

demonstrated an over-reliance on the hip strategy to maintain their balance, which may lower their postural stability when standing.^[13] It is unknown whether IWI would further jeopardize their standing balance performance given its desensitizing effect on the sensory system.

In addition, IWI is not always well tolerated. Athletes undergoing IWI commonly feel cold, or even pain, at temperatures of 5 to 10°C, while a comfortable temperature range is from 15 to 25°C.^[9] Previous evidence revealed that during the first 8 minutes of water immersion at 5 and 14°C, the rate of reduction in body temperature is similar.^[14] So, theoretically, the recovery effects should be identical. Normal human body temperatures range from 36 to 38°C.^[15] Technically, direct heat transfer (by conduction and convection) from the body to room-temperature water (25°C) is feasible.^[15] It is plausible that room-temperature water immersion (RWI) has a similar recovery effect to that of IWI at 5 to 10°C, which means that RWI may provide an acceptable alternative to IWI for athletes.

To the best of our knowledge, no study has previously compared the recovery effects of IWI to RWI on rugby players. Therefore, the aim of this study was to compare the effects of postexercise IWI, RWI, and no water immersion on the sensory organization of balance control and the lower limb joint proprioception of rugby players.

2. Methods

2.1. Study design

The study was a single-blinded three-armed randomized controlled trial. The study protocol was approved by the Human Research Ethics Committee of the University of Hong Kong. Written informed consent was obtained from the participants. All of the experimental procedures were in line with the University's guidelines and the Declaration of Helsinki on human experiments.

2.2. Participants

The participants were recruited from local recreational and university rugby clubs between June 2014 and July 2015 using advertisements on social networking sites and on the campus bulletin board. The eligible criteria were as follows: aged 18 to 35; took part in rugby training regularly (>3 hours/week); and had a minimum of 1 year of training experience. The exclusion criteria were as follows: recently sustained a serious injury that may affect balance performance; a significant musculoskeletal, cardiovascular, neurological, cognitive, visual, vestibular, or other sensorimotor disorder; muscle fatigue on the day of the assessment; cold sensitivity; an open wound or a dermatological or infectious disease; menstruation in female participants; and incontinence.

2.3. Screening and randomization

The participants were screened by a sports scientist before the baseline assessment, and they were randomly allocated (by drawing cards) to 1 of 3 groups: the IWI group, the RWI group, or the control group. Since a simple unrestricted randomization was used, disparities in group sizes were anticipated.^[16]

2.4. Interventions

A fatigue protocol was used to stress the participants' cardiovascular and muscular systems and to exhaust their aerobic energy systems. Each participant ran on a high-performance motorized

treadmill set at a 1.0% gradient and wore a safety harness to prevent falls. Each participant's heart rate (HR) and blood pressure (BP) were monitored continuously using a Polar Heart Rate monitor (Polar Electro Oy, Kempele, Finland) and a digital BP monitor (T4 (HEM-739-C32), Omron, Japan), respectively. The participants performed a 5-minute warm-up, consisting of 5 submaximal sprints for 5 seconds on the treadmill. Subsequently, the participants performed 14 sprints for 15 seconds with 45 seconds rest intervals on the treadmill. The treadmill speed was regulated (so that the athletes reached 90% of their VO_{2max})^[17] by a certified strength and conditioning specialist according to the participants' HR response during sprinting. Consistent verbal encouragement was given to the participants throughout the exercise.

Immediately after the fatigue protocol, the participants underwent the 1-minute recovery intervention. This duration was selected because it is the duration that is commonly used in practice due to the time constraints between matches.^[18] The participants were asked to wear swim shorts or swimsuits during the water immersion.

The participants in the IWI group stood in the water tank immersed in water up to the level of the iliac crest. The water temperature (5°C) was regularly monitored with a digital thermometer (TPI-326, Test Products International Inc., Beaverton, OR; accuracy: $\pm 1^\circ\text{C}$), and adjusted as necessary by adding crushed ice. Those in the RWI group stood in the same water tank, with the ice water replaced by tap water. The water temperature (25°C) was regularly monitored using the same thermometer. Those in the control group sat on a chair and did not undergo water immersion. All of the interventions were performed in a temperature-controlled laboratory (at 25°C with a relative humidity of 75%).

