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Interval Cryotherapy Decreases Fatigue During Repeated Weight Lifting

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Objective: To investigate the effect of icing the arm and shoulder between weight-pulling sets on work, velocity, and power.

Design and Setting: I used a 1 × 2 factorial, random, counterbalanced design in which each participant pulled 75% of his 1-repetition maximum on 2 separate days. The individuals pulled the weight 22 times for each set as fast as possible, then either iced (cryotherapy) or placed towels over their arms and shoulders for 3 minutes, and then rested 4.5 minutes at room temperature. The sets continued until the participants could not complete 22 pulls without stopping.

Subjects: Ten male members of a private athletic club, who weight lift on a regular basis, volunteered to participate in the study.

Measurements: Work was determined by the number of arm-pull sets completed before fatigue, velocity was measured by the time to complete each set, and power was determined by dividing work by velocity. Velocity and power were analyzed in 3 ways: first to fourth sets (88 pulls), matched sets (167.2 pulls), and all sets (191.4 cryotherapy and 167.2 towel pulls), using analysis of covariance with the base set as the covariate.

Results: Cryotherapy between sets resulted in a significantly greater number of total joules and arm pulls when compared with the towel treatment. Velocity was significantly faster for the first to fourth sets, matched sets, and all sets when subjects received intermittent cryotherapy. Power also was significantly higher for the first to fourth sets and matched sets. The all-sets comparison consisted of 14.5% more cryotherapy arm pulls.

Conclusions: Interval cryotherapy between weight-pulling sets is associated with increased work, velocity, and power.

Key Words: cold, ice, strength, work, velocity, power

Athletes consistently work to delay the onset of fatigue and improve motor performance. Skill development, weight training, cardiorespiratory exercises, and stretching are just a few of the many activities used to enhance achievement. Of these, almost all athletes use weight training. One possible way to increase the weight lifted is to apply cryotherapy (ice or cold therapy) to the skin surface before exercise.[1–20] Typically, cryotherapy is used in rehabilitation, but consideration can also be given to other possible uses, particularly in athletics.

Short-duration, local applications of cryotherapy lower muscle temperature and delay the onset of work fatigue.[1–10] Several researchers[1–5] indicated that the longest duration of work occurred when the average muscle temperature was near 27°C. Both higher and lower muscle temperatures resulted in a decrease in the duration of the contractions. Higher temperatures resulted in a significantly faster onset of work fatigue,[3,6,7] while mildly cold applications resulted in significantly longer work periods.[8,9] Extremely cold applications produced less work.[1,3,4,7] One group of investigators[10] obtained better performance using an increased temperature.

Later researchers[11–20] began to study the effects of cooling and warming on velocity and power. Applying cryotherapy reduced velocity and power.[11–15] Some investigators[11,14,16–18] reported enhanced performance as a result of warming muscles. Others[13,19,20] demonstrated that increasing temperature had little or no effect upon subsequent power and that cooling reduced performance. Most of the investigators who studied the relationship between velocity and warm applications used only 1 temperature above normal. In general, previous authors have not used interval cryotherapy between sets of exercises.

In 1 study,[21] 3-minute interval cryotherapy used by baseball pitchers between innings resulted in a significantly higher number of innings pitched and increased velocity with no difference in accuracy. The main purpose of the current study was to replicate the baseball study to determine if similar results would be obtained by increasing the weight from a baseball (142–149 mg) to 75% of the 1-repetition maximum (1RM) arm pull. The number of pulls for each set, cryotherapy time, and rest periods were similar to those used in the interval cryotherapy baseball study.

This procedure may be an innovative approach to delaying the onset of work fatigue while increasing velocity and power. A second area of interest was limiting cryotherapy to 3-minute time periods. Most investigations used a minimum of 20 minutes of cryotherapy immediately before motor performances.

METHODS

I used a 1 × 2 factorial, random, counterbalanced design. Participants received interval cryotherapy on 1 day and towels covering the arm and shoulder on the other day. The dependent variables were total work, velocity, and power.

