

RESEARCH

The Effect of Cryotherapy on Balance Recovery at Different Moments after Lower Extremity Muscle Fatigue

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The purpose of this study was to investigate the influence of cryotherapy on the balance ability after lower extremity muscle fatigue. Twelve table tennis players were selected in this research. The static and dynamic balance abilities of the participants at six different moments were collected by a 1000 HZ Kistler force platform and Y balance test system. SPSS19.0 software was used to analyze the results of experimental indicators by selecting two-factor repeated measurement ANOVA. 1) From the moment of 24 h post intervention, the effect of cryotherapy on dynamic balance recovery was significantly better than no cryotherapy. 2) Except for the COP (Center of Pressure) maximum displacement on ML (Medium-Lateral axis) at the moment of 72 h post intervention, the cryotherapy had no positive effect on the recovery of static balance ability. 3) Cryotherapy has a significant negative impact on the COP maximum displacement in ML and AP (Antero-Posterior axis) at the moment of post cryotherapy, which may lead to the decline of static balance ability. It was not recommended to use cryotherapy for balance recovery if the competition was on the same day or within 24 h. However, the cryotherapy was recommended to use if the competition was in the next day or after the next day.

Keywords: cryotherapy; balance ability; center of pressure; muscle fatigue

Introduction

Cryotherapy as an emerging physiotherapy gradually accepted and used by more athletes and coaches, cryotherapy originate from Japan, the main application is to treat rheumatism clinical diseases (Westerlund 2009), and in the following nearly 30 years, especially in Europe and the United States and other countries began to develop rapidly (Westerlund et al. 2006; Cholewka et al. 2006; Vybiral et al. 2000; Lu et al. 2021). Application field also gradually extended from clinical medicine to sports medicine, and further application in the practice of sports training, it can be a good pain relief, speed recovery and reduce the inflammatory response after injury, so for athletes can be a good means of recovery. Cryotherapy has the characteristics of convenient operation, short treatment time, comfortable treatment process and remarkable therapeutic effect, and has been widely used in some developed countries and high-level sports teams (White & Well 2013). In-depth exploration of cryotherapy is of great significance for enriching the means of athlete fatigue recovery and injury prevention, and to exploring the internal mechanism of cryotherapy. In recent years, the development of table tennis competition level is more and more intense, athletes have to do a lot of active movement in a small area, in order to reach the target area in time to complete high-quality batting, which requires athletes to have a good balance ability, especially dynamic balance ability. In competitive sports and daily life, the ability to balance plays an important role. As a risk factor of sports injury, muscle fatigue is an important factor indirectly causing poor balance ability. Rose et al. reported the relationship between athletes' balance level and fatigue, pointing out that there was no difference in athletes' balance level when they were not tired, but there was a significant difference between the balance level of fatigued athletes and non-fatigued athletes (Rose et al. 2000).

In order to facilitate better study of the factors affecting the ability to balance, the balance ability is usually divided into static and dynamic balance ability. Static balance refers to the ability of the human body to maintain a posture or stabilize and control its own center of gravity in a relatively static state (Faraldo-García et al. 2016; Bressel et al. 2007; Song et al., 2020). Dynamic balance refers to the ability of the human body to automatically adjust and maintain its posture and control its balance when it is moving or being subjected to external forces (Wikstrom, Tillman & Borsa 2005). The balance system is composed of the nervous system, the perception system and the movement system, the physiological condition of each component will affect the ability to balance, so there are many physiological factors that can lead to the decline of balance ability, such as the decline of visual ability (Angunsri et al. 2011), damage to the vestibular organs (Hansson, Beckman & Håkansson 2010), nervous system fatigue, muscle strength decline (Gu et al., 2011; Granacher et al. 2013), it will lead to the reduction of balance ability. Several studies have investigated that muscle fatigue, as an important inducing factor leading to sports injury, is also one of the indirect factors leading to reduced balance ability. Suscod et al. (2004) investigated that balance problems often plague injured athletes, and injuries caused by muscle fatigue indirectly lead to poor balance (Susco et al. 2004). Rose et al. (2000) reported that the balance of injured athletes improves as muscle strength and endurance recover as they gradually recover (Rose et al. 2000). When the human body stands still, the body has been essentially around its own balance point in a state of constant shaking, and the subjective consciousness of the human body can't control this shaking, physiologically, this phenomenon is called physiological posture shake. By allowing the subjects to stand on a fixed force platform, the platform's high sensitivity force sensor can be used to record the body swings of participant, and after a series of analytical software processing, it is possible to calculate the static balance evaluation parameters to evaluate human balance. The evaluation parameters of static balance include the position of the center of gravity of participant, the maximum displacement of the center of gravity or the area of gravity movement path, and the ratio of the center of gravity parameters when the subjects are measured with closed eyes and open eyes (Cavalheiro 2009). Winter points out that when the body is static or slowly moving, COP (Center of Pressure) can approximate the body's center of gravity. Therefore, this study uses COP-related parameters as an indicator to assess participant' balance ability (Winter 1995).

In the highly competitive and tightly scheduled large-scale professional table tennis league, athletes need to complete a large number of competitions in a few days, which requires athletes to have better recovery to promote their athletic ability. The temperature range of cryotherapy is generally controlled from 0°C to 15°C, and the duration of action varies from 20 seconds to 45 minutes, depending on the movement and purpose. Fische et al. (2009) investigated that 3 minutes cryotherapy will not have a negative impact on the athletic ability of participant, however, when the action time exceeds 10 minutes, it will adversely affect the motor capability and output power of the speed sports group (Fischer et al. 2009). Cryotherapy is through the surface skin gradually to the deep muscles in the skin penetration cooling process (Merrick et al. 1993), which will be affected by different thicknesses of sebum insulation and human circulatory system stress reheating (Bonde-Petersen, Schultz-Pedersen & Dragsted 1992). Cryotherapy of short-time or low temperature will also affect the cooling degree of shallow and deep tissue, resulting in the cold treatment effect is not ideal, so the cryotherapy temperature in this study to choose a lower temperature of 0°C. The introduction should briefly place the study in a broad context and highlight why it is important.

There have been some studies on the effects of cryotherapy on sports performance and fatigue recovery, but there have been few studies of 0°C lower limb cryotherapy for athletes with lower limb muscle fatigue, and few studies that repeatedly measure lower limb balance at different times. Therefore, the purpose of this study is to explore the effect of cryotherapy on the lower limb balance ability of table tennis players after fatigue, the application of cryotherapy to recover after the lower limb muscle movement fatigue, and the moment of post warm-up, post fatigue, post intervention, 24 h post intervention, 48 h post intervention, and 72 h post intervention to collect static and dynamic balance ability indicators, to explore the role of cryotherapy to balance capacity at different times. It provides a theoretical basis for the application of cryotherapy recovery.

Methods

Participant

As shown in **Table 1**. Twelve table tennis players volunteered to participate in this study, all participant were belonged to the national level one. Participant with no lower limb muscle and joint sports injuries within 3 months before the experiment. In addition, the experimenter will fully inform the participants of the possible risks and requirements of the experiment to ensure that the participants are physically and mentally able to withstand the cryotherapy experiment. All participants were asked to avoid any moderate

Table 1: Table of demographic information of participants.

