THE IMPACT OF COLD-WATER IMMERSION ON POWER PRODUCTION IN THE VERTICAL JUMP AND THE BENEFITS OF A DYNAMIC EXERCISE WARM-UP

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1Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut; 2Strength and Conditioning, St. John’s University, Queens, New York; 3Department of Physiology and Neurobiology, University of Connecticut, Storrs, Connecticut; 4Center for Aging, Division of Geriatric Medicine, University of Connecticut Health Center, Farmington, Connecticut; 5Department of Nutritional Sciences, University of Connecticut, Storrs, Connecticut; 6Department of Athletics, University of Connecticut, Storrs, Connecticut; and 7Department of Biology of Physical Activity and Neuromuscular Research Center, University of Jyväskylä, Jyväskylä, Finland

ABSTRACT

Dixon, PG, Kraemer, WJ, Volek, JS, Howard, RL, Gomez, AL, Comstock, BA, Dunn-Lewis, C, Fragala, MS, Hooper, DR, Häkkinen, K, and Maresh, CM. The impact of cold-water immersion on power production in the vertical jump and the benefits of a dynamic exercise warm-up. J Strength Cond Res 24(12): 3313–3317, 2010—The purpose of this study was to examine the influence of a cold treatment and a dynamic warm-up on lower body power in the form of a countermovement vertical jump (CMVJ). Nine physically active men, who were either current or ex-National Collegiate Athletic Association (NCAA) Division 1 athletes, consented to participate in the study. Using a balanced, randomized presentation and a within-subject design, each subject performed 4 environmental and warm-up protocols (i.e., ambient temperature without warm-up, ambient temperature with warm-up, cold without warm-up, or cold with warm-up). Two sets of 3 maximal effort CMVJs were performed on a force plate at each testing time point. For each protocol, the subjects completed a pretest set of CMVJ (pretreatment [PRE]), then either went through a 15-minute warm-up or were asked to sit in place. Then a final set of CMVJs was completed (posttreatment [PT]). The primary finding in this study was that warm-up was effective in offsetting the negative effects of cold exposure on CMVJ power. There was a significant main effect for Time (PRE > PT > IT), and there was a significant ($p \leq 0.05$) main effect for Trial (AMB = AMBWU > COLDWU > COLD).

Because athletic competitions happen in various colder climates, it is important to make sure that a proper warm-up be completed to maximize the athlete’s power output. The results of this study demonstrate that when athletes are exposed to cold conditions, it is recommended that before practice or play, a dynamic warm-up be employed to optimize performance.

KEY WORDS environmental, anaerobic, sport, neuromuscular

INTRODUCTION

In athletics, temperatures can vary in competition from 100 to 0° F with wind chill factors. Both extremes can have a detrimental effect on performance. With regards to the cold, the known effects of cold muscle temperatures include lower cell metabolism, vasoconstriction, decreased nerve conduction velocity, decreased muscle contractility, and decreased extensibility of collagen fibers (9,12). These effects could reduce athletic performance.

The effects of cold temperatures on force and power have been well studied. Howard et al. (8) examined the effects of cold-water immersion on isokinetic and isometric strength on physically active male college students. They demonstrated that cold-water immersion at 12°C significantly decreased the isokinetic average peak torque, average power, and total work. Interestingly, when examining force at this temperature, no significant changes were observed for isometric force or low velocity torque production indicating a more putative effect on high speed movements. Although other studies have observed reduced force production at cold temperatures (2,3), it seems that a consensus exists that power production is reduced with cold temperature exposures (2,5,11). However, how to combat such effects has been less studied beyond thermal barriers with clothing.
Cold and Power Performance

We hypothesized that the use of the so-called “warm-up” exercises may be able to offset these decrements. Traditionally, static stretching exercises have been used by many coaches to prepare athletes for sporting activity. However, studies have shown that static and proprioceptive neuromuscular facilitation (PNF) stretching may negatively impact jump performance and power output (1,6,13). Dynamic warm-up exercises now appear to be preferred after many studies have compared the 2 modes and demonstrated dynamic exercises to be much more effective (7,10,13).

The hypotheses of this study were threefold: (a) that warm-up would significantly improve CMVJ power performances, (b) cold temperatures would significantly decrease CMVJ power performances, and (c) warm-up after a cold treatment would significantly improve CMVJ power performance. Therefore, the purpose of this study is to examine the effects of cold exposure using cold-water immersion on the ability to produce power in a countermovement vertical jump (CMVJ) and further test the effects of a dynamic warm-up protocol after cold exposure.