2.5. Primary outcomes

The sensory organization of each participant's balance control was assessed using the sensory organization test (SOT) of a computerized dynamic posturography machine (SMART EquiT-est, NeuroCom International Inc., OR).^[19,20] The SOT is a valid^[21,22] and reliable test^[23,24] for measuring balance performance in younger individuals. The concurrent validity^[21] and discriminant validity^[22] have been reported. In addition, our previous study showed that the intraclass correlation coefficient (ICC) values for the SOT condition-specific equilibrium score (ES) ranged from 0.50 to 0.77 in healthy young persons, indicating moderate to good reliability.^[23]

During the test, each participant wore a security harness and stood barefoot on the force platform of the posturography machine. The foot placement was standardized according to the participant's height. The SOT involved the following 6 sensory conditions: eyes open with fixed support, eyes closed with fixed support, sway-referenced vision with fixed support, eyes open with sway-referenced support, eyes closed with sway-referenced support, and sway-referenced vision with sway-referenced support. Three trials were carried out for each sensory condition. The machine measured each participant's anterior-to-posterior center of gravity (COG) displacement, and automatically generated an ES for each sensory condition. A composite ES (ie, the weighted mean of the condition-specific ESs), representing each participant's overall balance performance, was also calculated. The condition-specific ESs and composite ES were used for analysis. A familiarization trial was included prior to the actual testing to minimize learning effects and improve the test-retest reliability.^[24]

2.6. Secondary outcomes

The active knee joint angle repositioning test is a valid and reliable test that assesses knee joint proprioception ($ICC_{3,3} = 0.775$; 95% CI: 0.638–0.866).^[25] The assessment procedures were described in detail in our previous study.^[25] In brief, the participants were blindfolded and they laid on their nondominant side on a platform. The participant's dominant leg was laid horizontally (using slings to counterbalance the effect of gravity), and the hips were kept at 45° of flexion. An air splint was applied to the foot and ankle being tested to minimize the influence of the cutaneous sensation. An electrogoniometer (Biometrics Ltd, UK) was attached on the lateral side of the knee joint along the femur and fibula. Starting from a 90° knee flexion position, the assessor moved the knee to a 20° to 75° flexion position and held it at this position for 3 seconds. The participant was instructed to remember this knee joint position. The knee was then moved back to its starting position. After a 5 seconds break, the participant was asked to reproduce the previous joint position. The error was calculated as the absolute difference between the reproduced angle and the assigned angle. Three trials were performed with 30 seconds rest intervals.^[25] The mean errors of 3 trials were used in the subsequent analysis.

2.7. Test procedures

The data were collected by 2 trained research assistants who were supervised by a sports scientist at the Human Performance Laboratory of the Education University of Hong Kong. The assessors were blinded to the group allocation. Each participant was assessed at baseline and immediately after the intervention. In addition to the HR and BP measurements, a thigh skin temperature (T_{skin}) measurement was also taken at baseline and postintervention using an infrared thermometer (MW-151, MediSain, Australia; accuracy: 0.3°C).

2.8. Statistical analyses

A sample size calculation was performed using G*Power software (version 3.1.0, Franz Faul, University of Kiel, Germany). The results of the pilot trial showed that there was a large effect size (1.15) related to the balance performance outcomes between the 2 groups at the postintervention assessment. With the statistical power set at 80% and the 2-tailed level of significance set at 5%, it was calculated that a minimum of 13 participants were needed per group, which amounts to 39 participants in total. Dropouts were not anticipated as the baseline and postintervention assessments were all taken during a single visit.