Height (cm)	Weight (kg)	History (years)	Age (years)	Leg length (cm)	Foot length (mm)	Foot width (mm)
175.17 ± 4.99	66.96 ± 4.44	9.58 ± 1.24	23 ± 1.65	90.79 ± 1.86	267.78 ± 5.04	102.07 ± 5.07

Note: The right leg of all participants was measured.

to vigorous physical activity and to follow a regular routine (no alcohol, caffeine and insomnia) two days before the study began.

Experimental Design

All participants were required to participate in two experiments: cryotherapy intervention (CI) and no intervention (CON). The first experimental was the CI, and in order to avoid possible influencing factors, the CON was three weeks later. In each single experiment, the balance ability of participants was measured at the six time points: post warm-up, post fatigue, post cryotherapy, 24 h post cryotherapy, 48 h post cryotherapy, and 72 h post cryotherapy. The temperature of the laboratory is uniformly controlled at 26°C through air conditioning. And the cryotherapy equipment (Chenhui Medical, Suzhou, China) in this study was cooled by a compressor and R134A tetrafluoroethane and an antifreeze fluid in the bladder were in contact with the skin. The lowest temperature of the cryotherapy equipment was -5°C, and the maximum working time of cryotherapy was 30 min. Therefore, the cryotherapy equipment was met the requirements of this experiment.

The participants first need to warm up at an adaptive speed for 4 minutes in the playground. After the warm up, the participants will have 2 minutes to fully familiarize themselves with the experimental environment and instruments. And then measured the balance ability of the dominant legs of the participants. After completing the pretest of the experimental indicators, the participants were subjected to exercise muscle fatigue modeling. The experimental indicators were measured again after fatigue. The experimental indexes were measured in a uniform order, the static balance ability index was collected first, and then the dynamic balance ability index was collected.

In the CI experiment, subjects were required to sit on the laboratory chair in a quiet state after fatigue modeling. Meanwhile, the experimenter wrapped the cryotherapy device on the thigh and lower leg of the subject's right leg. The temperature of CI in this study was set at 0°C. All subjects were wrapped in the same position to ensure full coverage of the thigh and lower leg area of the subject. The cryotherapy device was immediately attached to the subjects' limbs, and the experimenters recorded the time through a stopwatch. The intervention time was controlled for 10 minutes, during which the subjects were not allowed to drink or eat. When the stopwatch shows that the time is 10 minutes, the experimenter will remove the cryotherapy device from the subject's body, and the subject will measure the experimental indicators immediately.

In the CON experiment, after fatigue modeling, subjects were asked to sit on a chair in the laboratory in a quiet state. The intervention time was controlled for 10 minutes, and the experimenter recorded the time through a stopwatch. Subjects were not allowed to drink or eat during the intervention. At the end of the intervention, the subjects were asked to take measurements of the experimental indicators immediately.

Muscle Fatigue Model

After the participants have fully warmed up, they will be tested for maximum squat load. The participants will perform repeated squats with a weight of 50 KG. The barbell is required to position in the back deltoid muscle of the neck. The downward movement of the squat ends when the thigh is below the horizontal plane. During the whole process, participants' movements are supervised and protected by a professional physical fitness coach. The maximum strength of the participants was calculated by using Brzycki's (1990) 1 repetition maximum (RM) formula:

$$1RM \approx \frac{\omega}{1.0278 - (0.0278 * r)}$$

ω represents the weight of the barbell during squats, and r represents the total number of squats completed under the weight of the barbell. Referring to the motility muscle fatigue modeling method of Pearcey [2015] and MacDonald [2014] et al, 60% of 1 RM was uniformly selected as the exercise load of the experiment.

In a formal experiment, the participants performed 10 times *10 groups of weight-bearing squat training, and each group had 2-3 minutes of rest after the completion of the training. In addition, the time of each squat was

strictly controlled in this experiment. During the squat process (centrifugal movement), the time was controlled at 4 seconds to control the centrifugal contraction process of the lower limb muscles of the participants. At the end of the squat process, the thighs should be below the horizontal level and paused for 1 second to control the peak contraction process of the lower limb muscles. In the process of squatting, the time is strictly controlled at about 3 seconds to control the centripetal contraction process of the lower limb muscles of the participants. The time control of the whole process is carried out by the experimenter using a stopwatch.

Index and Calculation Method

The measurement of dynamic balance ability

YBT was used to measure the maximum extension reaching distance of participant in three directions of anterior, posteromedial, and posterolateral based on single leg standing. The right leg of all participants was selected as the standing leg. In the formal tests, repeat the test three times in each direction. The results are accurate to 0.5 cm. Retest if the following conditions occur during the test: 1) The standing leg deviates from the central footplate of YBT system; 2) The unstable center of gravity causes the reaching leg to touch the ground; 3) The reaching leg unable to back the starting position smoothly. The length of reaching leg during supine position was measured and recorded by experienced experimental (anterosuperior iliac spine to the center of the ipsilateral medial malleolus). Standardization of data: the reach distance in each direction was normalized to the leg length by calculating the maximized reach distance (%MAXD). %MAXD was used to evaluate the dynamic balance ability of the participant. The specific calculation formula (Lee et al. 2018) was: %MAXD = (anterior distance + posteromedial distance + posterolateral distance) / (3×leg length) × 100%.

The measurement of static balance ability

The static balance ability was evaluated by COP area, maximum displacement of COP on AP and ML, displacement velocity of COP on AP and ML. The data of COP track during the 30 seconds eye-opening single leg standing was collected by Kistler force platform (AMTI, Watertown, USA, sampling frequency of 1000 Hz). In order to avoid the influence of visual factors on the static balance ability of subjects with single-leg support, all subjects were required to focus their eyes on the two meter mark in front of them during the single-leg static balance test with eye-opening. The coordinates of each frame of COP was recorded by the force platform. Foot length and foot width were used to standardize the data.

The experimental indexes of static balance capacity are calculated as follows [Cavalheiro 2009]: 95% static COP area:

$$S_{APML} = \frac{1}{N} \sum_{i=1}^N AP(i) * ML(i)$$

$$D = \sqrt{(S_{AP}^2 + S_{ML}^2) - 4 * (S_{AP}^2 * S_{ML}^2 - S_{APML}^2)}$$

$$Major_{axis} = \sqrt{2 * (S_{AP}^2 + S_{ML}^2 + D)}$$

$$Minor_{axis} = \sqrt{2 * (S_{AP}^2 + S_{ML}^2 - D)}$$

$$Aera = \pi * Major_{axis} * Minor_{axis}$$

SAP and SML are the standard deviations of the distance between COP and AP and ML directions, SAPML is the covariance of the COP distance in the AP and ML.

The displacement velocity of COP in AP and ML:

$$V(n) = \frac{|d_{cop}(n+1) - d_{cop}(n)|}{T}$$

$$MV = \frac{1}{N-1} \sum_{i=1}^{N-1} v(i)$$

The displacement velocity of COP is obtained by calculating the average of all instantaneous velocities and finally all instantaneous velocities.

The maximum displacement of COP is calculated by calculating the difference between the maximum and minimum values in AP or ML. The formula is as follows: The maximum displacement in the ML = the

maximum value of X-axis – the minimum value of X-axis; The maximum displacement in the AP = the maximum value of Y-axis – the minimum value of Y-axis.

