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Research article

Warm-Up Intensity and Time Course Effects on Jump Performance

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Abstract

Jump performance is affected by warm-up intensity and body temperature, but the time course effects have not been thoroughly investigated. The purpose of this study was to investigate time course effects on jump performance after warm-up at different intensities. Nine male athletes (age: 20.9 ± 1.0 years; height: 1.75 ± 0.03 m; weight: 66.4 ± 6.3 kg; mean ± SD) volunteered for this study. The participants performed three warm-ups at different intensities: 15 min at 80% $\dot{V}O_2$ max, 15 min at 60% $\dot{V}O_2$ max, and no warm-up (control). After each warm-up, counter movement jump (CMJ) height, vastus lateralis temperature, heart rate and subjective fatigue level were measured at three intervals: immediately after warm-up, 10 min after, and 20 min after, respectively. Significant main effects and interactions were found for muscle temperature (intensity: $p < 0.01$, $\eta^2_p = 0.909$; time: $p < 0.01$, $\eta^2_p = 0.898$; interaction: $p < 0.01$, $\eta^2_p = 0.917$). There was a significant increase of muscle temperature from the baseline after warm-up, which lasted for 20 min after warm-up with 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max ($p < 0.01$). Muscle temperature was significantly higher with warm-up at 80% $\dot{V}O_2$ max than other conditions ($P < 0.01$). Significant main effects and interactions for CMJ height were found (intensity: $p < 0.01$, $\eta^2_p = 0.762$; time: $p < 0.01$, $\eta^2_p = 0.810$; interaction: $p < 0.01$, $\eta^2_p = 0.696$). Compared with the control conditions, CMJ height after 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max warm-ups were significantly higher ($p < 0.01$ and $p < 0.05$, respectively). CMJ height at 20 min after warm-up was significantly higher for 80% $\dot{V}O_2$ max warm-up than for 60% $\dot{V}O_2$ max warm-up ($p < 0.01$). However, CMJ height at 10 min after 60% $\dot{V}O_2$ max warm-up was not significantly different from the baseline ($p < 0.05$). These results showed that both high and moderate intensity warm-up can maintain an increase in muscle temperature for 20 min. Jump performance after high-intensity warm-up was increased for 20 min compared to a moderate intensity warm-up.

Key words: Counter movement jump, muscle temperature, recovery, heart rate, perceived fatigue.

Introduction

Warm-up is carried out before exercise to prevent injuries and optimize the subsequent exercise performance. A number of studies have observed that warm-up improves sports performance, for events such as running (Byrne et al., 2014; Smith et al., 2014), jumping (Burkett et al., 2005; Holt and Lambourne, 2008), swimming (Neiva et al., 2014; West et al., 2013) and cycling (Munro et al., 2017; Thatcher et al., 2012; Wittekind and Beneke, 2011). Since the duration of endurance running was not changed by the effect of warm-up (Takizawa et al., 2018), warm-up may affect explosive exercise more than endurance exercise. Hence, 5-min running warm-up with 70 % of their predicted maximum heart rate improved jump performance (Andrade et al., 2015). Another study also revealed that a 4-min running warm-up at a pace to feel warm improved jump performance (3.1%) (Young and Behm, 2003). Thus, jump performance is enhanced by warm-up (Andrade et al., 2015; Young and Behm, 2003).

Warm-up usually consists of aerobic exercises as a general warm-up for increasing body and muscle temperature followed by stretching to increase mobility and specific exercises focusing on performance enhancement (Fradkin et al., 2010). Purported mechanisms of warm-up comprise increased muscle metabolism (Robergs et al., 1991), kinetics of oxygen uptake (VO_2) (Burnley and Jones, 2007) and post-activation potentiation (Derrenne, 2010). Previous studies have reported that increasing body temperature led to enhancement in ATP utilization and increase in type II muscle fiber recruitment (Gray et al., 2006; 2008). Further, Bishop (2003a) noted that muscle temperature and the transmission speed of nervous impulses are related, which indicates that muscle and nerve conduction speed may be accelerated by increased muscle temperature. Such studies suggest that an increase in body temperature achieved by warm-up would be strongly related to jump performance. Furthermore, muscle temperature increase was also positively related to improved vertical jump performance (Bergh and Ekblom, 1979).