The statistical analyses were conducted using SPSS 21.0 software (IBM, Armonk, NY). Descriptive statistics were used to describe the demographic and outcome variables. Shapiro–Wilk tests and/or histograms were used to check the normality of the data depending on the type of variable being assessed. One-way analyses of variance (ANOVAs) were used for the continuous data, and chi-square tests were used for the categorical data to examine the between-group differences in the demographic and outcome variables at baseline. Any significant between-group differences in the baseline values of the demographic variables indicated that these variables were to be treated as covariates. Two-way repeated measures ANOVA was used to compare the effects of the interventions on the primary and secondary outcomes. The within-subject factor was time (time effect) and the between-subject factor was group (group effect). An

intention-to-treat approach, specifically, the last observation carried forward method, was used to handle the missing data due to attrition.

If a significant time effect, group effect, or group-by-time interaction effect was found in the 2-way repeated measures ANOVAs, follow-up analyses were performed using paired *t* tests, 1-way ANOVAs, and post hoc pairwise comparisons, as appropriate. The 2-tailed significance level was set at 0.05 and the LSD correction method was used, where necessary, to maintain the level of type I errors at 5%.

3. Results

3.1. Participants

The study flowchart is shown in Fig. 1. Two volunteers (3.6%) were excluded as one had experienced a significant musculoskeletal injury within the previous 12 months and the other had a high resting BP. Fifty-three eligible participants were randomly assigned to the IWI group ($n = 13$), the RWI group ($n = 18$), and the control group ($n = 22$). Table 1 shows the participants' baseline characteristics. No significant between-group differences were found for any of the demographic variables ($P > 0.05$).

3.2. Physiological responses

The HR responses to the fatigue protocol were similar between the groups ($P = 0.471$). The fatigue protocol significantly increased the mean of the participants' HRs from the resting level (67.9 ± 7.7 beats/minute) to the high-intensity level (184.2 ± 8.6 beats/minute, $P < 0.001$). There were no significant differences between the groups regarding either the systolic or diastolic BP at any time point ($P > 0.05$), and both BP measures returned to the baseline levels after the interventions ($P > 0.05$). As expected, there was a significant group-by-time interaction effect on T_{skin} . After the interventions, T_{skin} in the IWI group ($23.2 \pm 1.9^\circ\text{C}$) was significantly lower than that in the control group (-6.8°C ; 95% CI, $-8.3, -5.4$, $P < 0.001$) and the RWI group (-5.0°C ; 95% CI, $-6.5, -3.5$, $P < 0.001$). The postassessment T_{skin} increased in the IWI group, but remained relatively stable in the RWI and control groups. The postassessment T_{skin} remained below baseline in both immersion groups (IWI: $P = 0.003$, RWI: $P < 0.001$).

3.3. Primary outcomes

The primary outcomes (composite ES and condition-specific ESs) and secondary outcome (knee joint repositioning error) are shown in Table 2. The values of these variables were similar in the 3 groups at baseline ($P > 0.05$). There was no statistically significant group-by-time interaction effect on the composite ES ($F(2, 50) = 36.556$, $P = 0.052$, $\eta_p^2 = 0.111$). No significant changes between the baseline and postintervention assessments were found for the composite ES in any of the groups ($P > 0.05$). There were no statistically significant group-by-time interactions associated with the 6 condition-specific ESs ($P > 0.05$). We also found no significant change over time in the mean of each condition-specific ES ($P > 0.05$).

3.4. Secondary outcome

There was a significant group-by-time interaction effect on knee joint proprioception ($F(2, 50) = 4.757$, $P = 0.013$, $\eta_p^2 = 0.160$). Those in the RWI group tended to have lower errors over time, but those in the IWI and control groups tended to have increased