Experimental Intervention Method

The intervention of this experimental mainly included sitting recovery (CON) and cryotherapy recovery (CI). Subjects received sitting recovery and cryotherapy recovery in the same laboratory. The temperature of the laboratory was stabilized at 26°C by air conditioning, and the CI intervention temperature in this study was set at 0°C. After completing fatigue modeling and accepting CON intervention, subjects were required to sit in a laboratory chair in the same position in quiet state for 10 minutes. The intervention time was controlled by the experimenter through a stopwatch. During the intervention, subjects were not allowed to drink or eat. When the stopwatch shows the time as 10 minutes, the intervention is over, and the subjects are required to measure the experimental indicators immediately. After completing fatigue modeling and receiving CI, the subjects were asked to sit in the laboratory chair in the same position in the quiet state. Meanwhile, the experimenter wrapped the cryotherapy instrument on the subjects' right thigh and calf, and all subjects were wrapped in the same position to ensure that the subjects' thigh and calf areas were all covered. Immediately after the cryotherapy device was attached to the subjects' limbs, the experimenter recorded the time through a stopwatch, and the intervention time was controlled for 10 minutes. During the intervention, the subjects were not allowed to drink or eat. When the stopwatch shows that the time is 10 minutes, the experimenter will remove the cryotherapy device from the subject's limb and the subject will immediately measure the experimental indicator.

Data Statistics and Analysis

SPSS 21.0 statistical software (SPSS Inc., IL, USA) was used for statistical analysis of the collected data, which were expressed in the form of Mean \pm SD. All data in this study are programmed and calculated by Matlab2016a software. Determine whether the data of each group is normal based on the boxplot, and the Shapiro-Wilk test was used to determine whether the data of each group followed an approximate normal distribution. The Two-way Repeated Measures ANOVA to evaluate the subjects in different means of intervention and different points in time the change of dynamic balance and static balance ability. Mauchly's spherical hypothesis test was used to determine whether the data of each group met the spherical hypothesis. When Mauchly's spherical hypothesis is satisfied, the influence of interaction terms on the dependent variable is judged to be statistically significant. If Mauchly's spherical test was not satisfied, greenhouse-Geisser method was used to correct it and to judge again whether the influence of interaction terms on dependent variables was statistically significant. When the influence is statistically significant, the individual effects of factors within the study object should be analyzed one by one and Bonferroni pairwise comparison of Post-Hoc Analysis should be used for subsequent Analysis. If there is no statistical significance, the main effect of factors within the study object should be analyzed. When the main effect exists, pairwise comparisons are made. The significance level of this study was set as $P < 0.05$.

Results

Effect of cryotherapy on static balance recovery

Effect of cryotherapy on COP area

As shown in **Figure 1** and **Table 2**. Repeated measurement ANOVA was conducted for COP area. Mauchly's spherical hypothesis test found that interaction term group * time met the spherical test ($P = 0.509$), and the interaction between the two was not statistically significant, $F(5, 35) = 1.557$, $P = 0.237$. Therefore, it is necessary to further interpret the principal effect of group factors and time factors. If the principal effect of factors within the study object is greater than two levels, pairwise comparison should be carried out later. Since there are only two levels of grouping factors, there is no need to test whether the spherical hypothesis is true. The principal effect of group factors on COP area was not statistically significant, $F(1, 7) = 0.13$, $P = 0.912$. The principal effect of time factor on COP area was not statistically significant, $F(5, 35) = 1.992$, $P = 0.104$. The COP area of the CI was 5.788 (95% CI: -125.708 ~ 114.133) mm² smaller than that of the CON, and the difference was not statistically significant.

Effect of cryotherapy on the maximum displacement of COP in ML

As shown in **Figure 2** and **Table 3**. Repeated measurement ANOVA was performed for the maximum displacement of COP in ML. Mauchly's spherical hypothesis test found that interaction term group * time meets the spherical test ($P = 0.313$), and the interaction between them was significant, $F(5, 35) = 7.485$,

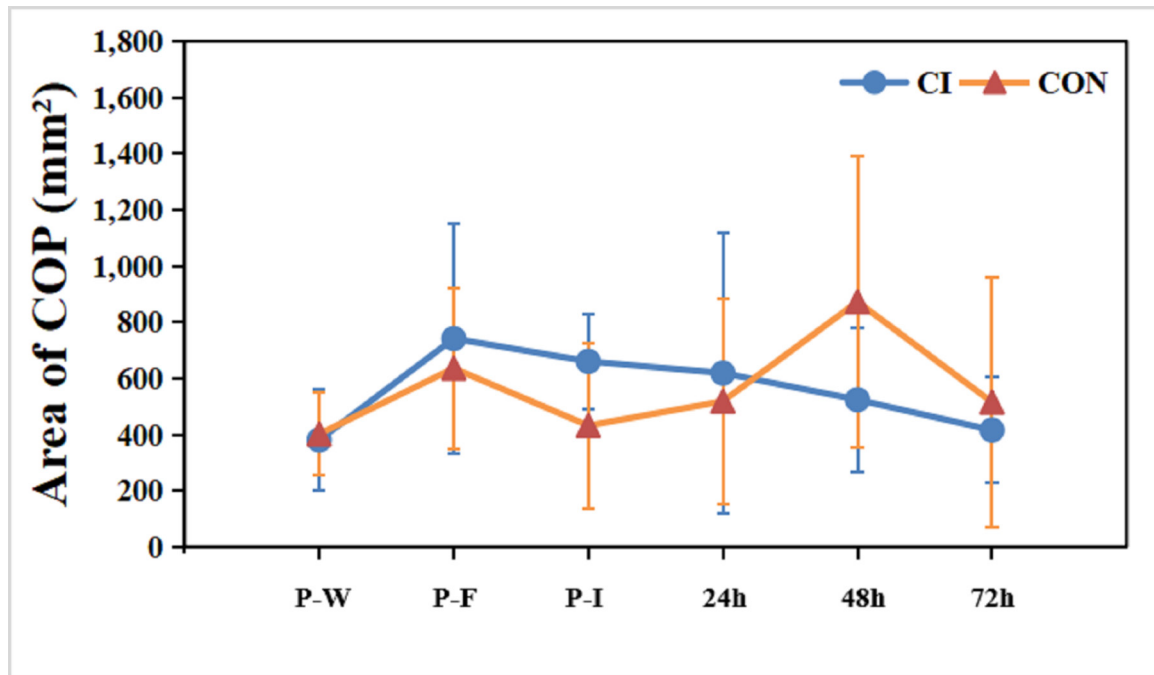


Figure 1: The difference of COP area between CI and CON at each moment.

Table 2: Table of COP area of two intervention at each moment.