Jump performance may be affected by warm-up intensity, duration as well as the subsequent resting period. Low-intensity warm-up may not improve jump performance due to insufficient rise in muscle temperature (Bishop, 2003a; 2003b). Conversely, high-intensity warm-ups were found to impair performance by muscle fatigue due to overheating (Bishop et al., 2001; Yaicharoen et al., 2012). One of the main reasons for warm-up is to increase muscle temperature (Racinais and Oksa, 2010), which is related to subsequent performance enhancement. Thus, insufficient warm-up duration can change subsequent performance. As such, it is important for athletes to perform their warm-up exercises at optimal intensity and duration in order to improve their jump performance. The resting period after warm-up is also important for jump performance. Body temperature is increased through exercise, and

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gradually drops within a few min while resting. From the research mentioned above, body temperature rise after exercise is also thought to affect jumping performance. Therefore, warm-up intensity, duration, and the resting time period are all considered to affect subsequent jump performance. Bishop (2003a) reported that although performance was enhanced by warm-up, this improvement effect gradually decreased after the end of the warm-up exercises. However, Bishop's review article (2003a) did not take warm-up intensity into account. The optimal degree of both warm-up intensity and resting period should be determined in order to achieve high performance in sports.

Thus, it is necessary to clarify optimal warm-up protocols depending on the characteristics of the sport. To the best of our knowledge, no studies have reported the effects of time course on jump performance at the resting period after warm-up with different intensities. Therefore, the purpose of this study was to investigate time course effects after warm-up with different intensities on jump performance.

Methods

Study design

We adopted a randomized cross-over design including three experimental sessions, as shown in Figure 1. On the first day, all participants' physical and physiological characteristics were assessed, and the participants then practiced jumping. From the second to fourth days, the participants performed one of three different intensity warm-ups (determined by their individual physiological assessment on the first day), and each outcome was measured. The three warm-up intensities consisted of 80% $\dot{V}O_2$ max (high intensity), 60% $\dot{V}O_2$ max (moderate intensity) and no warm-up (control). During the second to fourth days, the participants sat in a resting state for 10 min in order to reach an equivalent body temperature in the experimental environment after they came to the laboratory. Thereafter, the order of warm-up intensities performed was assigned randomly. The warm-up consisted of running on a treadmill for 15 min at a steady speed. After warm-up, each participant sat and rested, except for the jump test. The jump performance was evaluated by counter-movement jump (CMJ). Muscle (vastus lateralis) temperature, heart rate, and subjective fatigue levels were also assessed, in order to determine whether jump performance was affected by those factors. These measurements were taken before warm-up, immediately after, 10 min after, and 20 min after warm-up, respectively. Participants performed each test at the same times on different days. To avoid fatigue, the second experiment session was held for a week after the first day of the experiment, and the third and fourth days of the experiment were performed at least two days apart.

Participants

Nine male athletes who belonged to university sport teams and took part in national as well as provincial collegiate championships (age: 20.9 ± 1.0 years; height: 1.75 ± 0.03 cm; weight: 66.4 ± 6.3 kg; BMI: 21.7 ± 2.2 kg/m^2; $\dot{V}O_2$ max: 45.7 ± 3.1 ml/min/kg) volunteered for this study. The participants regularly play sports (six track and field (jump events) athletes, two basketball players, and one lacrosse player). Participants with orthopedic and neurological diseases were excluded. The participants were instructed to avoid intense exercise and alcohol consumption for a period of 24 hours before the experiment session, and to refrain from eating for two hours before each experiment session. The participants wore the same t-shirt, shorts and shoes throughout all experiments. All participants were provided with a verbal explanation as well as written documentation and were required to sign a consent form prior to enrolling. This study was approved by the local institutional ethics committee.

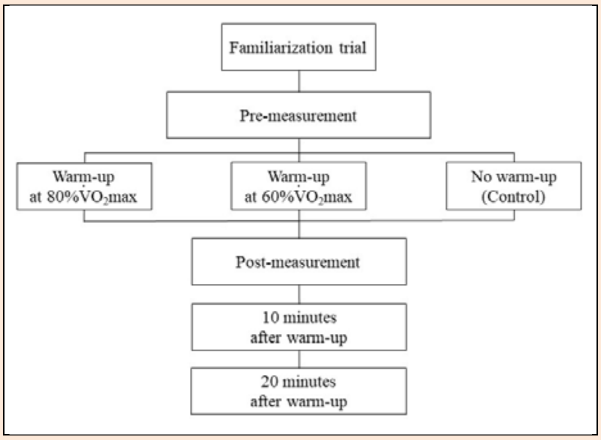

Figure 1. Study design.