METHODS

Experimental Approach to the Problem

The experimental design involved a within-group testing design with subjects acting as their own control to reduce the variability in the testing measures. Thus, each subject completed 4 sequences of the testing protocol, including 2 ambient conditions and 2 cold treatment conditions each with standing control and active warm-up conditions. The presentation of the sequences was essentially balanced with 2-3 subjects starting with each sequence to eliminate any statistical order effects. Random crossovers to 1 of the other treatment sequences were accomplished in 2-4 days. Thus, this study design was a 2 (temperature) × 2 (warm-up or no warm-up) × 3 (time points) design. This allowed us to determine the impact of the cooling on vertical jump power production and the impact of a warm-up in each condition.

Subjects

Nine trained men who were or had been National Collegiate Athletic Association (NCAA) Division I athletes gave voluntary consent to participate in the investigation (age 22.1 ± 1.5 years, height 177.8 ± 5.2 cm, and body mass 82.1 ± 8.9 kg). All subjects signed informed consent forms to participate in this experiment after receiving a full explanation of the methods, procedures, and risks of the study. The investigation was approved by the Institutional Review Board for use of human subjects at the University of Connecticut. A medical questionnaire was completed by each subject and reviewed by our physician medical monitor to exclude anyone with medical conditions, prior to thermal injury, or medications that would confound the experiment. Subjects were also instructed not to exercise during the 24 hours before testing, and activity and dietary logs were used to replicate activity and dietary behaviors 48 hours before each testing sequence. None of the subjects reported any history of cold injury, heat illness, or thermoregulatory disorders. Alcohol consumption was not permitted during the 24-hour period before testing.

Procedures

Familiarization. The subjects were given an opportunity to practice all aspects of the study before the investigation. This included practicing the CMVJ test protocol, the exercises used in the dynamic warm-up protocol, and the cold-water exposure treatment. Practice trials allowed for solid test–retest reliabilities in the experiment.

Experimental Time Line. The subjects were asked to complete 2 sets of 3 maximal effort CMVJs with a 2-minute rest period in between sets of jumps on a force plate. Table 1 illustrates the treatments that were used in a balanced and randomized sequence with subjects acting as their own control. Again, each subject participated in 4 sequences of testing: (a) an ambient temperature standing control; (b) an ambient temperature active warm-up condition; (c) a cold temperature active warm-up condition; and (d) a cold temperature active warm-up condition.

Cooling Protocol. The water immersion procedure from Howard et al. (8) was used to create the cooling effect on the lower body musculature. This involved cold-water treatment (12°C) with both legs immersed in a circulating water tank leveled to each individual’s gluteal fold. The water temperature was monitored and adjusted throughout the immersion sessions to maintain the 12 ± 1°C. A flexible

<table>
<thead>
<tr>
<th>TABLE 1. Treatment sequences including both a control condition and active warm-up experimental condition.*</th>
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<tr>
<td>Pretest</td>
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<tr>
<td>CMVJ Ambient temperature</td>
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<tr>
<td>CMVJ Ambient temperature</td>
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<tr>
<td>CMVJ Cold immersion</td>
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<td>CMVJ Cold immersion</td>
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*CMVJ = countermovement vertical jump.
thermister (series 401, Yellow Springs Instruments, Yellow Springs, OH, USA) was inserted 10 cm beyond the external anal sphincter to monitor rectal temperature with a lower limit of 35°C with the maximum rate of change up or down in rectal temperature being 0.6°C in 5 minutes.

**Power Determinations.** The CMVJs were performed on a Quadra-jump force plate (Kistler Instruments, Inc, Amherst, NY, USA) that is interfaced with a computer, which recorded the power output for each set of jumps. Two sets of 3 maximal effort jumps were performed with the highest power output (W) used for analyses from each set of jumps.

