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Original Article

Effects of contrast water therapy on proprioception of the knee joint and degree of fatigue in sprinters after high intensity training

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Abstract: Objective: To investigate the effect of contrast water therapy on proprioception of the knee joint and indicators associated with fatigue in sprinters after high intensity training. Methods: A total of 40 sprinters were selected and divided into an observation group and a control group. The observation group got 14 minutes of contrast water therapy, while the control group took 14 minutes of sitting rest after training. The knee position sense, muscle force sense, joint reaction angle to release, knee joint function, and indictors associated with fatigue were evaluated before and after exercise at different time points. Results: At 24 h, 48 h, and 72 h after exercise, the active position sense and muscle force sense of the control group were significantly lower than those of the observation group (all $P<0.05$). At 48 h after exercise, the passive position sense of the control group was significantly lower than that of the observation group (all $P<0.05$). At 24 h and 48 h after exercise, the joint reaction angle to release of the control group was significantly greater than that of the observation group (all $P<0.05$). Additionally, the IKDC2000 and Lysholm scores after interference in the observation group were greater than those of the control group (all $P<0.05$). The indicators associated with fatigue after interference in the observation group were significantly lower than those of the control group (all $P<0.05$). Conclusion: Contrast water therapy can effectively alleviate muscle force sense, promote muscle proprioception, improve knee joint function, and enhance recovery from fatigue.

Keywords: Contrast water therapy, high intensity training, position sense, muscle force sense, joint reaction angle to release

Introduction

For sprinters, high intensity training is considered to be a fast, high-power, concentric-eccentric contraction, continuous interleaved load exercise. This kind of training uses many muscles and is effective for enhancing explosive power and leaping ability of the lower limb as well as specialized agility and flexibility [1]. Therefore, this method has been adopted in the training of high-level sprinters to maximize voluntary isometric contraction of the quadriceps by improving neuromuscular recruitment ability, and promote the flexibility and coordination of the lower limb muscles [2]. However, high intensity training contains many eccentric contraction components, which can cause fatigue, delayed-onset muscle soreness, and possibly injury [3]. Therefore, in addition to improving training methods, prevention against post exercise fatigue and injury also is significant for improving athletic performance.

Fatigue and functional recovery are recurring themes in sprinter training cycles. Skillful management of the relationship between fatigue and functional recovery is an important prerequisite for improving their competitive edge. Many elite athletes leverage specific technical measures to accelerate recovery, alleviate fatigue, and gain a competitive edge. Hydrotherapy has been widely used in the field of sport healthcare, including cold water immersion, thermoneutral water immersion, and contrast water therapy (CWT) [4]. Among these, CWT is a novel therapy involving regular alternating

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immersion in cold and thermoneutral water and found to be beneficial for the recovery of athletes [5].

The proprioceptive sensation comes from the mechanical receptors in deep muscles, tendons, and joints, as well as the feedback from free nerve endings to the central nervous system. It is considered to be the basis for determining the position, direction, speed, and strength of limbs [6]. Thus, a good sense of proprioception is crucial in sports performance and safety. High intensity training can bring significant challenges to lower limb joints in sprinters and may lead to adverse effects on the proprioceptive sensation of knee joints [7]. It was previously reported that most knee joint injuries in professional athletes were due to a decrease in proprioceptive sensation caused by exercise fatigue [8]. These athletes are unable to timely perceive changes in external factors, which impact the stability of knee joints and limit rapid feedback to the central nervous system, resulting in secondary injury to the joints and their surrounding tissue structures [9]. Therefore, finding a fast and effective recovery method is important in the field of sports science. Previous studies showed that, compared to passive recovery, CWT could significantly alleviate muscle pain, promote muscle strength recovery, and accelerate recovery from injury after eccentric exercise [10]. However, the effects of CWT on proprioception and fatigue degree in sprinters are still not yet clear. In this context, this study, based on the well-established knee joint proprioception evaluation methods [11, 12] and fatigue degree indicators [13], explored the intervention effect of CWT on knee joint proprioception and degree of fatigue after high-intensity exercise in sprinters. The results of this study may inform athletes and coaches on exercise recovery strategies, reduce the risks of motor injury, and help improve sports performance.