Determination of warm-up intensity and lactate threshold (LT)

A treadmill (Auto-Runner 200, MINATO, Tokyo, Japan) was used for incremental exercise tests. The participants ran on a treadmill in a staged incremental exercise at 4 min per stage to assess maximal and submaximal capacity. The treadmill was started at 167 m/min (6 min/km) and then increased to 200 m/min (5 min/km), followed by 222 m/min (4 min 30 s/km), 250 m/min (4 min/km), 273 m/min (3 min 40 s/km), 300 m/min (3 min 20 s/km), 333 m/min (3 min/km), and 346 m/min (2 min 45 s/km) (Takizawa et al., 2018). The incremental exercise test was completed when either the oxygen uptake level reached a plateau, the respiratory quotient (RQ) was more than 1.1 (RQ is defined as the ratio of carbon dioxide production (VCO_2) divided by oxygen consumption ($\dot{V}O_2$)), or the subject was no longer able to run. Oxygen uptake was measured using a respiratory gas analyzer (AE–280, MINATO, Tokyo, Japan) every 10 seconds, and the final 30-second averaged data at each velocity was used to determine the warm-up intensity. The highest value during the incremental exercise was defined as the $\dot{V}O_2$ max, and the running velocity at 60% and 80% $\dot{V}O_2$ max was determined from the relationship between running velocity and oxygen uptake. During the one-min rest periods between each running set, blood samples were collected from fingertips, and blood lactate accumulation was examined using a portable lactic acid analyzer (Lactate Pro, LT-1710; Arkray, Kyoto, Japan). In addition, the running velocity at LT was calculated as the first inflection point of the blood lactate curve, using analysis software (Meqnet LT Manager, Arkray, Kyoto, Japan).

Data measurement

Vastus lateralis muscle temperature was measured with core body thermometer (Core temp CTM-205, Telmo, Tokyo, Japan) being attached with adhesion tapes throughout the experiment. Heart rate (HR) was measured using a portable heart rate monitor (RCX5, Polar, Kempele, Finland). Visual analog scale (VAS) was adopted to determine subjective fatigue levels (Lee et al., 1991). The VAS consisted of a 100mm horizontal line, labeled "no fatigue" at 0 and "too tired to walk" at 10.

After warm-up, each participant sat and rested, except for the jump test. The jump performance was evaluated by counter-movement jump (CMJ) height, with the participants' hands on their hips, estimated using a force plate (Ex-jumper, DKH Inc, Tokyo, Japan). The sampling frequency of the force plate was 1,000 Hz. Participants were verbally encouraged to jump as high as possible. Each participant performed CMJ twice, and the highest height was used for further analysis (Imai et al., 2016). The CMJ measurements' coefficient of variation (CV) and test-retest intraclass correlation coefficient (ICC) were 7.54% and 0.94, respectively.

Statistical analysis

G*Power software (version 3.1.9.6; University of Kiel, Kiel, Germany) was utilized to calculate the sample size needed for this repeated-measures study (Faul et al., 2007): a minimum sample size of 7 per group was required to reach a statistical power level ($1 - \beta$) of 0.80 based on an α level of 0.05 and a predicted effect size of 0.25.

Statistical analyses were performed using SPSS software (ver. 22, IBM, Chicago, USA). We used the Shapiro-Wilk test for testing normality. One-way repeated ANOVA was used to compare the variations in room temperature, humidity, and running velocity. Two-way repeated ANOVA (intensity [80% $\dot{V}O_2$ max, 60% $\dot{V}O_2$ max, control] × time [before warm-up, immediately after warm-up, 10 min and 20 min after warm-up]) was applied to compare the variations in heart rate, VAS, muscle temperature and CMJ height. We used the Bonferroni correction for the post-hoc test, and the significance level was set at $p < 0.05$. For the effect size, partial eta-squared values (η^2_p) for repeated measures were calculated.

Results

Room temperature and humidity

Throughout the experiment, the room temperature was: 80% $\dot{V}O_2$ max: 23.8 ± 0.3°C; 60% $\dot{V}O_2$ max: 23.7 ± 0.2°C; Control: 23.7 ± 0.3°C. The humidity of the room was: 80% $\dot{V}O_2$ max: 23.3 ± 3.0%; 60% $\dot{V}O_2$ max: 23.0 ± 3.0%; Control: 23.3 ± 3.3%. There were no significant differences among the three conditions of the room temperature and the humidity.