**Table 2.** Warm-up procedure used to reduce the impact of the thermal cooling.

<table>
<thead>
<tr>
<th>Continuous warm-up 1 (20 yds)</th>
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<tbody>
<tr>
<td>1. Arm circles forward × 1: walking forward on the toes while circling the arms forward with the arms parallel to the ground</td>
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<tr>
<td>2. Backward heel walk w/arm circles backward × 1: walking backward on the heels while circling the arms backward with arms parallel to the ground</td>
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<tr>
<td>3. High knee walk: walking forward and pulling the knee up to the chest with both arms, alternates as you walk</td>
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<tr>
<td>4. High knee skip: skipping forward and bringing the knee up so that the quadriiceps is parallel to the ground</td>
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<tr>
<td>5. High knee run: running while focusing on bringing the knees up so that the quadriiceps is parallel to the ground</td>
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<tr>
<td>6. Butt kicks: running while bringing the heel to the glutes</td>
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<tr>
<td>7. Tin soldiers: walking forward and kicking a single leg up in front while keeping the knee locked in extension (alternates)</td>
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<tr>
<td>8. One leg SLDL walk forward × 1: walking forward with straight legs, lean forward on 1 leg and reach for the foot with the opposite hand</td>
</tr>
<tr>
<td>9. 1 Leg SLDL Walk Backward × 1: walking backward with straight legs, lean forward on 1 leg and reach for the foot with the opposite hand</td>
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<tr>
<td>10. Backward skip: moving backward and skipping at the same time</td>
</tr>
<tr>
<td>11. Backward run: running backward and extending the rear foot behind you</td>
</tr>
<tr>
<td>12. Back peddle: moving backward while shuffling the feet and keeping them low to the ground</td>
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<tr>
<td>13. Overhead lunge walk: hands on the head while doing walking lunges forward</td>
</tr>
<tr>
<td>14. Inchworm: starting in the push-up position, walk the feet into the hands; then walk the hands out to the push-up position</td>
</tr>
</tbody>
</table>

After the 45-minute treatment, a second testing set of CMVJs was performed, and then a 15 minute rest period was used where the subject either performed an active warm-up or was asked to stand quietly. After the 15-minute treatment, a third group of CMVJs was performed. The warm-up procedure can be seen in Table 2.

**Statistical Analyses**

Statistical evaluation of the power performances was accomplished using a 2-way analysis of variance (temperature) × 2 (warm-up or no warm-up) × 3 (time points) design. Subsequent pairwise differences were determined using a Tukey post hoc test where appropriate. All the statistical assumptions were met for linear statistics. No statistical order effects were observed for testing order. Using the nQuery Advisor software (Statistical Solutions, Saugus, MA, USA), the statistical power for the n size used was 0.88. Test–retest reliability of the CMVJ power test was shown to have interclass correlation coefficients of $R = 0.92$. Significance in this experiment was set at $p \leq 0.05$.

**Results**

The primary finding in this study was that warm-up as defined in this study was surprisingly
There was a significant main effect for Time (PRE < PT < IT) and Trial (AMB = AMBWU > COLDWU > COLD), and there was a significant Time × Trial interaction (Table 3 and Figure 1).

The data in Table 3 show the differences between treatments where AMB and COLD (12°C) temperatures were paired with both a warm-up (WU) and without a warm-up. The power outputs in each of the 4 trials were consistent in the pretreatment (PRE) measurements. In the initial measurement (IT) after the treatment, both of the AMB groups stayed the same in comparison to their PRE power data. In contrast, there was a significant decrease in the power output of the 2 cold treatment groups when compared to their PRE data. The data of the COLD groups were also significantly lower than the IT data of 2 AMB groups.

Finally, the posttreatment power output was significantly increased in the AMBWU, COLD, and COLDWU groups. It is important to note that the increase was larger for the groups that completed the warm-up. The AMB group showed no significant change when compared to the IT group. Overall, the highest power data came from the PT measurement of the AMBWU group.

In the AMB group, there were no significant differences between the PRE, IT, and PT. In the AMBWU group, there were significant differences between PT (PT < PRE[AMB]), PT > IT[AMBWU]) and a difference between groups (PT > PT[AMB]). In COLD group, there were significant differences between IT (IT < PRE[AMB], IT < PRE[AMBWU], IT < PRE[COLD]), and PT (PT < PT[AMB], PT < PT[AMBWU], PT < PT[AMBWU], PT < PRE[COLD], PT < IT[COLD]).