COP area (mm ²)	①CI		②CON		P-value	Δ (①-②)
	Mean ± SD	95% CI	Mean ± SD	95% CI		
Post warm up	380.43 ± 179.10	[230.694–530.161]	401.68 ± 148.06	[277.897–525.455]	0.912	-5.788
Post fatigue	741.44 ± 409.30	[399.259–1083.623]	635.56 ± 287.52	[395.189–875.936]		
post intervention	660.15 ± 169.63	[518.337–801.968]	431.70 ± 294.44	[185.542–677.863]		
24 h Post intervention	618.55 ± 501.74	[199.086–1038.02]	518.14 ± 366.19	[211.998–824.286]		
48 h Post intervention	523.66 ± 257.03	[308.779–738.546]	872.63 ± 516.23	[441.049–1304.21]		
72 h Post intervention	415.71 ± 187.73	[258.771–572.658]	514.96 ± 445.14	[142.819–887.111]		
RM ANOVA	Whether the spherical hypothesis is satisfied? Yes (P = 0.509)		F (5, 35) = 1.557		The interaction was not significant (P = 0.237)	

$P < 0.001$. Therefore, separate effect tests for group and time factors are needed further. Simple effect analysis of group factors found that the group factor at 72 h post intervention had a statistically significant effect on the maximum displacement of COP in the ML. The maximum displacement of COP on ML in CI was smaller than that in CON, and there was a significant difference ($P = 0.005$, $F(1, 7) = 16.433$). The time factor of CI met the spherical test ($P = 0.068$). The intrasubjective effect test showed that the influence of time factor on the maximum displacement of COP in ML was statistically significant in the CI, $P = 0.001$, $F(5, 35) = 5.027$, so another pairwise comparison of six time points was needed. After the simple effect analysis of the time factor, it was found that the maximum displacement of COP in the ML at the moment of post warm up was less than post intervention in the CI, and there was a significant difference ($P = 0.007$). The time factor of the CON met the spherical test ($P = 0.195$), and the intrasubjective effect test showed that the influence of time factor on the maximum displacement of COP in the ML was not statistically significant ($P = 0.053$, $F(5, 35) = 2.449$).

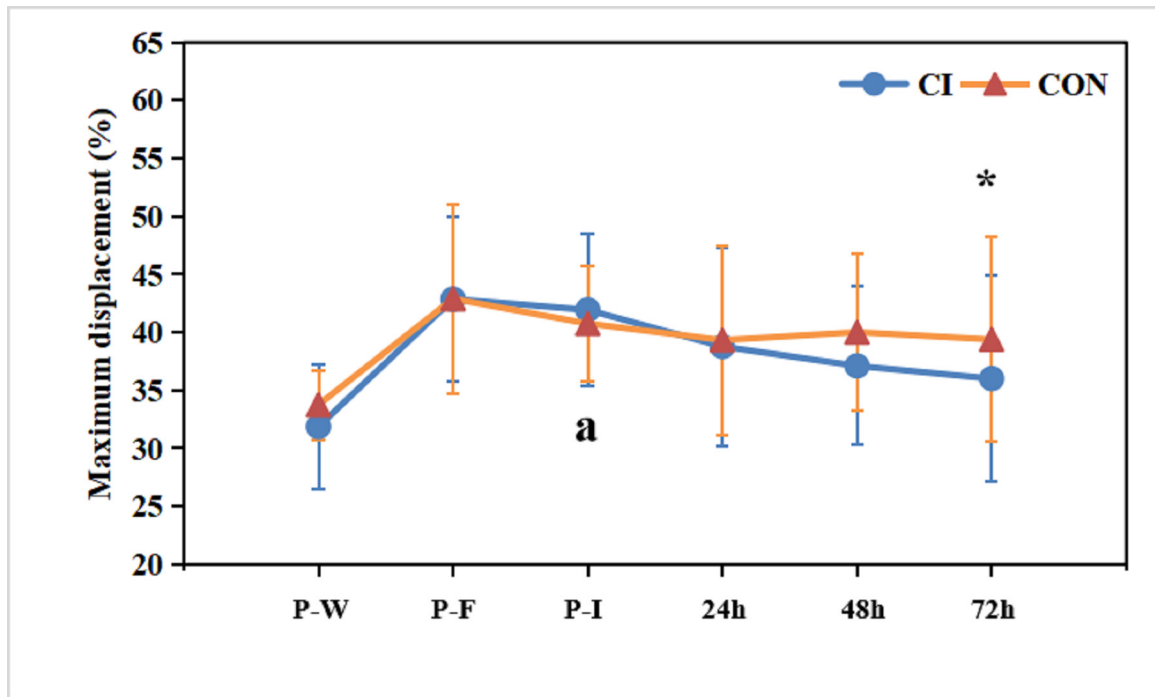


Figure 2: The difference of COP maximum displacement in ML between CI and CON at each moment. Note: “a” indicates that there is a significant difference between the moment of post warm up and other moments (post fatigue, post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention). “*” indicates that there was a significant difference between the CI and the CON.

Table 3: The COP maximum displacement of the two intervention at each moment in ML.

Maximum displacement (%)	①CI		②CON		P-value	Δ (①-②)
	Mean ± SD	95% CI	Mean ± SD	95%CI		
Post warm up	31.88 ± 5.38	[27.374–36.376]	33.75 ± 3.01	[31.232–36.268]	0.243	-1.875
Post fatigue	42.87 ± 7.15	[36.898–48.849]	42.90 ± 8.16	[36.075–49.723]	0.991	-0.025
post intervention	41.94 ± 6.58a	[36.439–47.446]	40.76 ± 4.98	[36.596–44.922]	0.653	1.184
24 h post intervention	38.78 ± 8.57	[31.615–45.936]	39.33 ± 8.17	[32.506–46.160]	0.853	-0.557
48 h post intervention	37.11 ± 6.84	[31.396–42.825]	40.01 ± 6.71	[34.401–45.618]	0.106	-2.899
72 h post intervention	36.01 ± 8.88*	[28.585–43.439]	39.39 ± 8.85	[31.993–46.784]	0.005	-3.376*
RM ANOVA	Whether the spherical hypothesis is satisfied? Yes (P = 0.313)		F (5,35) = 7.485		The interaction was significant (P < 0.001)	

Note: “a” indicates that there is a significant difference between the moment of post warm up and other moments (post fatigue, post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention). “*” indicates that there was a significant difference between the CI and the CON.

Effect of cryotherapy on the maximum displacement of COP in the AP

As shown in **Figure 3** and **Table 4**. Repeated measurement ANOVA was performed for the maximum displacement of COP in AP. The interaction item group * time met the spherical test (P = 0.053), and the interaction was significant, F (5, 35) = 4.110, P = 0.005. Therefore, separate effect tests for group and time factors are needed further. After simple effect analysis of group factors, it was found that the influence of group factors on the maximum displacement of COP in AP was not statistically significant (P = 0.407). Simple effect analysis of the time factor showed that the time factor in the CI did not meet the spherical hypothesis (P = 0.016). After greenhouse-geisser correction, the influence of the time factor on the maximum displacement of COP in the AP was statistically significant (P = 0.015, F (5, 35) = 4.966). It was found that the maximum displacement of COP in AP at the moment of post warm up in the CI was less than post