Subjects

Ten male volunteers (age = 29.0 ± 2.8 years; height = 174.8 ± 7.1 cm; weight = 72.0 ± 2.0 kg; weight-training

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experience = 5.5 ± 1.1 years; number of different sport experiences = 3.0 ± 0.3) who were athletic club members participated in the study. They indicated that they did not have any health, physical, arm, or shoulder problems that could influence the results of their performance before each treatment day.

Treatments

Interval cryotherapy treatment consisted of applying 5 plastic bags (28 × 46 cm) one-third filled with ice cubes (1.9 × 2.5 × 1 cm each) for 3 minutes: 3 on the shoulder and arm and 2 covering the arm and elbow. New ice bags were used after each 3 sets. The towel treatment consisted of covering the shoulder and elbow with 1 towel each for 3 minutes. This may be considered a mild warming of the arm and shoulder similar to baseball pitchers' wearing jackets between innings to keep the arm and shoulder warm. The participants did not lift weights for 1 week before testing, and the treatments were administered 7 days apart.

Work Load

A weight-training device (Figure 1) was used to fatigue the arm and shoulder muscles with a pulling motion. To fatigue the muscles, 74% ± 1.4% of a participant's 1RM was used for resistance. The pull started from a standing position, facing away from the weights, with the subject's upper body rotated to the dominant side, arm fully extended behind the shoulder, and holding the weight-lifting grip in his hand, palm up, with arm parallel to the ground. He positioned himself so that the weights were just off their support. For the right-handed subject, the right foot was at a 45° angle to the pull, while the left foot was parallel to the pull, with the knees slightly bent. On the command "start," the subject pulled the hand grip straight forward by flexing the elbow and shoulder, rotating the shoulder and hips, and finishing the pull with the hand grip in front of the shoulder and the arm fully extended. The pulling motion tended to be in a straight line parallel to the floor. The subject then returned the arm to the original starting position. This constituted 1 pull. The participant pulled the weight 22 times (1 set) as quickly as possible and rested 8 minutes. He repeated pulls and rest periods until muscle fatigue prevented him from completing the 22 pulls without stopping.

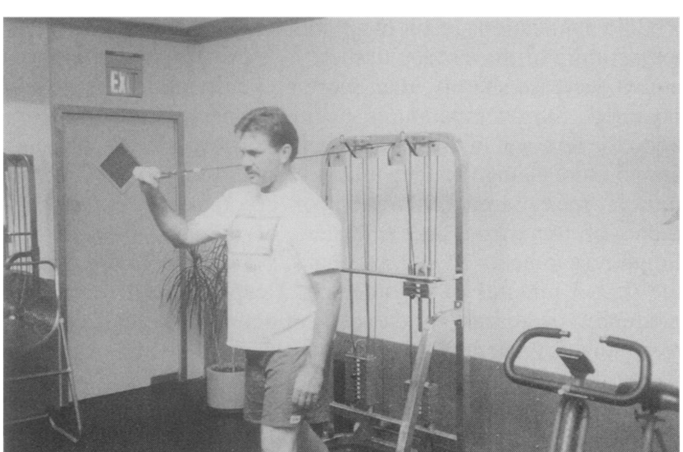

Figure 1. Arm-pull weight-lifting device.

Procedures

During the habituation session, the participants were informed of the purpose and procedures of the study, signed an informed consent form approved by San Francisco State University Committee for the Protection of Human Subjects (which also approved the study), and were randomly assigned to a group for testing order. They warmed up for 3 minutes, observed a demonstration of the movement, and performed 10 pulls with a weight of 6.8 kg (15 lb). The subject's maximum weight for 1 pull was determined by starting with a weight of 18.14 kg (40 lb), followed by the addition of 2.27-kg (5-lb) increments until he could not pull the weight through the full range of motion. Each participant was then tested to determined arm-pull length and pulled approximately 75% of 1RM weight 22 times as fast as possible. (Because the weights were in 2.27-kg increments, I could not obtain exactly 75% of a person's 1RM.) The subject was then scheduled for the 2 testing sessions.