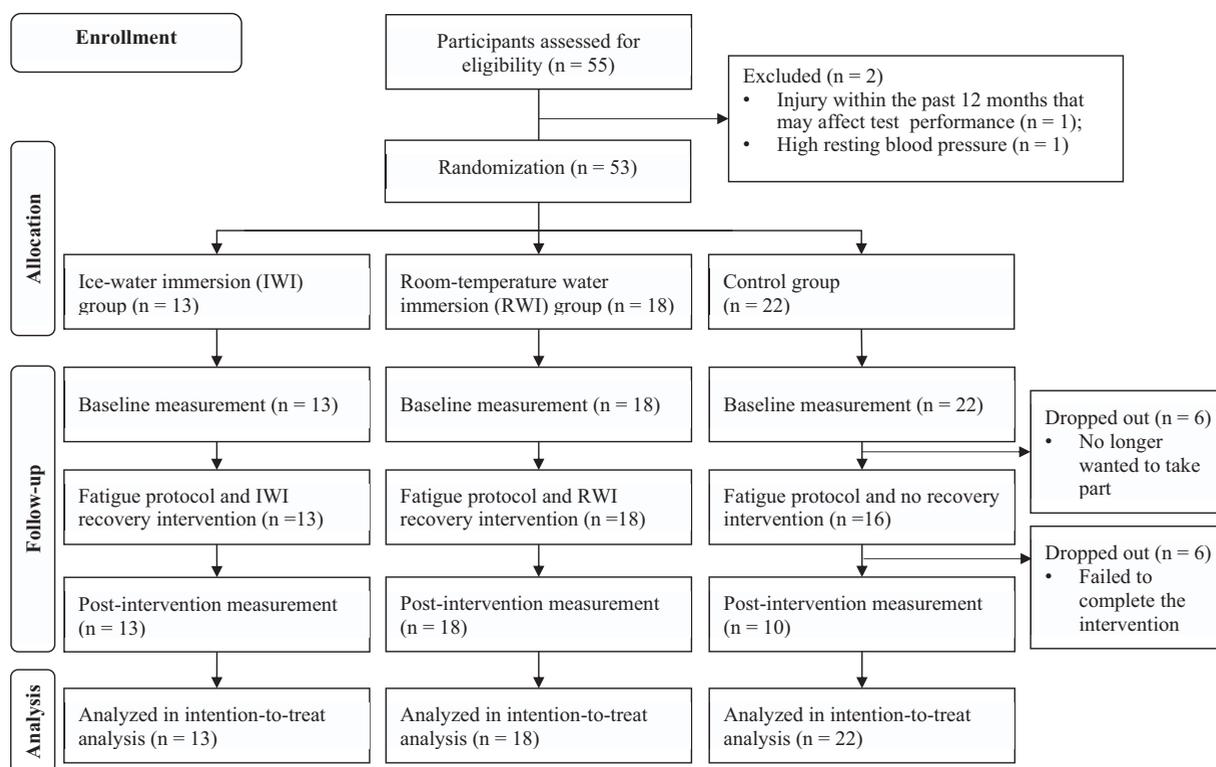


Figure 1. Study flowchart. IWI=ice-water immersion, RWI=room-temperature water immersion.

errors over time. It seems that the increase was more pronounced in the IWI group than in the control group ($P > 0.05$). Post hoc pairwise comparisons showed that the IWI group had significantly higher error score than the RWI group at postintervention ($P = 0.022$) (Table 2).

3.5. Adverse events

No adverse events related to the fatigue protocol, interventions, or assessments occurred during the study.

4. Discussion

This study is the first to demonstrate the effect of IWI and RWI following individualized exhaustive exercise on the sensory organization of balance control in a group of amateur rugby players. Although significant reductions in skin temperature were observed in both immersion groups, our results showed that both IWI and RWI did not impair the rugby players' bipedal balance performance. Contrary to our research hypothesis, IWI did not influence the sensory organization of balance control. This

Table 1

Characteristics of the participants at baseline.