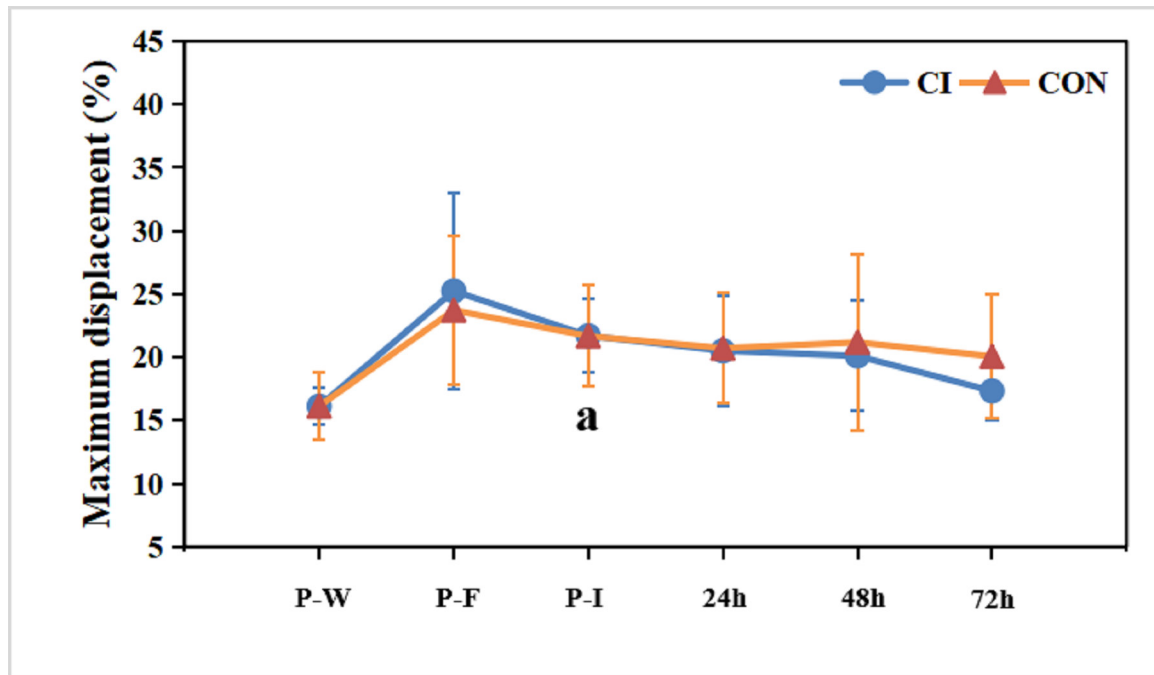


Figure 3: The difference of COP maximum displacement in AP between CI and CON at each moment. Note: “a” indicates that there is a significant difference between the moment of post warm up and other moments (post fatigue, post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention).

Table 4: The COP maximum displacement of the two intervention at each moment in AP.

Maximum displacement (%)	①CI		②CON		P-value	Δ (①–②)
	Mean ± SD	95% CI	Mean ± SD	95% CI		
Post warm up	16.13 ± 1.46	[14.906–17.344]	16.13 ± 2.64	[13.916–18.334]	1	0
Post fatigue	25.25 ± 7.74	[18.780–31.717]	23.72 ± 5.92	[18.770–28.673]	0.457	1.527
Post intervention	21.70 ± 2.91 ^a	[19.269–24.128]	21.68 ± 4.02	[18.315–25.037]	0.988	0.022
24 h post intervention	20.51 ± 4.39	[16.838–24.178]	20.72 ± 4.34	[17.088–24.349]	0.903	–0.211
48 h post intervention	20.10 ± 4.36	[16.456–23.753]	21.18 ± 7.00	[15.324–27.036]	0.752	–1.076
72 h post intervention	17.34 ± 2.32	[15.395–19.280]	20.06 ± 4.87	[15.995–24.134]	0.211	–2.728
RM ANOVA	Whether the spherical hypothesis is satisfied? Yes (P = 0.053)		F (5, 35) = 4.110		The interaction was significant (P = 0.005)	

Note: “a” indicates that there is a significant difference between the moment of post warm up and other moments (post fatigue, post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention).

intervention, and there was a significant difference ($P = 0.023$). The time factor in the CON met the spherical hypothesis ($P = 0.195$), and the intrasubjective effect test showed that the time factor in the CON had no statistical significance on the maximum displacement of COP in the AP ($P = 0.053$, $F(5, 35) = 2.449$).

Effect of cryotherapy on the displacement velocity of COP in the ML

As shown in **Figure 4** and **Table 5**. The displacement velocity of COP in ML was analyzed by repeated measurement ANOVA. The interaction group * time met the spherical test ($P = 0.067$), and the interaction between the two groups was not statistically significant, $F(5, 35) = 0.968$, $P = 0.45$. Therefore, separate effect tests for group and time factors are needed further. If the principal effect of factors within the study subjects is greater than two levels, subsequent pairwise comparisons are required. Since the group factor has only two levels, there is no need to test whether the spherical hypothesis is met. The principal effect of group factors on the displacement velocity of COP in the ML was not statistically significant, $F(1, 7) = 0.033$, $P = 0.860$. The

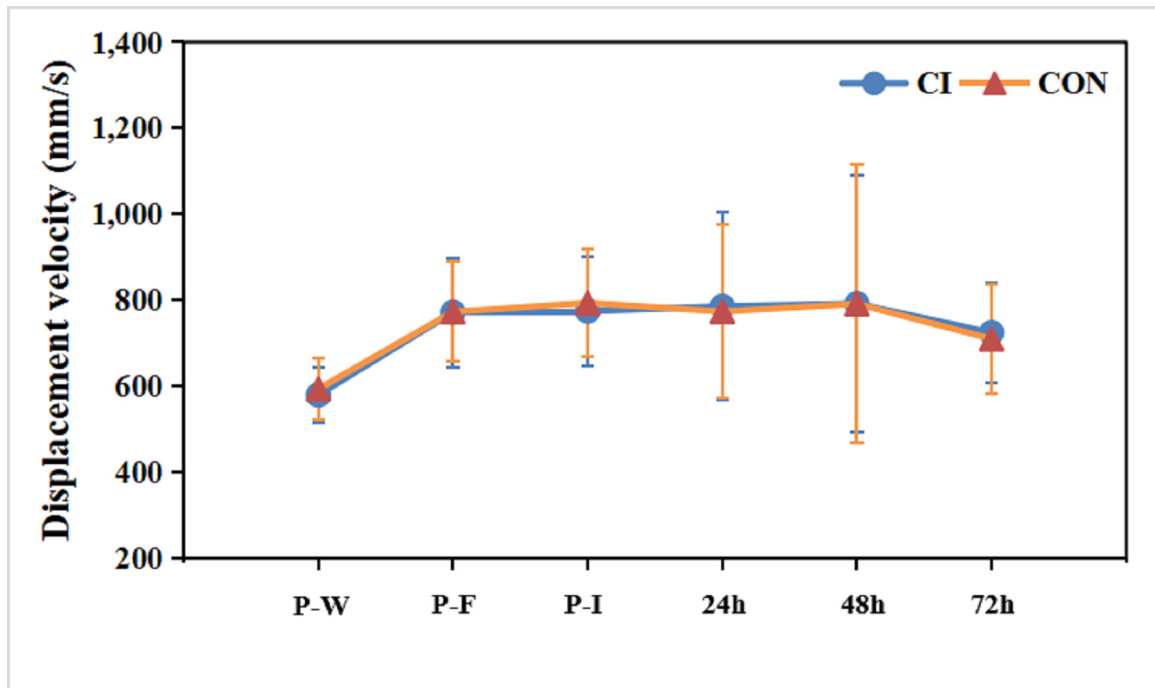


Figure 4: The difference of COP displacement velocity in ML between CI and CON at each moment.

Table 5: The COP displacement velocity of the two intervention at each moment in ML.