Materials and methods

General information

This retrospective study recruited 40 sprinters as participants through posters in Hunan Applied Technology University. Inclusion criteria: sprinters who were the second rank athletes; non-smokers in good health; those without a history of sports injuries and lower limb injuries; those who signed the informed consent. Exclusion criteria: sprinters who experienced skeletal muscle injuries within the past three months; those did vigorous activities within 24 hours before the test; those did not understand or master the movements required in experimental tests. This trial was authorized by Hunan Applied Technology University (Ethics approval number: 202302).

Training methods

The exercise took place in a track and field gymnasium at room temperature (23±2)°C and relative humidity (50±3)%. After a 5-minute jog warm-up, formal exercise was performed. Referring to a high-intensity enhanced exercise program reported by previous studies [14], it was adjusted according to pre-experiment results and actual subject conditions. The exercise consisted of 10 sets, with 2-3 minutes' interval between each set. Each set included 20 squat jumps with 10 kg weights and 50 m frog leaps, with 1-2 minutes' rest between squat jumps and frog leaps.

Recovery included the following two stages. In the first stage, the subjects from both groups sat quietly for 5 minutes after exercise, with attention to fluid intake. In the second stage, after a 5-minute sitting rest, the subjects in a control group sat quietly for another 14 minutes, while those in an observation group underwent CWT for 14 minutes.

CWT methods

The ICOOL thermostatic pool manufactured in Australia served as the hot-water pool and the INTEX thermostatic pool from The United States functioned as the cold-water pool. The two pools were placed adjacent to each other to ensure rapid change from one pool to another (within 5 s). The hot water was maintained at (38±1)°C and the cold water at (15±1)°C. The subjects wore standard swimming trunks and began by immersing themselves in the hot water pool up to the neck for 1 minute, then transitioned to the cold water pool for 1 minute. This alternating cycle continued until the 14-minute mark, at which point subjects emerged from the cold-water pool and dried themselves.

Examination of position sense

The Biodex System-3 isokinetic muscle force tester (Biodex Company, USA) was used to assess position sense [15]. The knee joint position perception test mode was set with a target angle of 45°. For the active position sense test, subjects were seated at a 90° angle with the upper body, right thigh and lower leg secured. The knee joint was positioned at an initial angle of 90°. In the preparation stage, the subjects actively extended their knee to the target angle, keeping for 10 seconds, then returned to the initial angle. The subjects were helped to put on eye masks and earmuffs, in order to avoid visual and auditory interference. During the testing phase, the subject actively extended their knee and indicated when they felt that the target angle was reached by pressing a button. The systems recorded the angle without informing the subjects. This test was repeated 3 times with one minute interval, and the final results were calculated according to the following formula: Active position sense = [(actual angle 1 + actual angle 2 + actual angle 3) - (3 × target angle)]/3.

For the passive position sense test, the procedure was similar, except that the knee joint started at an initial angle of 0° and was moved passively to the target angle by the instrument. Subjects then indicated when they perceived the target angle by pressing a button, with the same precautions against visual and auditory interference.

Examination of muscle force sense

The Muscle force sense test was conducted with the Biodex System-3 isokinetic muscle force tester (Biodex Company, USA) [16] using the equal length test mode. Subjects' maximum voluntary isometric contraction (MVIC) of the quadriceps femoris in the right leg (dominant leg) was measured, with 50% of MVIC selected as the target force value. Subjects were seated with the upper body and right thigh secured, and the knee joint positioned at 90°. In the preparation stage, the subjects watched the monitor and actively extended their knees to exert forces. When the 50% of MVIC was reached, they were asked to hold for 5 seconds before returning to the initial position. During the testing phase, eye masks and earmuffs were applied to avoid visual and auditory interference. The subjects were instructed to actively extend their knee, mimicking the knee extension torque in the first stage for 5 seconds, and the actual torque was recorded without informing subjects. This test was repeated 3 times with a one minute interval. The final results were calculated according to the following formula: Muscle force sense = [(actual torque 1 + actual torque 2 + actual torque 3) – (3 × target torque)]/3.