On testing days, participants were asked if they had any soreness or injury to their shoulder or elbow. They then warmed up with the following: 1) running in place for 2 minutes, 2) stretching the arm and shoulder for 1 minute, 3) observing a demonstration of 6 pulls, 4) pulling approximately 75% of maximum weight lifted 11 times at a slow pace within 1 minute, 5) resting 1 minute, 6) pulling the weights 11 times as fast as possible, and 7) resting 3 minutes. The session's remaining procedures were then explained.

Subjects then completed 1 set of 22 pulls as quickly as possible for a base time. The procedures for the next 8 minutes consisted of a 30-second transition from the exercise to the treatments, 3 minutes of cryotherapy or towel treatment, 4 minutes of rest, and another 30-second transition from the rest to the next set of pulls. The number of pulls, treatment times, and rest periods were similar to those used in the previous interval cryotherapy baseball study.[21] This procedure continued until the subject could not complete the 22 pulls without stopping. Ice packs were applied to the shoulder, arm, and elbow for 10 minutes after completion of each testing day. The day after the second testing session was completed, the participants were asked to compare the interval cryotherapy and towel treatments as they related to next-day arm and shoulder soreness.

Length of the arm pull, weight lifted, number of arm-pull sets completed before fatigue, and time to complete repetitions (work rate) were measured; total work (joule = 1 $kg{\cdot}m^2{\cdot}s^{-2}$ = 0.738 ft·lb) and power (watt = $joule{\cdot}s^{-1}$) were calculated. Work was obtained by multiplying the weight lifted by the length of arm pulled, and power was determined by dividing work by time.

Statistical Analysis

The first set did not have a treatment before the 22 pulls. Because this set was not influenced by the cryotherapy or towels, it was used as a covariate in the analysis of covariance. The treatments occurred after this set. The dependent variables of velocity and power were analyzed in 3 different ways: means for first through fourth sets, means for matched sets, and means for all sets. The first through fourth sets include information for all participants. Data are missing from the remaining sets due to fatigue. The scores from sets 5 through 15 were included as part of means analyzed in matched and all sets. Matched scores included those sets with both interval cryotherapy and towel scores for the same set. If a participant had an interval cryotherapy score for the 5th set but not a towel score for the same set, the interval cryotherapy score for the set was eliminated from the analysis. This standardized the amount of work completed in each treatment. All sets included every participant's interval cryotherapy and towel scores. The subjects' interval cryotherapy sets included 14.1% more total work or 14.5% more pulls. Work consisted of the pulled total joules completed before fatigue, excluding the base set.

A 1 × 2 factorial, random, counterbalanced design was used. An analysis of variance was used to analyze work at the 0.05 level of significance. An analysis of covariance, with the base set as the covariate, was used for velocity and power.

RESULTS

Room temperature during testing ranged from 21.1° to 22.2°C. The mean arm-pull length was 1.44 ± 0.045 m, weight lifted was 21.89 ± 1.321 kg, and 1 RM was 29.94 ± 2.079 kg. The Table presents the means, standard errors, and percentage differences for work, velocity, and power.

Work

Participants performed 14.1% more total work ($F_{1,9}$ = 19.02, P = .002) and 14.5% more arm pulls ($F_{1,9}$ = 22.22, P = .001) during the interval-cryotherapy sets. Eight of the 10 participants performed more sets during the cryotherapy condition. The other 2 performed the same number of sets.

Velocities

Velocities for the first to fourth sets ($F_{1,8}$ = 7.45, P = .03), matched sets ($F_{1,8}$ = 12.35, P = .008), and all sets ($F_{1,8}$ = 6.25, P = .04) were higher with cryotherapy. No significant difference in the base sets was seen ($F_{1,9}$ = 0.07, P = .79). Velocity increased for interval cryotherapy between the base and the first to fourth sets, while it decreased during the towel condition. During both interval-cryotherapy and towel conditions, velocities showed a slight decline with each succeeding set, which is typical for fatigue.