	IWI group (n=13)	RWI group (n=18)	Control group (n=22)	P
Demographics				
Age, year	22.9 (2.43)	21.78 (3.37)	20.7 (2.36)	0.074
Sex (male/female), n	7/6	10/8	12/10	0.995
Height, cm	168.5 (10.4)	168.2 (9.74)	168.5 (8.9)	0.993
Weight, kg	64.1 (10.2)	64.6 (12.3)	62.4 (13.7)	0.836
Body mass index, kg/m ²	22.5 (1.3)	22.7 (3.4)	21.7 (3.1)	0.565
Percentage of body fat, %	14.2 (6.6)	14.8 (7.0)	14.8 (7.3)	0.960
Resting heart rate, beats/minute	68.2 (7.1)	70.1 (7.4)	66.0 (8.3)	0.258
Resting blood pressure				
Systolic blood pressure, mmHg	113.4 (6.9)	112.8 (11.8)	117.9 (9.3)	0.214
Diastolic blood pressure, mmHg	70.9 (5.9)	70.4 (8.5)	71.6 (9.0)	0.898
Physical activity level, MET hour/week	133.4 (108.8)	142.8 (74.9)	147.0 (113.9)	0.929
Training history				
Training volume, hour/week	7.8 (2.9)	6.5 (4.0)	6.9 (2.9)	0.577
Rugby experience, year	3.2 (1.3)	3.3 (2.5)	4.9 (4.0)	0.155
Injury history				
Mild concussion, n, %	2 (15.38%)	0 (0%)	2 (9.09%)	0.261
Sprained ankle, n, %	10 (76.92%)	14 (77.78%)	16 (72.73%)	0.925
Sprained knee, n, %	2 (15.38%)	5 (27.78%)	3 (13.63%)	0.489

Means (with standard deviations) are presented unless otherwise specified. IWI=ice-water immersion, MET=metabolic equivalent of task, RWI=room-temperature water immersion.

Table 2
Outcome measurements.

Outcome measure	IWI group (n=13)		RWI group (n=18)		Control group (n=22)		Group effect	Time effect	Group × time effect
	Baseline	Postintervention	Baseline	Postintervention	Baseline	Postintervention	P	P	P
Sensory organization test									
ES 1	93.77 (1.86)	93.85 (2.16)	94.46 (1.86)	93.52 (1.81)	93.71 (2.11)	94.09 (1.62)	0.958	0.469	0.035
ES 2	92.18 (2.73)	92.82 (1.91)	92.37 (2.99)	91.74 (2.82)	93.24 (2.04)	92.73 (2.25)	0.411	0.615	0.284
ES 3	90.31 (8.60)	92.33 (2.44)	92.59 (2.62)	92.07 (2.16)	93.27 (3.00)	93.35 (2.57)	0.167	0.444	0.343
ES 4	83.64 (7.94)	81.03 (11.08)	81.06 (9.29)	82.41 (7.45)	78.94 (11.17)	78.92 (11.25)	0.514	0.601	0.175
ES 5	64.67 (13.82)	65.03 (12.92)	58.70 (12.55)	63.18 (18.27)	63.71 (9.76)	64.70 (9.93)	0.596	0.173	0.436
ES 6	61.79 (20.36)	60.62 (17.54)	51.28 (16.14)	61.91 (10.37)	55.75 (20.08)	55.53 (21.47)	0.633	0.094	0.015
Composite ES	78.46 (8.19)	77.39 (8.55)	74.28 (7.26)	77.39 (7.20)	75.45 (7.34)	75.77 (8.22)	0.643	0.254	0.052
Knee joint repositioning error, °	3.92 (3.86)	7.15 (4.90)*	6.17 (5.66)	4.00 (3.03)	4.36 (2.92)	5.82 (3.30)	0.899	0.244	0.013†

Means (with standard deviations) are presented unless otherwise specified. ES=equilibrium score, IWI=ice-water immersion, RWI=room-temperature water immersion.

* Denotes a difference significant at $P < 0.05$ when compared with the RWI group at postintervention.