Examination of joint reaction angle to release

Using the same instrument as above, the test was set to the isometric mode. Subjects were seated with their right leg (or dominant leg) knee joint positioned 15° from the horizontal line. With the entire body relaxed and wearing eye masks and earmuffs to minimize sensory distraction, the switch was pressed to allow the lower leg to fall freely under the action of gravity, without informing the subjects. Upon feeling the lower leg falling, subjects were required to react promptly to stop the fall at the fastest speed possible and maintain the angle. The actual angle was recorded, with the test repeated three times at one-minute intervals. The final results were calculated as follows: Joint reaction angle to release = [(actual angle 1 + actual angle 2 + actual angle 3) - (3 × target angle)]/3 [17].

Evaluation of knee joint function

The intervention effect on knee joint function was assessed using Lysholm scores [18], with a total score of 100 points across 8 evaluation items. Lower scores indicated poorer knee function, while higher scores indicated better knee function. In addition, subjective knee function scores were evaluated using the IKDC2000 scale [18], which comprised ten items. Again, lower scores indicated poorer knee function.

Evaluation of indicators associated with fatigue

Enzyme-linked immunosorbent assay (ELISA) analysis was employed to detect fatigue-associated indicators [19]. Blood samples from different groups were collected and centrifuged at 3500 rpm for 10 minutes. Levels of lactic acid (Lot numbers: CEV643Ge, Cloud-Clone Company, USA), creatine kinase (Lot numbers:

Table 1. Comparison of general information between the two groups

Group	Control group (n=20)	Observation group (n=20)	t/χ^2	P
Training years	6.58±1.06	6.71±1.12	0.685	0.427
Age (years)	19.51±0.58	20.12±0.67	1.314	0.155
Height (cm)	186.35±5.18	185.72±6.25	1.647	0.136
Weight (Kg)	83.22±8.65	85.01±9.71	1.085	0.319
Maximal oxygen uptake (ml/kg·min)	46.94±4.18	47.38±4.67	0.373	0.548
Fat mass (%)	19.58±6.14	18.95±5.76	0.084	0.815

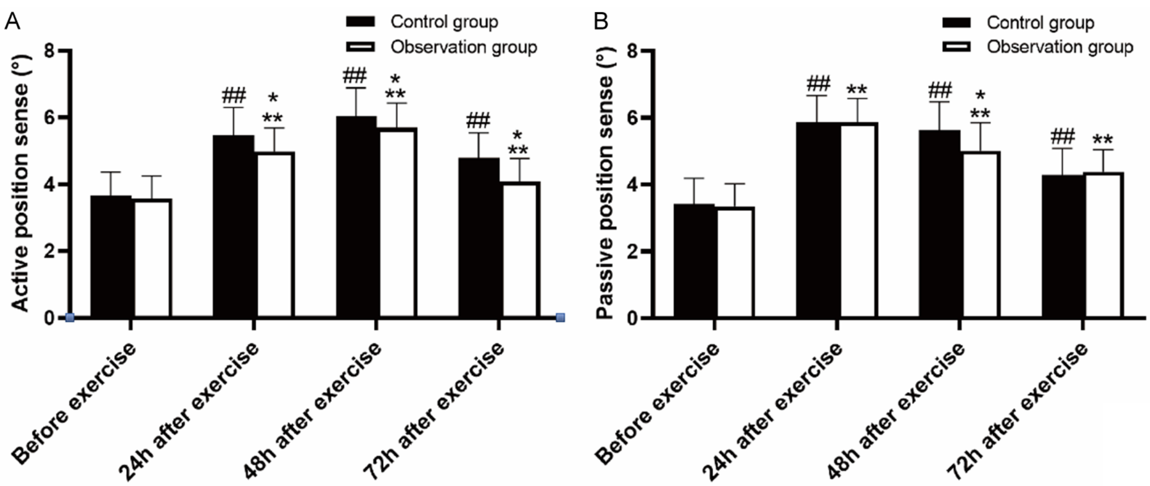

Figure 1. Comparison of active and passive position sense before and after exercise between the two groups. A: Active position sense. B: Passive position sense. *P<0.05 vs. control group, ##P<0.01 vs. before exercise in control group, **P<0.01 vs. before exercise in the observation group.