Descriptive Statistics for Work, Velocity, and Power

Dependent Variable	Cryotherapy Mean ± SE	Towels Mean ± SE	Difference from Placebo (%)
Work			
Total joules	60233 ± 8223	52795 ± 7424	14.1%
Arm pulls	191.4 ± 23.7	167.2 ± 22.1	14.5%
Velocity* (seconds)			
Base set	38.9 ± 2.2	38.6 ± 1.8	.8%
1st to 4th sets	38.2 ± 1.8	39.7 ± 2.2	−3.7%
1st set	37.9 ± 2.0	38.4 ± 2.3	−1.4%
2nd set	37.5 ± 1.9	39.1 ± 2.1	−4.1%
3rd set	38.0 ± 1.7	40.5 ± 2.5	−6.1%
4th set	39.4 ± 1.7	40.7 ± 2.3	−3.2%
Matched sets	39.1 ± 2.0	41.4 ± 2.6	−5.5%
All sets	39.7 ± 2.1	41.4 ± 2.6	−4.2%
Power (watts)			
Base set	184.2 ± 18.2	182.8 ± 17.5	.8%
1st to 4th sets	185.8 ± 17.7	179.7 ± 17.2	3.4%
1st set	188.3 ± 18.6	185.8 ± 18.0	1.4%
2nd set	189.9 ± 18.7	181.0 ± 16.7	4.9%
3rd set	186.0 ± 17.4	176.6 ± 17.4	5.3%
4th set	178.8 ± 16.6	175.3 ± 16.9	2.0%
Matched sets	182.0 ± 17.7	174.2 ± 17.4	4.5%
All sets	180.1 ± 17.4	174.2 ± 17.4	3.4%

*Lower numerical values indicate faster times.

Power

Participants performed higher power values for the first to fourth sets ($F_{1,8}$ = 6.73, P = .03) and matched sets ($F_{1,8}$ = 8.41, P = .02) when treated with cryotherapy. However, there were no differences for all sets ($F_{1,8}$ = 3.23, P = .11) or base sets ($F_{1,9}$ = 0.09, P = .77). Power increased for interval cryotherapy between the base and the first to fourth sets, while the towel treatment power decreased. Both interval-cryotherapy and towel power values reflected a slight decline with each succeeding set.

Soreness

Six of 10 participants reported having less soreness on the day after lifting when treated with interval cryotherapy. Three could not distinguish a difference between the 2 conditions, and 1 felt more soreness after cryotherapy.

DISCUSSION

The rationale for this study was that muscle temperature remains in a relatively narrow range during resting conditions[22] but increases slowly in a warm environment[23] and rapidly when exercising.[24] Webb[23] reported that in a comfortable environmental condition of 27°C, temperatures were lowest at the skin surface and gradually increased to the highest at a 4-cm muscle site. When sweating starts, comfortable temperature differences tend to disappear. Heat production during exercise may cause muscle temperature to rise as high as 45°C.[25] When muscle temperature increases, the body must adjust rapidly by increasing heat loss in order to return to a normal balance (homeostasis).[26] The 3 major routes for heat dissipation are radiation, convection, and evaporation, with the last being the primary mechanism by which muscle heat is released during exercise.[27] Heat loss by conduction under normal conditions is very small. However, for people sitting or lying on very cold surfaces, conductive heat losses may be a considerable portion of their total heat loss. Cryotherapy results in conductive heat loss[28,29] and may assist the other body mechanisms in reducing muscle temperature to a more appropriate level.

Cold applications result in an immediate and rapid decline in temperature of the surface tissues.[28–32] Initially, these temperatures decrease sharply, then more gradually until a plateau is obtained. Skin temperatures begin to increase immediately upon the removal of the ice application. The amount of muscle-temperature change in deep muscle depends on the depth of the muscle measurement, duration of cryotherapy application, mode of treatment, and thickness of adipose tissue.[29,33,34] Some researchers[29,34] suggest that no effect is evident during the first 3 minutes of cryotherapy. Deep-muscle temperature gradually decreases for several minutes immediately after removing cryotherapy,[34] then muscle temperature begins to increase.