Displacement velocity (mm/s)	①CI		②CON		P-value	Δ(①-②)
	Mean ± SD	95% CI	Mean ± SD	95% CI		
Post warm up	579.72 ± 65.48	[524.979–634.468]	593.50 ± 71.92	[533.378–653.630]	0.86	-1.098
Post fatigue	772.05 ± 127.01	[665.861–878.229]	772.95 ± 116.02	[675.954–869.937]		
post intervention	774.56 ± 127.33	[668.112–881.007]	793.34 ± 125.11	[688.740–897.934]		
24 h Post intervention	785.67 ± 218.65	[602.879–968.470]	773.72 ± 203.16	[603.875–943.560]		
48 h Post intervention	791.77 ± 298.87	[541.907–1041.626]	791.48 ± 322.49	[521.874–1061.094]		
72 hPost intervention	724.57 ± 117.08	[626.687–822.454]	709.94 ± 128.52	[602.491–817.389]		
RM ANOVA	Whether the spherical hypothesis is satisfied? Yes (P = 0.067)		F (5, 35) = 0.968		The interaction was no significant (P = 0.45)	

principal effect of time factor on the displacement velocity of COP in the ML was not statistically significant, $F(5, 35) = 2.227, P = 0.073$. The displacement velocity of COP in the CI on the ML was 1.098 (95%CI: -15.325 ~ 13.128) mm/s smaller than the CON, but the difference was not statistically significant.

Effect of cryotherapy on the displacement velocity of COP in AP

As shown in **Figure 5** and **Table 6**. The displacement velocity of COP in AP was analyzed by repeated measurement ANOVA. The interaction group * time met the spherical test ($P = 0.704$), and the interaction was not statistically significant, $F(5, 35) = 1.326, P = 0.276$. Therefore, separate effect tests for group and time factors are needed further. If the principal effect of factors within the study subjects is greater than two levels, subsequent pairwise comparisons are required. Since the group factor has only two levels, there is no need to test whether the spherical hypothesis is met. The principal effect of group factors on the displacement velocity of COP in the AP was not statistically significant, $F(1, 7) = 0.273, P = 0.618$. The principal effect of time factor on the displacement velocity of COP in AP was not statistically significant,

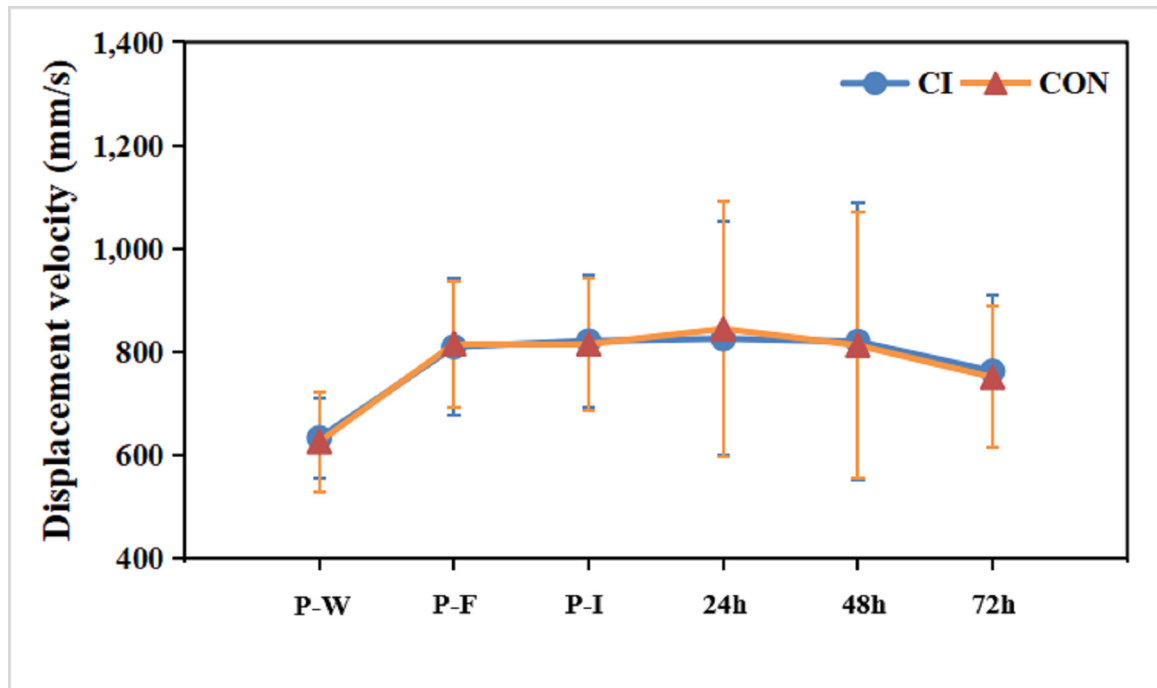


Figure 5: The difference of COP displacement velocity in AP between CI and CON at each moment.

Table 6: The COP displacement velocity of the two intervention at each moment in AP.

Displacement velocity (mm/s)	CI		②CON		P-value	Δ(①-②)
	Mean ± SD	95% CI	Mean ± SD	95% CI		
Post warm up	633.411 ± 27.647	[568.037–698.784]	625.903 ± 34.089	[545.296–706.510]	0.618	1.395
Post fatigue	809.653 ± 46.837	[698.901–920.406]	815.240 ± 43.338	[712.763–917.717]		
post intervention	821.016 ± 45.384	[713.700–928.332]	814.846 ± 45.505	[707.243–922.449]		
24 h Post intervention	825.317 ± 80.098	[635.916–1014.718]	844.387 ± 87.485	[637.519–1051.255]		
48 h Post intervention	819.955 ± 94.528	[596.432–1043.477]	812.482 ± 91.238	[596.739–1028.225]		
72 h Post intervention	762.436 ± 52.411	[638.505–886.367]	750.560 ± 48.440	[636.019–865.101]		
RM ANOVA	Whether the spherical hypothesis is satisfied? Yes (P = 0.704)		F (5, 35) = 1.326		The interaction was no significant (P = 0.276)	

F (5, 35) = 2.106, P = 0.088. The displacement velocity of COP in AP in the CI was 1.395 (95%CI: -4.922 ~ 7.712) mm/s higher than the CON, and the difference was not statistically significant.

Effect of cryotherapy on dynamic balance recovery

As shown in **Figure 6** and **Table 7**. The dynamic balance was analyzed by repeated measurement ANOVA. The interaction item group * time met the spherical test (P = 0.198), and the interaction was significant, F (5, 35) = 15.004, P < 0.001. Therefore, separate effect tests for group and time factors are needed further. After simple effect analysis of group factors, it was found that the group factors 24 h post intervention had a significant impact on dynamic balance ability, and the score of dynamic balance ability of the CI was higher than CON, with significant differences (P = 0.004, F (1, 7) = 18.142). The group factors at 48 h post intervention had a significant influence on dynamic balance ability. The score of dynamic balance ability in