SBJ-H1277, Nanjing SenBeiJia Biological Technology Co., Ltd.), blood urea nitrogen (Lot numbers: SBJ-H2001, Nanjing SenBeiJia Biological Technology Co., Ltd.), and lactate dehydrogenase (Lot numbers: SBJ-H1179, Nanjing SenBeiJia Biological Technology Co., Ltd.) were measured using ELISA according to protocols of the manufacturer. The optical density was examined at 450 nm using a microplate reader.

Statistical analysis

All data were analyzed using SPSS 23.0. The measured data were expressed as mean ± standard deviation (mean ± SD), and the independent sample t-test was used for comparison between two groups. Paired sample t test was used for comparison between before and after intervention. The multiple time point data were analyzed by repeated measurement analysis of variance. P<0.05 was considered statistically significant.

Results

Comparison of general information

Table 1 shows that there were no significant differences regarding age, training age, weight, height, maximal oxygen uptake, or fat mass between the control group and the observation group (all P>0.05), indicating comparability. Throughout the intervention, there were no participants who withdrew due to personal injury. There were 20 participants in each group.

Comparison of position sense

As shown in **Figure 1**, there was no significant difference in position sense before exercise between the two groups. At 24 hours, 48 hours, and 72 hours after exercise, both groups showed a significant increase in active and passive position sense compared to before exercise (all P<0.01). However, the observation group exhibited significantly lower active position sense at 24 hours, 48 hours, and 72 hours

Table 2. Comparison of muscle force senses between the two groups

Group	Before exercise	24 h after exercise	48 h after exercise	72 h after exercise
Control group	4.09±0.96	8.05±1.04**	8.87±1.20**	5.78±1.15**
Observation group	4.13±0.87	9.68±1.17**,###	9.23±1.25**	7.99±1.18**,###
t value	0.138	4.657	0.929	5.998
P value	0.891	<0.001	0.359	<0.001

Note: **P<0.01 vs. before exercise in the same group, ###P<0.001 vs. control group.

Table 3. Comparison of joint reaction angle to release between the two groups

Group	Before exercise	24 h after exercise	48 h after exercise	72 h after exercise
Control group	6.95±0.88	8.87±1.02**	7.97±1.12**	7.08±0.85
Observation group	7.10±0.95	7.98±1.04**,#	7.19±0.98#	6.96±0.79
t value	0.518	2.732	2.344	0.463
P value	0.607	0.010	0.024	0.646

Note: **P<0.01 vs. before exercise in the same group, #P<0.05 vs. control group.

after exercise, as well as lower passive position sense at 48 hours than the control group (all P<0.05).

Comparison of muscle force sense

As shown in **Table 2**, there was no significant difference in muscle force senses between the two groups before exercise. At 24 hours, 48 hours, and 72 hours after exercise, both groups showed a significant increase compared to before exercise (all P<0.01), and the increase was greater in the observation group at 24 hours and 72 hours after exercise (all P<0.001).

Comparison of joint reaction angle to release

As seen in **Table 3**, there was no significant difference in joint reaction angle to release before exercise between the two groups. At 24 h after exercise, the joint reaction angles to release were significantly increased in both groups compared to those before exercise (all P<0.05). At 48 h after exercise, the joint reaction angle to release in the control group was still significantly higher than that before exercise (P<0.05), while the difference in observation group was no longer significant (P>0.05). Furthermore, at both 24 h and 48 h after exercise, the joint reaction angle to release in the control group was significantly greater than that in the observation group (all P<0.05).