Researchers[35] measured temperature change in leg muscles at 1 cm during contrast therapy of 4 minutes of heat and 1 minute of ice for 20 minutes. The control group immersed the leg in a hot whirlpool (40.6°C) for 20 minutes. The contrast group had a significantly smaller increase (0.39°C) in muscle temperature than the control group (2.83°C). Alternating heat and cold treatment resulted in very little muscle-temperature change at 1 cm. Perhaps similar results occurred in this study. The heat production during the weight-pulling exercise may resemble the hot-whirlpool treatment in increasing muscle temperature. This, followed by the 3 minutes of icing and 4.5 minutes of rewarming, could have produced results comparable with the contrast treatment.

I applied 3-minute interval cryotherapy between innings on university baseball pitchers.[21] The participants threw 26% more pitches, which is greater than the 14% obtained with the heavier resistance in the current study. Interval cryotherapy appears to be effective for both light (142–149 mg) and heavy (21.9 kg) resistance-type work. Other studies[1–9,30–32] suggest that the most effective localized muscle temperature for accomplishing the most work is lower than normal temperature. As one moves away from this effective temperature, less and less work is accomplished: extremely high or low temperatures produced the least amount of work. Researchers[1] using water-bath temperatures of 2°C, 10°C, 14°C, 18°C, 26°C, 34°C, and 42°C reported the maximum duration of sustained contraction was at 18°C. A graph of the investigators' results[1–9,21] was similar to a normal probability curve, with its center being slightly below normal temperature (Figure 2). The 3-minute icing with 4.5 minutes of rewarming may have brought the temperature closer to the optimal work temperature. In general, more work is accomplished when the temperature is lower than normal.[1–9,21]

Lowering tissue temperatures results in decreased velocities,[12–14,19] but the literature is conflicting on the effect of motor performance at normal and higher-than-normal muscle temperatures. Several investigators[11,16–18] reported greater velocities at increased temperatures than at normal conditions, while others[13,19,20] indicated that increasing temperature above normal had little or no effect on subsequent velocity. Interestingly, 2 of these studies[19,20] used water baths of 40°C and 46°C, respectively, which suggests that extremely high temperatures may be no different than normal temperatures. Perhaps the velocity performances' distribution could also be similar to a normal probability curve[11–20] with its center somewhere between normal and high temperatures (Figure 2).

The velocity results were similar to those obtained in the baseball investigation.[21] The baseball interval-cryotherapy velocities were significantly faster by 3.7% for second to fourth, 3.7% for matched, and 2.9% for all innings. These percentage changes tended to be either equal to or lower than the respective weight-lifting sets of 3.7%, 5.5%, and 4.2%.

Participants' cryotherapy power values were higher for the first to fourth sets and matched sets but not for all sets. The lack of significant difference in all sets may be associated with the 14.1% more work completed in the interval-cryotherapy treatment.

In the baseball investigation,[21] 5 of 6 pitchers indicated they had less arm soreness the next day with interval cryotherapy. In my study, 6 of 10 participants reported less soreness. The participants in both studies performed more work.

One factor that may have influenced the results is the Hawthorne[36] effect, by which participants performed better because they believed they were receiving special attention and treatment. Because the interval-cryotherapy treatment was counter to all previous practices in weight training, the participants may have believed they were receiving special attention. Although towels were used in this study, the Hawthorne effect may have influenced performance.

The direct application of interval cryotherapy to weight training still needs to be demonstrated. Strength development usually involves 6 to 12 repetitions per set at a low speed, with 3 minutes' rest between sets. The 22 repetitions at a high velocity with 8 minutes of rest between sets may not be transferable to strength training. Further research must be conducted to support the use of interval cryotherapy in weight training.

The exact nature and cause of the complex phenomenon of muscle fatigue remains obscure. Performances affected by different localized environmental temperatures may be concurrently affected by many other factors, such as muscle temperature, the beneficial effects of cryotherapy on pain reduction, the functioning of the arm and shoulder joints, the depletion of substances needed for muscle contraction, byproducts of muscle contractions, accumulation of waste products in the muscles, reduction of secondary hypoxic injuries, the functioning of the central nervous system, rapid change in local environmental temperature, psychological considerations, or a combination of these. Researchers developing models dealing with fatigue should consider including the variable of muscle temperature.