† Significant effect ($P < 0.05$).

finding may be explained by the study by Dewhurst et al^[26] that showed that a moderate change in leg muscle temperature ($\pm 3^\circ\text{C}$) does not affect postural stability during standing. In contrast, significant reductions in muscle temperature (6.4°C in the thigh and 6.7°C in the calf) have been shown to lead to alterations in unipedal balance test results and in the limit of stability.^[8,27] Additionally, Chesterton et al^[28] indicated that a significant reduction in T_{skin} of 12.5°C can reduce the NCV by 10%. However, in IWI, the deeper tissues of the leg may cool much more slowly than the skin of the thigh.^[29] In our study, the reductions of T_{skin} in the IWI and RWI groups were only 6.7 and 2.4°C , respectively. Therefore, the reductions in NCV and muscle temperature may not be sufficient to harm postural control. As a result, we concluded that 1-minute of IWI may not provide a sufficient cooling effect to alter postural stability via changes to the deep motor nerve conduction and deep tissue function.

Postural control is a complex process that involves integration of sensory information from 3 sensory systems (the visual, vestibular, and somatosensory systems). It has been suggested that sensory reweighting (ie, shifting the reliance from somatosensory inputs to visual inputs) after cooling contributes to the regulation of balance control when the sole plantar sensation is suppressed.^[7] In our study, compensation by sensory reweighting was explored using the condition-specific ES, including condition 2 (eyes closed with fixed support), condition 4 (eye open with sway-referenced support), and condition 5 (eyes closed with sway-referenced support). The decrease in the condition-specific ESs (from SOT condition 1 to 6) is not surprising because the conditions increased in difficulty from 1 to 6. However, the condition-specific ESs was similar between groups. IWI did not appear to disturb the sensory inputs for postural control, including the somatosensory inputs via the feet, which indicated that sensory reweighting did not occur after cooling.

Our study also revealed a significant group-by-time interaction effect on the knee joint repositioning error. Further analysis showed that the knee joint reposition sense was inferior in the IWI group compared to the RWI group after immersion. This finding was in agreement with previous studies^[30,31] showing that cryotherapy had a negative effect on joint position sense primarily because the application of ice reduces superficial NCV, limits muscle spindle afferent fiber and Golgi tendon organ discharge, alters the viscoelastic properties of ligaments,^[30] and increases joint stiffness.^[31] It is reported that for each 1°C fall in skin temperature, NCV decreased by 0.4 m/second .^[32] The fall in

skin temperature was drastic in the IWI group compared to the RWI group. Therefore, the superficial sensory NCV and joint position sense was affected more in the IWI group than the RWI group.

Both our study and Paschalis et al's study^[33] demonstrated that joint position sense was impaired immediately after intense exercise. This may be related to the accumulated metabolites^[33] or body tissue heating.^[34] Stimulating heat receptors (due to an increase in body temperature) can alter cutaneous sensations and probably compromise joint position sense.^[34] The application of cold could normalize tissue temperature and hence joint sense. However, extremely cold condition is detrimental to the recovery of joint position sense as explained above. Cooling the skin, muscles, and joints by less intense cold (room-temperature) water immersion may be the best method for improving joint position sense after exercise.

Our results are relevant to those interested in recovery after physical activity. The study showed that immersion in both very cold and room-temperature water does not alter athletes' bipedal standing balance performance after exhaustive exercise. The T_{skin} cooling pattern in the immersion groups was gradual, which indicates that the treatment could provide a relatively comfortable recovery option for athletes. RWI may be a better choice than IWI for treating heat-related fatigue in nonemergency situations.

This study has some limitations. First, due to the nature of the interventions, the participants were not blinded to the treatment allocation. Therefore, the placebo effect may have introduced bias in the results. Second, we only measured the sensory aspect of postural control using a computerized dynamic posturography machine but postural control is a complex process involving multisystems. Further studies may explore the effects of water immersion on the motor aspect of postural control and the functional or sports performance of amateur rugby players. Finally, our results can only be generalized to specifically rugby players, but not other types of high-performance athletes.

5. Conclusions

Neither postexercise IWI nor RWI had a significant effect on the sensory organization of amateur rugby players' balance control. RWI had a less detrimental effect on knee joint proprioception to IWI. Our results demonstrated the feasibility of using RWI, a relatively comfortable treatment, in place of IWI for reducing

heat-related fatigue among rugby players in nonemergency situations.

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