Comparison of fatigue-related indicators

As seen in **Figure 2**, there was no statistical differences in the level of blood urea nitrogen after intervention between the two groups. The levels of blood lactic acid, creatine kinase, and lactic dehydrogenase after intervention were significantly lower in the observation group than those in the control group (all P<0.05). Moreover, the levels of blood lactic acid, creatine kinase, and lactic dehydrogenase in the observation group were obviously decreased after intervention in contrast to before intervention (all P<0.05).

Comparison of knee joint function

As seen in **Figure 3**, there was no significant differences in IKDC2000 and Lysholm scores between before and after intervention in the control group, while both scores in the observation group were greater after intervention than those before intervention. In addition, the scores in the observation group were significantly higher than those of the control group after intervention (all P<0.05).

Discussion

Since Cochrane [20] proposed the potential benefits of CWT for recovery of sports performance, numerous studies have investigated its effect after various sports events. However, most of the research results did not find such benefits of CWT, with only a few studies reporting positive outcomes [21]. The discrepancies may stem from different types of sports and diverse approaches to the water bath. At present, there is no standardized protocol for CWT, encompassing parameters such as total

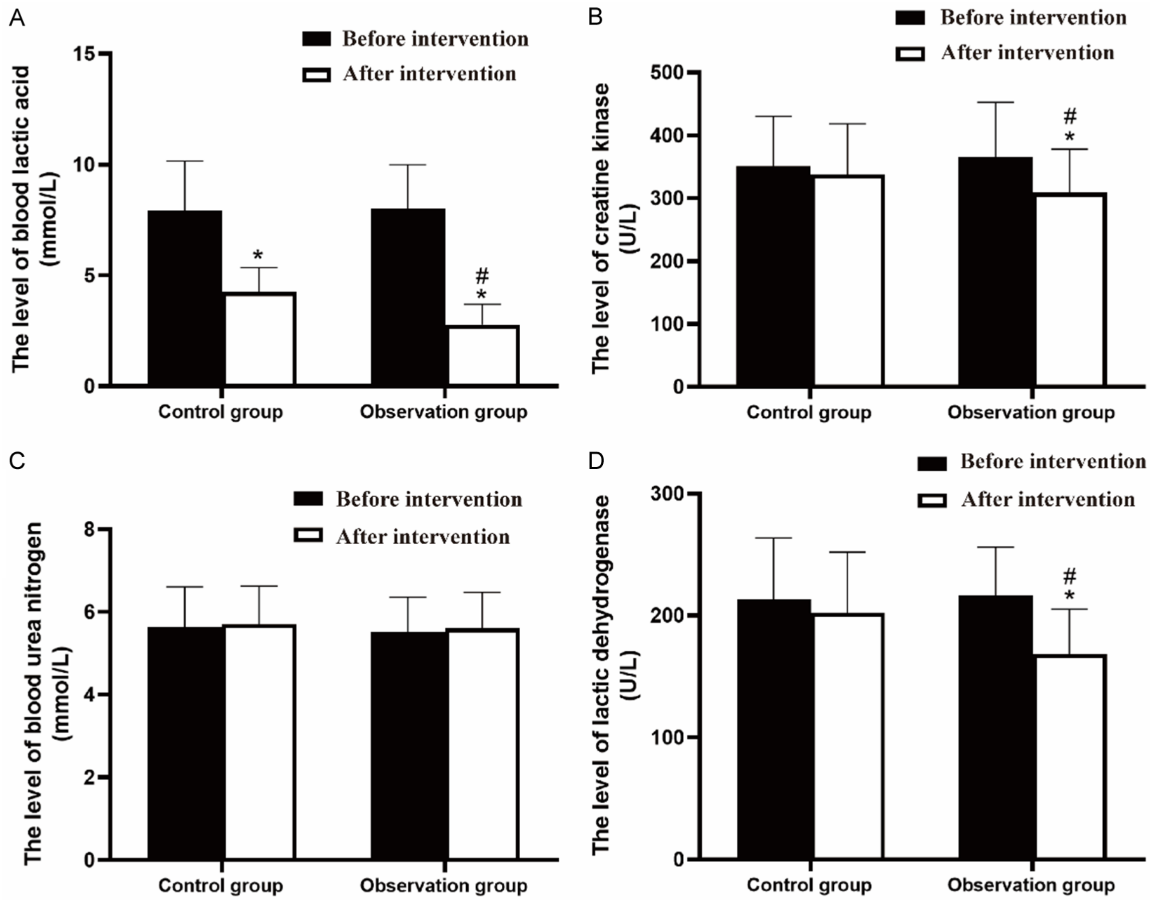

Figure 2. Comparison of fatigue-related indicators before and after exercise between the two groups. A: The level of blood lactic acid. B: The level of creatine kinase. C: The level of blood urea nitrogen. D: The level of lactic dehydrogenase. *P<0.05 vs. before intervention in the same group, #P<0.05 vs. control group.