Incremental exercise test

The average value of $\dot{V}O_2$ max in this study's participants was 45.7 ± 3.1 ml/min/kg. Running speeds for 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max conditions were calculated for each individual from the linear regression of running speed and oxygen intake, with average values being 12.5 ± 1.3 km/hr and 8.9 ± 1.0 km/hr, respectively. Also, the running speed of the LT level was 11.8 ± 1.4 km/hr. Exercise intensity at 80% $\dot{V}O_2$ max was significantly higher than at 60% $\dot{V}O_2$ max and LT level ($p < 0.001$ and $p < 0.01$, respectively). In addition, the running speeds at the LT level were lower than at 80% $\dot{V}O_2$ max and higher than at 60% $\dot{V}O_2$ max in all participants.

Heart rate

The main effects of intensity, time and interaction (intensity × time) for heart rate were observed (intensity: $p < 0.01$ $\eta^2_p = 0.97$; time: $p < 0.01$, $\eta^2_p = 0.99$; interaction: $p < 0.01$, $\eta^2_p = 0.98$). The post-hoc test revealed a significant increase of heart rate from the baseline after warm-up, which lasted for 20 min after warm-up at 80% $\dot{V}O_2$ max ($p < 0.05$). In the 60% $\dot{V}O_2$ max condition, a significant increase of heart rate was maintained even 20 min after warm-up ($p < 0.05$). Heart rate after warm-up at 80% $\dot{V}O_2$ max was significantly higher than other conditions ($P < 0.01$), and heart rate after warm-up at 60% $\dot{V}O_2$ max was significantly higher than for the control ($p < 0.05$, Figure 2A).

Subjective fatigue level

Significant main effects (intensity and time) and interaction effects (intensity and time) were found for subjective fatigue level (intensity: $p < 0.01$, $\eta^2_p = 0.94$; time: $p < 0.01$, $\eta^2_p = 0.88$; interaction: $p < 0.01$, $\eta^2_p = 0.81$). The post-hoc test showed a significant increase in subjective fatigue level from the baseline after warm-up, which lasted for 20 min after warm-up at 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max conditions ($p < 0.05$). The subjective fatigue levels after warm-ups of 80 % $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max were significantly higher than for the control ($p < 0.05$). Immediately after warm-up, the subjective fatigue level of the 80% $\dot{V}O_2$ max condition was significantly higher than other conditions, as shown in Figure 2B ($p < 0.01$).

Muscle temperature

There were significant main effects (intensity and time) and interaction (intensity and time) for muscle temperature (intensity: $p < 0.01$, $\eta^2_p = 0.91$; time: $p < 0.01$, $\eta^2_p = 0.90$; interaction: $p < 0.01$, $\eta^2_p = 0.92$). The post-hoc test showed a significant increase of muscle temperature from the baseline after warm-up, which lasted for 20 min after warm-up with 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max ($p < 0.01$). Muscle temperature after warm-up at 80% $\dot{V}O_2$ max was significantly higher than other conditions ($p < 0.01$), and muscle temperature after warm-up at 60% $\dot{V}O_2$ max was significantly higher than the control ($p < 0.01$, Figure 2C).

Counter movement jump height

Significant main effects (intensity and time) and interacttion (intensity and time) for CMJ height were found (intensity: $p < 0.01$, $\eta^2_p = 0.76$; time: $p < 0.01$, $\eta^2_p = 0.81$;

interaction: $P < 0.01$, $\eta^2_p = 0.70$). The post-hoc test indicated a significant increase of CMJ height from the baseline after warm-up. This increase lasted for 20 min after warm-up with 80% $\dot{V}O_2$ max, and for 10 min after warm-up with 60% $\dot{V}O_2$ max, respectively ($p < 0.05$). Immediately after warm-up, 10 min after, and 20 min after warm-up, CMJ height at 80% $\dot{V}O_2$ max was significantly higher than for the control ($p < 0.01$). CMJ height immediately after warm-up at 60% $\dot{V}O_2$ max was significantly higher than for the control ($p < 0.05$, Figure 2D).

