RPE ± SD	Post S1	15.33 ± 1.303	14.92 ± 1	15.08 ± 0.90
RPE ± SD	Post 10 min	8.42 ± 1.165	8.58 ± 1.95	9 ± 1.758
RPE ± SD	Post 5 min	8.75 ± 2.261	7.08 ± 0.99	8.33 ± 2.425
RPE ± SD	S2	15.92 ± 1.24*	14 ± 1.95*	15.42 ± 1.56

* Significant difference between the 3 immersion conditions, SD ± = Standard Deviation, S1 = Sprint 1, S2 = Sprint 2

The performance variable sprint 2 had no significant difference between any of the immersion conditions with p = 0.996 analysed through one-way ANOVA. The same was observed across RPE during the first 3 measurement times except post sprint 2 (Table I). One-way ANOVA was run to compare the means of RPE post sprint 2. The mean of Sprint_2_RPE was statistically significant with F = 3.995, p = 0.034 (Welch ANOVA). Post Hoc Tests (Games_Howell) for multiple comparisons recorded the difference was only between the immersion condition 10-15 °C and 16-20 °C, as there was no significance between the two cold-immersions and 29-32 °C.

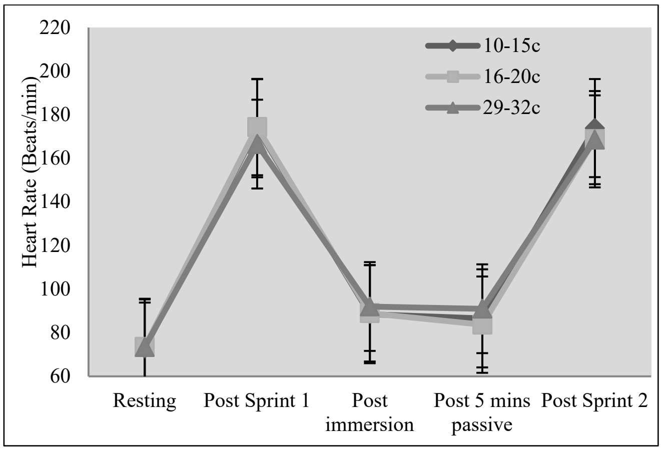

Fig. 1 The mean HR changes during the experimental conditions

Figs. 1 and 2 record the variation of HR and BLa from the resting state to post sprint 2. None of the recorded data during the different times of the study were significant between the three immersion conditions.

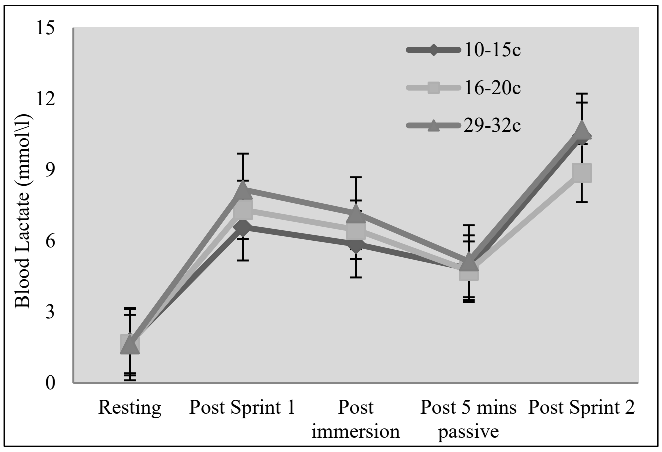

Fig. 2 The mean BLa changes during the experimental conditions

V. Discussion

The present study examined the effect of different temperatures of water immersion for recovery in sprint swimming in a tropical environment. The swimmers concluded two maximal sprints replicating training/competition conditions. The hypotheses were that immersion temperature of 16-20 °C would result in a better time sprint 2-post recovery, and the HR and BLa measured after 5 minutes passive rest would be lower in the 16-20 °C condition in comparison to the other two conditions.