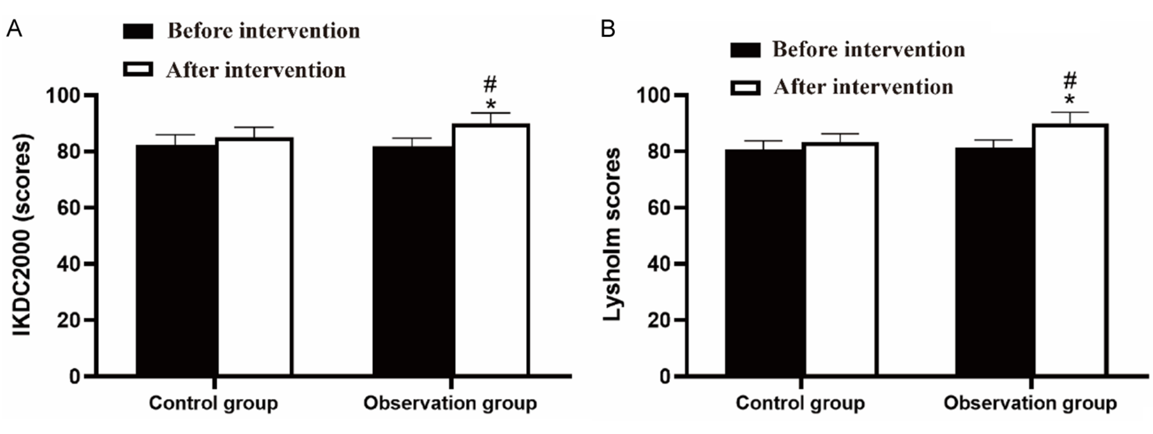

Figure 3. Comparison of knee joint function before and after intervention between the two groups. A: IKDC2000 scores. B: Lysholm scores. *P<0.05 vs. before intervention in the same group; #P<0.05 vs. control group.

immersion time, water temperature, immersion position, and post-exercise interval. In the several experiments that confirmed the beneficial effects of CWT, they used immersion up to the shoulders, alternating between 38°C hot water and 15°C cold water for 1-min interval, with a total duration of 14 minutes. Therefore, the same water immersion method was adopted in this study. It is worth noting that the several experiments that confirmed the beneficial effects of CWT [22] have focused on lower extremity high-intensity sports such as sprints and cycling, which involve excessive use of knee joints. In addition, in these experiments, the method to evaluate the recovery of sports performance was to repeat running, riding or weight-bearing squat jump, and isometric squat for a period of time after exercise. Obviously, these movements have certain requirements for knee proprioception. Therefore, we considered to explore the possibility that CWT can promote the recovery of knee proprioception, so as to explain the observed improvement in sports performance. Our findings not only confirmed the role of CWT in promoting the recovery of knee proprioception after intensive exercise, but also suggested the beneficial role of CWT in sprinting, which has higher requirements on knee joint, by promoting the recovery of sports performance. This may be related to the recovery of knee proprioception.