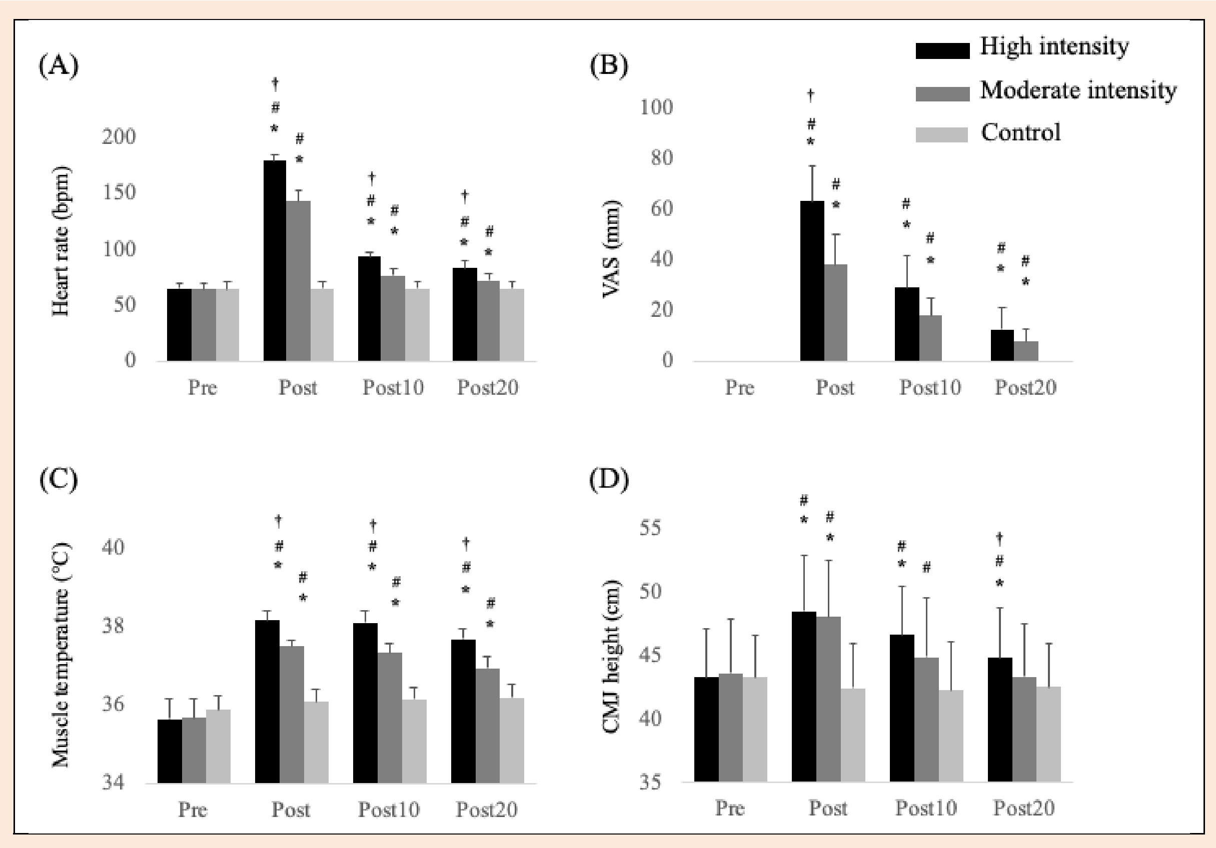

Figure 2. Time course effects of warm-up on heart rate (A), subjective fatigue scale (B), muscle temperature (C) and CMJ height (D). * indicates a significant difference from Pre warm-up ($p < 0.05$). † indicates a significant difference from Moderate intensity ($p < 0.05$). # indicates a significant difference from Control ($p < 0.05$). Data are presented as mean ± SD.

Discussion

The present study investigated time course effects of warm-up at different intensities on physiological responses as well as on jump performance and clarified whether warm-up at high intensity could maintain increased muscle temperature and jump performance for a longer time compared to moderate-intensity warm-up. The results of the incremental exercise test showed that running speed at 80% $\dot{V}O_2$ max was significantly faster than LT level ($p < 0.05$), and that running speed at 60% $\dot{V}O_2$ max was significantly slower than LT level ($p < 0.05$). As for muscle temperature, warm-up at 80% $\dot{V}O_2$ max increased muscle temperature rapidly and maintained a significant increase for 20 min after warm-up, compared to warm-up at 60% $\dot{V}O_2$ max and the control. Thus, exercise intensity was related to high heat production by ATP catabolism during exercise and ATP regeneration after exercise increased with exercise intensity (Fisher et al., 1999). It was suggested that high intensity warm-up is appropriate for increasing and maintaining muscle temperature for 20 min.