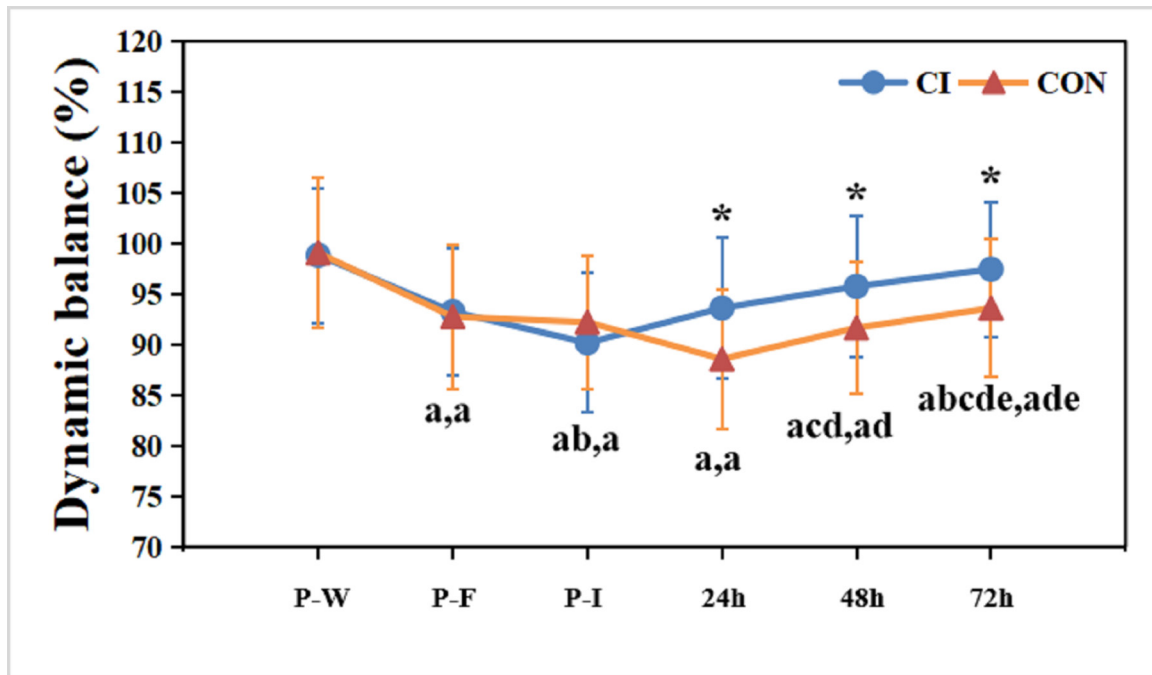


Figure 6: The difference of dynamic balance between CI and CON at each moment. Note: “a” indicates that there is a significant difference between the moment of post warm up and other moments (post fatigue, post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention). “b” indicates that there is a significant difference between the moment of post fatigue and other moments (post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention). “c” indicates that there is a significant difference between the moment of post intervention and other moment (24 h post intervention, 48 h post intervention and 72 h post intervention). “d” indicates that there is a significant difference between the moment of 24 h post intervention and other moment (48 h post intervention and 72 h post intervention). “e” indicates that there is a significant difference between the moment of 48 h post intervention and the moment of 72 h post intervention. “*” indicates that there was a significant difference between the CI and the CON.

Table 7: Table of dynamic balance of the two intervention at each moment.

Dynamic balance (%)	①CI		②CON		P-value	Δ(①-②)
	Mean ± SD	95%CI	Mean ± SD	95%CI		
Post warm up	98.83 ± 6.69	[93.24–104.42]	99.07 ± 7.38	[92.90–105.24]	0.643	-0.239
Post fatigue	93.26 ± 6.34 ^a	[87.96–98.56]	92.76 ± 7.13 ^a	[86.80–98.73]	0.232	0.499
post intervention	90.17 ± 6.87 ^{ab}	[84.43–95.92]	92.22 ± 6.61 ^a	[86.69–97.75]	0.145	-2.046
24 h Post intervention	93.62 ± 6.92 ^{a*}	[87.83–99.41]	88.57 ± 6.90 ^a	[82.81–94.34]	0.004	5.049*
48 h Post intervention	95.77 ± 6.94 ^{acd*}	[89.97–101.57]	91.65 ± 6.55 ^{ad}	[86.17–97.13]	0.002	4.113*
72 h Post intervention	97.46 ± 6.69 ^{abcde*}	[91.87–103.05]	93.61 ± 6.84 ^{ade}	[87.89–99.33]	0.001	3.857*
RM ANOVA	Whether the spherical hypothesis is satisfied? Yes (P = 0.198)			F (5, 35) = 15.004	The interaction was significant (P = 0)	

Note: “a” indicates that there is a significant difference between the moment of post warm up and other moments (post fatigue, post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention). “b” indicates that there is a significant difference between the moment of post fatigue and other moments (post intervention, 24 h post intervention, 48 h post intervention and 72 h post intervention). “c” indicates that there is a significant difference between the moment of post intervention and other moment (24 h post intervention, 48 h post intervention and 72 h post intervention). “d” indicates that there is a significant difference between the moment of 24 h post intervention and other moment (48 h post intervention and 72 h post intervention). “e” indicates that there is a significant difference between the moment of 48 h post intervention and the moment of 72 h post intervention. “*” indicates that there was a significant difference between the CI and the CON.

the CI was higher than CON, and there were significant differences ($P = 0.002$, $F(1, 7) = 21.284$). At 72 h post intervention, the group factors had a significant impact on dynamic balance. The score of dynamic balance in the CI was higher than CON, and there were significant differences ($P = 0.001$, $F(1, 7) = 27.354$). After the simple effect analysis of the time factor, it was found that the CI did not meet the spherical hypothesis ($P = 0.001$). After greenhouse-geisser correction, the influence of the time factor on the dynamic balance was statistically significant, $F(5, 35) = 46.508$, $P < 0.001$. Pairwise comparisons are required at six more time points. In the CI, Post fatigue ($P < 0.001$), post intervention ($P < 0.001$), 24 h post intervention ($P < 0.001$), 48 h post intervention ($P = 0.001$), 72 h post intervention ($P = 0.016$) and the scores of dynamic balance post warm-up were significantly different. There were significant differences between post fatigue and post intervention ($P = 0.046$) and 72 h post intervention ($P = 0.009$). There were significant differences between post fatigue and 48 h post intervention ($P = 0.005$) as well as 72 h post intervention ($P = 0.001$). The moment of 24 h post intervention, 48 h post intervention ($P = 0.001$), and 72 h post intervention ($P < 0.001$) there were significant differences. Besides, there was a significant difference between 48 h post intervention and 72 h post intervention ($P = 0.006$). The simple effect analysis of time factors found that the CON met the spherical hypothesis ($P = 0.171$), so the impact of time factors on dynamic balance in the CON was statistically significant. Pairwise comparisons are required at six more time points. In the CON, post fatigue ($P = 0.007$) and post intervention ($P < 0.001$), 24 h post intervention ($P < 0.001$), 48 h post intervention ($P = 0.001$), 72 h post intervention ($P = 0.001$), and the scores of dynamic balance at post warm-up were significantly different. There were significant differences between 24 h post intervention, 48 h post intervention ($P = 0.010$) and 72 h post intervention ($P = 0.004$). And there was a significant difference between 48 h post intervention and 72 h post intervention ($P = 0.044$).