Our results showed that CWT was helpful to recover active and passive position sense, especially active position perception. This advantage can be attributed to the different influencing factors of active and passive activities on positional perception. Active motion can trigger the receptors in the muscle to the maximum extent, so active positional perception can fully reflect the changes of muscle receptors [23]. Passive motion does not involve active muscle contraction, so passive position perception can effectively avoid the increase of information caused by active muscle contraction [24]. Previous studies have pointed out that CWT contributes to the recovery of muscle strength after eccentric exercise [4]. Therefore, the role of CWT in promoting the recovery of positional sense is possibly due to its mechanism of promoting the recovery of muscle strength.

Muscle force sense is used to describe the conscious sensation of output force during voluntary contraction of skeletal muscles [25], which can reflect the body's perception of force and its ability to replicate the degree of force exerted. The results of this study showed that the muscle strength sense of both groups significantly decreased after exercise, and reached the lowest value at 24-48 hours after exercise. Although the muscle strength perception of the CWT group also decreased, the degree of decline was lower than that of the control group, reflecting the beneficial role of CWT in alleviating muscle strength perception decline. Another study [26] proposed that the feeling of effort related to muscle contraction is the foundation of muscle force perception. However, factors that affect muscle strength perception are not only related to the sensation of effort, but also the accumulation of metabolites (bradykinin, prostaglandin E2, lactate, etc.) that affect the sensitivity of chemical receptors at the end of sensory input nerves. In intense exercise, the accumulation of metabolic products caused by the rapid and continuous stretching of lower limb muscles is inevitable, and CWT helps to clear the metabolic products [27]. The cold water immersion allows the peripheral blood vessels to contract, and warm water allows peripheral blood vessels to relax. The alternating cycles create a pumping effect on the blood vessels, thus increasing vascular elasticity, promoting metabolism, and excreting metabolic products and inflammatory mediators produced by exercise through blood flow perfusion. In addition, the hydrostatic pressure of water also contributes to the clearance of metabolic products. The water pressure applied to the skin is deeply transmitted to the tissues around the arterioles, thereby reducing the transmural pressure gradient of blood. The decrease in pressure gradient can cause arterial dilation (myogenic response), associating with reduced peripheral resistance, increased blood flow per unit time, higher oxygen level, and nutrient transport in working muscles. This mechanism ultimately facilitates the recovery from fatigue.

Joint reaction angle to release can reflect the response speed of joint and muscle to sudden stimulation (naturally falling due to gravity). The proprioceptive receptors sense the stimulation and transmit impulses, which are transmitted through the somatosensory center of the cerebral cortex, causing joint and muscle reaction. This reflects the control and reaction ability of the knee joint under stress conditions [28] and can be used as an evaluation index for knee joint motion perception. Studies have shown that the starting angle of the knee joint has a significant impact on the joint reaction angle, and the 'reaction is most sensitive when the angle between the knee joint and the horizontal line is about 15°. Therefore, this angle of 15° was used as the starting position for testing in this study. The data revealed a significant decrease in joint reaction angle during limb descent after centrifugal exercise, indicating a decrease in reaction sensitivity. It reaches its lowest point 24 hours after exercise and gradually recovers, which is consistent with previous research results [29]. Comparison between group found that at 24 and 48 hours after exercise, the joint reaction angles in the CWT group were smaller than those in the control group, indicating that CWT is beneficial for the recovery of joint reaction.

The limitations of this study are as follows. First, the ground that the sprinters in this study came into contact with was the laboratory ground, which differs from that of the actual outdoor training or competition venue. Second, this study was conducted through both kinematics and dynamics; however, it was not performed from the perspective of electromyography. Third, the test movements in this study only focused on high intensity training. Although these are common movements in sprinters' trainings, the forms of movement in this study were limited.

In conclusion, our study demonstrates that CWT can effectively alleviate the decline in muscle force sense caused by muscle centrifugation during high-intensity training, promote the recovery of muscle proprioception, alleviate post-exercise fatigue, and enhance the recovery of knee joint function. These findings provide experimental evidence for preventing knee joint injury and minimizing risk in sprinters during training.

Disclosure of conflict of interest

None.

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