Our results indicated that 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max warm-ups were both effective for the improving jump height and no significant differences were found in CMJ height with warm-up at 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max immediately after the warm-up. Muscle temperature immediately after warm-up at 80% $\dot{V}O_2$ max was significantly higher (by 0.7 °C) than warm-up at 60% $\dot{V}O_2$ max immediately after warm-up. However, there was no difference in CMJ heights after warm-up at 80% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max conditions. Several studies using warm-up at 80% $\dot{V}O_2$ max reported that warm-up at high intensity led to fatigue after warm-up, which may have negative acute effects on athletic performance (Bishop et al., 2001; Stewart and Sleivert, 1998; Vandenboom, 2004; Yaicharoen et al., 2012). Therefore, our results indicated that there was no additional increase in jump height as a result of a 15-min warm-up at 80% compared to 60% due to the possibility of fatigue as the shown by the subjective fatigue level, which was significantly higher at 80% than 60%.

The results of the present study indicated that high-intensity warm-up was more beneficial for the purpose of improving and maintaining jump performance for a long duration. This study showed that CMJ height 20 min after warm-up at 80% $\dot{V}O_2$ max was significantly higher than 20 min after warm-up at 60% $\dot{V}O_2$ max. In contrast, CMJ height 10 min after warm-up at 60% $\dot{V}O_2$ max was not significantly different compared with before warm-up.

With subjective fatigue level, there were no significant differences in VAS scores between the warm-up conditions at 20 min after warm-up, although the VAS score of warm-up at 80% $\dot{V}O_2$ max was significantly higher than immediately after warm-up at 60% $\dot{V}O_2$ max. Byrne et al. (2014) reported that warm-up at 75% $\dot{V}O_2$ max impaired performance immediately after, but the negative effects disappeared within 5 min. This result suggests a decrease of fatigue. Similarly, the present study showed that there were decreases at 20 min after high-intensity warm-up even when muscle temperature was maintained, which resulted in higher CMJ height after warm-up at 80% $\dot{V}O_2$ max. Consequently, our data showed that high-intensity warm-up is more appropriate for boosting jump performance than moderate-intensity if athletes are required to rest for a period of time between warm-up and their athletic events.

High-intensity warm-up may improve and maintain jump performance for a long duration by increasing sympathetic activity. HR is adjusted by the balance of sympathetic and parasympathetic activities, and is increased by sympathetic dominance (Zaglia and Mongillo, 2017). The sympathetic nervous system is often referred to as the “fight-or-flight response” (Zaglia and Mongillo, 2017). In this study, HR for 20 min after warm-up was higher for 80% $\dot{V}O_2$ max than other warm-ups. HR was affected not only by sympathetic and parasympathetic activities but also hormonal activities and other factors.

The present study results imply that muscle temperature and jump performance after both middle and high intensity warm-ups were significantly increased for 10 min. Then muscle temperature and jump performance were maintained with high intensity warm-up. Jump performance was related to muscle temperature (Bergh et al., 1979). Further, jump performance is also associated with muscle strength as well as sprint performance (Comfort et al., 2014; Tsiokanos et al., 2002). Therefore, high intensity warm-up is effective and lasts for a longer time period before athletic event. If an athlete is able to secure more than 10-min resting time between warm-up and games or competitions, a high-intensity warm-up is recommended. However, moderate-intensity warm-up is recommended when an athlete must perform immediately after warm-up. Therefore, athletes who are starting members should adopt different warm-up intensity than substitute athletes. Furthermore, athletes who compete in track and field events, especially the high jump, should change their warm-up intensity taking into account their starting heights. We can consider that sufficient intensity of warm-up is important in order to maintain raised muscle temperature and HR.

There are a few limitations to this study. Firstly, the participants came from a diverse range of sports backgrounds, specifically track and field (jump events), basketball, and lacrosse. The different sports backgrounds might have affected the present results. Secondly, only jump height was analyzed for the performance effects only and other outcomes were not determined in this study.

Conclusion

High-intensity (80% $\dot{V}O_2$ max) warm-up is recommended if an athlete is able to secure more than 10 min resting time between the warm-up and the athletic event. If the event is held immediately after warm-up, we would recommend moderate intensity warm-up (60% $\dot{V}O_2$ max warm-up). In order to maintain jump performance after warm-up for a long duration, a relatively high warm-up intensity is necessary to maintain muscle temperature and HR.

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Key points

- We investigated time course effects after warm-up with different intensities on jump performance.
- Moderate intensity warm-up (60% $\dot{V}O_2$ max) is recommended if athletic event is held immediately after warm-up.
- High-intensity warm-up can maintain an increase in muscle temperature and jump performance for 20 minutes compared to moderate intensity warm-up.

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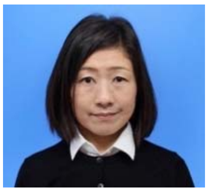

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