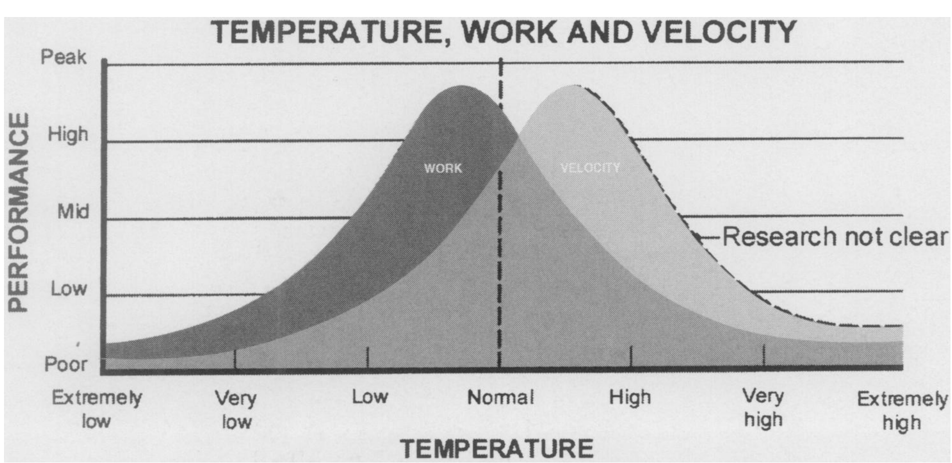

Figure 2. Model for temperature, work, and velocity as related to efficient motor performance.[1–9,11–21]