The final trial group, COLDWU, experienced the most significant differences between trials and groups: IT differences (IT < PRE[AMB], IT < PRE [AMBWU], IT < PRE[COLD]) and PT differences (PT < PRE[AMB], PT < PRE[AMBWU], PT < PRE[COLD], PT < PRE[COLDWU], PT < IT [COLDWU]).

**DISCUSSION**

The purpose of this study was to examine the effects of a dynamic warm-up on lower body power as measured by CMVJ after exposure to a cold environment. The primary findings of this investigation were that cold-water exposure does in fact decrease power as measured by the CMVJ. In addition, a dynamic warm-up after cold-water exposure can significantly improve lower body power. Thus, from a practical perspective, the use of a dynamic warm-up may be important for individuals exposed to cold environments in competitive outdoor sports (e.g., soccer, American football).

The findings of this study were in agreement with other research studies that have demonstrated a reduction in power characteristics with exposure to cold temperatures (2,6,8,11) (Table 3 and Figure 1). Drinkwater (4) stated that almost any level of cooling can reduce muscle power because of slowed enzymatic processes and nerve conduction that impair the rate of force development. Church et al. (1) proposed that biological rate processes slow down by as much as one-half and the muscle–tendon unit stiffness and the stretch tolerance of the muscle changes with a temperature decrease. This could impact the stretch shortening cycle in a CMVJ and help to explain the reduced power observed after the cold exposure used in this study.

It has been generally understood and expected that cold temperatures can reduce power performance. What can be done to address this effect beyond clothing barriers to limit the absolute temperature exposure has not been clearly elucidated. Athletes are often faced with cold exposure and have to wait on sidelines or on the bench waiting to return to play (e.g., American football, soccer, and hockey). We had previously identified the problem with cold exposure (8) but now wanted to see if a simple solution might be using just a proverbial “warm-up.” Many coaches and athletes wonder what might be...
done to rescue neuromuscular performance after the cold exposure other than simply time in a warm ambient environment? The answer is of interest to sport scientists, strength and conditioning professionals, and sport coaches. Interestingly, 1 study (5) examined vertical jump performance and shuttle run times and demonstrated these results to be reduced up to 20 minutes after the athletes were exposed to ice bags.

Such data support the need for an intervention for rapid recovery from cold exposure as competitive situations may not allow the time for passive warming or cold exposure may well continue during a game or match. This study has shown that dynamic warm-up after cold exposure appears to be a logical approach to helping rescue or optimizing muscle neuromuscular performance.

The term “warm-up” is so widely used in the literature and in coaching that it has become synonymous with “whatever an athlete does before practice or competition starts.” This can be static stretching, jogging, or use of a heat pack to warm the skin. In designing our warm-up protocol, both the neuromuscular and physiological needs of an athlete were considered. Our series of dynamic movements required the participant to move over a 20-yd space and combine upper body and lower body exercises at different speeds. The goal was to increase the heart rate, blood flow, intramuscular temperature, and range of motion in each subject to optimize the power output without negatively affecting power with stretching other than using dynamic stretching movements (10,14).

The results of this experiment were quite clear because the CMVJ power was significantly reduced as expected by the cold-water immersion exposure and the warm-up exercise protocol dramatically improved the power performance. The pattern of the normal ambient temperature showed that the warm-up did help with the progression of the vertical jump, but the delta magnitude of the improvement was much greater from the cold exposure treatment condition. Thus, warm-up appears to be important even in ambient conditions. Again, we used a dynamic exercise protocol to ensure a lack of influence on the results, and dynamic warm-up has been shown to enhance vertical jump performance compared to static stretching (10). Thus, the findings of this study not only showed that such a warm-up protocol can help rescue the cold muscle but also help prepare the inactive muscle for power performances.

**Practical Applications**

There is much debate in the world of sports as to how to properly prepare for exercise or competition. The ability to be explosive is heavily focused on in both strength training and competition preparation. Across the body of literature, different so-called protocols have been used with varying degrees of effectiveness. The findings of this study illustrate that a wel-thought-out warm-up can have a significant and positive impact on explosive exercise, especially when exposure to the cold is involved. Thus, it is now clear that adequate warm-up is needed and is something that needs to be seriously considered for optimal practice, especially in cold environments when power output plays a major role in performance. Coaches should consider using a similar warm-up consisting of dynamic stretching and exercise movements before the onset of practice or games to maximize their athletes’ power performances. Again, this might be especially important when games or practice involve playing under cold conditions.

**References**