The findings suggested that sprint 2 performance was not significantly different between the immersion conditions. In [17], it was suggested that cold-water immersion and CWT both had significantly improved performance time and significantly different RPE results, which read "fairly light" (11 in the Borg scale) in comparison to the other immersion condition. This was not apparent in the current study when the two cold-water conditions were compared against the 29-32 °C condition. However, in the cycling studies conducted by [22] where 1 km time trials were performed in immersion of 14 °C cold-water for 20 minutes, the immersion condition had a decrease in power and no difference between pre and post conditions in terms of maximal isokinetic concentric torque. Further the extreme cold-water temperatures such as 5-15 °C can have detrimental effects on repeated sprint performances. It has been suggested that following 15 minutes of immersion, HR increases to maintain core and skin temperature and the inhibitory effect on nerve conduction and subsequent force production [17], [18], [14].

The findings of BLa and HR results at all time points were not significantly different between the three immersion conditions. This was different to the study conducted by [17] where they found significant differences between BLa removal (9th minutes post sprint) and HR reduction 6 minutes post sprint performance in comparison with HWT (40 °C).

The findings further suggested that the RPE post sprint 2 showed a difference between the means of the three conditions and the significant difference was recorded between 10-15 °C and 16-20 °C, with 16-20 °C recording a difference of -1.95 of the scale post sprint 2, suggesting that after the immersion of 16-20 °C of cold-water the swimmers felt marginally better recovered than the other cold immersion condition. It has been stated that cold-water immersion had a 2% reduction in RPE, when participants were immersed in 14 °C of cold water after sprint 2 [23]. It is possible that the increased parasympathetic activity post cold-water immersion and its reciprocal reduced sympathetic over-activity contribute to greater feelings of wellbeing as measured through the total quality of recovery questionnaire by [17], the result suggested that cold-water and CWT had a better score in comparison to HWT. However, it is unclear as to why 10-15 °C would record a higher mean RPE (0.5) in comparison to 29-32 °C as found in the current study based on [17] & [23].

Reference [6] conducted a study on 100m swim time, different passive and active recovery modalities suggested that the swimmers possibly held back maximum speed in S1 as they knew they had to perform an optimal effort swim 15 minutes later, this finding of the current study suggests that that only 20% of the performances recorded the sprint 1 being faster than sprint 2. Reference [21], in the review article on cold-water immersion for athletic recovery, stated that the demands imposed by the exercise results in different effects on recovery associated with fatigue. As per the findings reported in Table I, the sprint time between sprint 1 (S1) and sprint 2 (S2) was not significantly different and this was apparent across the three different days of testing for the majority of the sprint efforts, therefore the assumption would be the onset of fatigue to the level required would have not been achieved post S1, allowing the swimmers to recover fully before the S2 making the differences of the recovery modalities invalid. Comparing the level of BLa to similar studies that conducted 100m sprints, which followed by recovery modalities, suggested that the mean BLa recorded was between 8.5-10 mmol/L [17], [6]. This was different to the findings of this study, which recorded a lower BLa range of 6-8 mmol/L further suggesting the swimmers presumably did not exert sufficient effort in the initial sprint.

VI. Study Limitations

A notable limitation of this study was participant bias, as suggested by [6], the swimmers held back on the first sprint on all three days despite the repeated instructions for swimming with maximal effort on both the sprints, thereby reducing the ability of the recovery conditions to take effect on the body to provide a meaningful result. All test were conducted outdoors therefore the pool temperature variance during the trial of the 29-32 °C condition in comparison to the other two was uncontrolled. If the change was over 4 °C it would have had an impact on the result of the study.

VII. Conclusion

There have been very minimal studies comparing two cold-water immersion conditions between two short maximal effort sprints. Furthermore, only limited studies of cold-water immersion have been conducted in a tropical environment. The findings of the study suggest that there is no significant difference in performance in the immersion conditions. However, there is a "feel-good" factor after the 16-20 °C immersion although it is minimal. This raises the question as to why the participants did not feel the same after the 10-15 °C condition. The same has been suggested in the discussion. The fact that 10-15 °C had a higher HR 5 minutes post immersion can possibly be the reason as to why RPE was higher in the said condition (pre cooling factor). Finally, the fact that the swimmers possibly did not exert sufficient effort in the initial sprint may have skewed the results. Therefore, further study might be required to understand if there is a benefit in immersing in a higher temperature (> 15 °C) of cold-water in a tropical environment than in cooler environments for faster recovery.

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