REFERENCES

1. Clarke RS, Hellon RF, Lind AR. The duration of sustained contraction of the human forearm at different muscle temperatures. *J Physiol.* 1958;220: 454–473.
2. Galloway SDR, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Med Sci Sports Exerc.* 1997;29:1240–1249.
3. Grose JE. Depression of muscle fatigue curves by heat and cold. *Res Q.* 1958;29:19–23.
4. Lind AR. Muscle fatigue and recovery from fatigue induced by sustained contraction. *J Physiol.* 1959;147:162–177.
5. Olschewski H, Bruck K. Thermoregulatory, cardiovascular, and muscular factors related to exercise after precooling. *J Appl Physiol.* 1988;64: 803–811.
6. Chastain PB. The effect of deep heat on isometric strength. *Phys Ther.* 1978;58:543–546.
7. Edwards RH, Harris RC, Hultman E, Kaijser L, Koh D, Nordesjo LO. Effects of temperature on muscle energy metabolism and endurance during successive isometric contractions, sustained to fatigue, of the quadriceps muscle in man. *J Physiol.* 1952;220:335–352.
8. McGowan HL. The effects of cold application on maximal isometric contraction. *Phys Ther.* 1967;47:185–192.
9. van Beek EJ. *Effects of Reducing Intramuscular Temperature on Delaying the Onset of Fatigue: An Electromyographical Analysis* [master's thesis]. London, Ontario, Canada: University of Western Ontario; 1975.
10. King PC, Mendryk S, Reid DC, Kelly R. The effect of actively increased muscle temperature on grip strength. *Med Sci Sports Exerc.* 1970;2: 172–175.
11. Berg U, Ekblom B. Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. *Acta Physiol Scand.* 1979;96:33–37.
12. Carlos J. *The Effects of Short-Term and Long-Term Ice Pack Applications on Peak Power and Mean Power* [dissertation].Tallahassee, FL: Florida State University; 1991.
13. Howard RL, Kraemer WJ, Stanley DC, Armstrong LE, Maresh CM. The effects of cold immersion on muscle strength. *J Strength Cond Res.* 1994;8:129–133.
14. Mattacola C, Perrin DH. Effects of cold water application on isokinetic strength of the plantar flexors. *Isokinet Exerc Sci.* 1993;3:152–154.
15. Oksa J, Rintamaki H, Rissanen S. Muscle performance and electromyogram activity of the lower leg muscles with different levels of cold exposure. *Eur J Appl Physiol Occup Physiol.* 1997;75:484–490.
16. Davies CTM, Mecrow IK, White MI. Contractile properties of the human triceps surae with some observations on the effects of temperature and exercise. *Eur J Appl Physiol.* 1982;49:255–269.
17. Davies CTM, Young K. Effect of temperature on the contractile properties and muscle power of triceps surae in humans. *J Appl Physiol.* 1983;55(1 Pt 1):191–195.
18. Sargeant AJ. Effect of muscle temperature on leg extension force and short-term power output in humans. *Eur J Appl Physiol Occup Physiol.* 1987;56:693–698.
19. Clarke DH, Royce J. Rate of muscle tension development and release under extreme temperatures. *Int Z Angew Physiol Einschl Arbeitsphysiol.* 1962;19:330–336.
20. Cornwall MW. Effect of temperature on muscle force and rate of muscle force production in men and women. *J Orthop Sports Phys Ther.* 1994;20:74–80.
21. Verducci FM. Interval cryotherapy and fatigue in university baseball pitchers. In: Fourth International Olympic Committee World Congress on Sports Sciences: Congress Proceedings; October 22–25, 1997; Monte Carlo; p 107. Abstract.
22. Hardy JD. The physiology of temperature regulation. *Physiol Rev.* 1961;41:521–601.
23. Webb P. Temperatures of skin, subcutaneous tissue, muscle and core in resting men in cold, comfortable and hot conditions. *Eur J Appl Physiol Occup Physiol.* 1992;64:471–476.
24. Nielsen B, Nielsen M. Body temperature during work. *Skan Arch Physiol.* 1962;56:120–129.
25. Salo DC, Donovan CM, Davies KJ. HSP70 and other possible heat shock or oxidative stress proteins are induced in skeletal muscle, heart, and liver during exercise. *Free Radic Biol Med.* 1991;11:239–246.
26. Bazett HC. The regulation of body temperature. In: Newburgh LH, ed. *Physiology of Heat Regulation and Science of Clothing.* Philadelphia, PA: WB Saunders; 1949:109–122.
27. Stitt JT. Central regulation of body temperature. In: Gisolfi CV, Lamb DR, Nadel ER, eds. *Perspectives in Exercise Science and Sports Medicine: Exercise, Heat and Thermoregulation.* Vol 6. Dubuque, IA: William C Brown & Benchmark; 1993;1–39.
28. Knight KL. *Cryotherapy: Theory, Technique and Physiology.* Chattanooga, TN: Chattanooga Corp; 1985:73–82.
29. Knight KL. *Cryotherapy in Sport Injury Management.* Champaign, IL: Human Kinetics; 1995:64–73.
30. Myrer JW, Measom G, Durrant E, Fellingham GW. Cold- and hot-pack contrast therapy: subcutaneous and intramuscular temperature change. *J Athl Train.* 1997;32:238–241.
31. Myrer JW, Measom G, Fellingham GW. Temperature changes in the human leg during and after two methods of cryotherapy. *J Athl Train.* 1998;33:25–29.
32. Ray CA, Hume KM, Gracey KH, Mahoney ET. Muscle cooling delays activation of the muscle metaboreflex in humans. *Am J Physiol.* 1997; 273(5 Pt 2):2436–2441.
33. Lowden BJ, Moore RJ. Determinants and nature of intramuscular temperature changes during cold therapy. *Am J Phys Med.* 1975;54:223–233.
34. Merrick MA, Knight KL, Ingersoll CD, Potteiger JA. The effects of ice and compression on intramuscular temperatures at various depths. *J Athl Train.* 1993;28:236–245.
35. Myrer JW, Draper DO, Durrant E. Contrast therapy and intramuscular temperature in the human leg. *J Athl Train.* 1994;29:318–322.
36. Brown JAC. *The Social Psychology of Industry.* Middlesex, England: Penguin; 1954.