Discussion

This research through the CI and CON two ways to professional table tennis players after lower limb exercise fatigue recovery intervention, by measuring the athletes' static balance and dynamic balance ability at six moments change, and to explore the cryotherapy for professional table tennis players, the influence of recovery after lower limb exercise fatigue, from the perspective of biomechanics, further reveals the human body after exercise fatigue recovery mechanism. This study aims to provide powerful theoretical guidance and support for coaches and athletes to choose more effective recovery methods after exercise fatigue. The innovation of this study is that 1) The cryotherapy instrument was used to perform cryotherapy at 0°C on the thighs and calves of subjects after fatigue of lower limb muscles. 2) cryotherapy instrument can put the accurate temperature control at 0°C, make up for the research blank of this temperature, provide theoretical basis for the researchers. 3) researches on table tennis players' static balance ability and dynamic balance ability are few, and this study further enriches the research content in this field. The main results of this study are as follows: 1) Under the intervention of CI and CON, the COP area of athletes showed no difference at six moments. 2) At the moment of 48 and 72 hours post intervention, YBT was significantly improved in both the CI and CON, and the recovery effect of the CI was significantly better than CON. Moreover, 24 h post intervention, the CI showed significantly better dynamic balance recovery effect than the CON. 3) At the moment of post intervention, the maximum displacement of COP in the AP and ML of CI was significantly greater than the post warm-up, showing poor recovery. 4) At the moment of 72 h post intervention, the maximum displacement of COP of the CI in ML was significantly less than CON, showing a good recovery. The main results of this study are discussed in detail below.

Effect of cryotherapy on static balance

The results of this study showed that the maximum displacement of COP in AP and ML at the moment of post intervention was significantly greater than the post warm up in CI, which indicated that the static balance ability of CI did not recover to the pre-exercise level at the moment of post intervention. This result has been supported by previous studies. Kernozek et al. (Kernozek et al. 2008) investigated that the static COP wobble in the ML was significantly enhanced after cryotherapy was applied to a group of subjects with lateral ankle sprain. Fukuchi et al. (Fukuchi et al. 2014) reported that under bipedal standing conditions, cryotherapy increased COP standard deviation and velocity in the ML. The COP displacement velocity in AP and ML was higher after cryotherapy under the condition of one-legged standing. This means that cryotherapy would result in negative effects before more challenging postural control activities. Macedo et al. (2016) explored the effect of cryotherapy on electromyographic response and balance of lower limb during monopod jump landing, they investigated that cryotherapy increased the amplitude and average velocity of COP.

In many competitive sports competitions, athletes are usually treated with cryotherapy immediately after physical injury (Covington & Bassett 1993). After cryotherapy for an acute knee injury, the athlete can return to training or competition (Oliveira, Ribeiro & Oliveira 2010). There is some physiological and clinical evidence that cold compresses can effectively reduce nerve conduction velocity (Kanlayanaphotporn 2005), muscle power and muscle strength generation (Sargeant 1987). For every 1°C in skin temperature, nerve conduction velocity slows down by 1.5 to 2 meters per second [Rutkove 2001], and for every 1°C decrease in muscle temperature, muscle spindle discharge rate decreases by 1–3 pulses per second (Eldred, Lindsley & Buchwald 1960). The decrease of the static balance control ability at the moment of post intervention is probably because of cryotherapy result in the human body sensors of proprioception loss, which may lead to the change of the posture stability (Fukuchi et al. 2014; Magnusson et al. 1990). And because of the nerve conduction velocity after cryotherapy may damage (Algaflly & George 2007), the ability of muscles to control and adjust posture after the body balance is disrupted may also be affected. Cryotherapy has been shown to reduce incoming somatic sensory information from the knee joint. Hopper et al. (1997) found that application of cryotherapy to the ankle resulted in a significant decrease in ankle proprioception, while application of cryotherapy to the knee resulted in less change in knee proprioception, but this subtle reduction in proprioception can lead to a decline in static and dynamic balance on the field.

At the moment of 72 h post intervention, the maximum displacement of COP in the CI on the ML was significantly less than CON, showing a good recovery. Due to the fatigue of lower limb muscles, athletes will suffer from joint relaxation and proprioception decline, which will lead to the decline of joint stability. However, rapid cryotherapy after fatigue can reduce body energy consumption, improve joint stiffness and activate the central regulation mechanism (Steib 2013). Furthermore, at the moment of post 72 h of intervention, the recovery of dynamic balance ability was improved with the elimination of fatigue.

Effect of cryotherapy on dynamic balancing

Table tennis is a competitive sport played on a small field, which requires players to run continuously in a small range during playing. At the same time, players need to complete a series of instantaneous explosive movements and change direction quickly and frequently in the process of continuous movement in order to achieve the purpose of effective hitting (Pradas et al. 2005; Le Mansec et al. 2018; Zhou et al. 2021). Table tennis is characterized by fast speed, varied rotation, and small size of the ball (He et al. 2020; He et al. 2021), which is a great test for players' rapid reaction ability, stride speed, strength and endurance quality. The center of gravity of mastering transformation is the key point of footwork skill in table tennis, footwork movement balance to keep the body in the trunk and reasonable position, to ensure the stability of barycenter, to avoid large fluctuation of center of gravity in up and down direction, the focus of the substantial guarantee for athletes in a fast moving high quality shots provides stable body support. In addition, the balance of the torso provides guarantee for the athlete to start and brake quickly. Therefore, good posture adjustment ability is not only conducive to reducing the occurrence of sports injuries, but also conducive to improving the quality of technical movements of table tennis players. In this study, the YBT performance of the participants at different moments were used to evaluate the effect of cryotherapy recovery on table tennis players' dynamic balance ability.

At the moment of 24 h, 48 h, 72 h post intervention, the CI has a significant positive effect on dynamic balance ability of players that compared with CON. The YBT performance of players at 72 h post intervention was significantly better than 48 h post intervention. This indicated that cryotherapy began to positively promote the dynamic balance ability of athletes at 24 h post fatigue of lower limb muscle, and the promoting effect lasted until at 72 h post intervention. However, the YBT performance of players at the moment of post intervention were significantly lower than the post fatigue in CI. These results indicated that the dynamic balance ability of athletes decreased further after cryotherapy, which is consistent with some previous studies. Montgomery et al. (2015) investigated that 10 minutes of CI below the hip joint at 12°C significantly reduced the dynamic balance ability of participant. The study of Kernozek et al. (2008) showed that after cryotherapy on participants with lateral ankle sprains, mediolateral swing variability increased. In the YBT, the farther the subjects touched, the greater their neuromuscular strength, proprioceptive control, and range of joint motion (Olmsted et al. 2002). Any disturbance to the body of these factors can impair balance, and cold stimulation as a disturbance will result in reduced blood flow to the extremities. This redistribution of blood flow may damage neuromuscular and somatosensory components that are important for performing dynamic sensory tasks such as balance and strength (Asmussen et al. 1976; Faulkner et al. 1990; Hensel & Zotterman 1951).

Conclusion

This study further reveals the timeliness impact of cryotherapy on the recovery of human balance ability. The results of this study will provide guidance for clinical medicine, sports rehabilitation and sports teams in the treatment of patients and training. 1) CI had significant negative effects on both static and dynamic balance ability of table tennis players at the moment of post intervention. 2) From the moment of 24 h post intervention, the effect of CI on dynamic balance recovery was significantly better than CON. 3) Except for the maximum displacement of COP on ML at the moment of 72 h post intervention, CI had no positive effect on the recovery of athletes' static balance ability. It is not recommended to use CI as the recovery method for balance ability if the competition is on the same day or within 24 hours. But the CI was recommended to use if the competition on the next day or after the next day.

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Competing Interests

The authors have no competing interests to declare.

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