ABSTRACT

JANOT, J. M. Heart rate and perceived exertion responses during climbing in beginner and recreational sport climbers. MS in Adult Fitness/Cardiac Rehabilitation, May 1997, 43pp. (J. Steffen)

This study was designed to determine if heart rate (HR) and perceived exertion responses (RPE) differed between beginner and recreational sport climbers. Thirty-four beginner (n = 10 males, 7 females) and recreational (n = 10 males, 7 females) climbers were instructed to climb 2 routes that varied in difficulty (5.6 and 5.8) on an indoor climbing wall. HR responses were recorded at rest (HRrest), during the climb (HRclimb), and after each climb (HRrecv). RPE values were also recorded after each climb. Significant ($p < .05$) differences were found in HRrest, HRclimb, and RPE values between climbing groups in males for routes 2 and 4. Significant ($p < .05$) differences were also found in HRrest, HRclimb, and RPE between climbing groups in females for routes 2 and 4. An analysis of HRrest and HRrecv revealed significant ($p < .05$) differences for routes 2 and 4 in male beginner climbers. The differences found between beginner and recreational climbers could have been due to route familiarity, efficient climbing technique, a pressor response, or psychological influences. The extent to which these factors affected the HR and RPE responses was not explored in this investigation.

HEART RATE AND PERCEIVED EXERTION RESPONSES DURING CLIMBING IN BEGINNER AND RECREATIONAL SPORT CLIMBERS

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Dean of Graduate Studies Date

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HEART RATE AND PERCEIVED EXERTION RESPONSES DURING CLIMBING IN BEGINNER AND RECREATIONAL SPORT CLIMBERS

INTRODUCTION

The use of the crosstraining principle to supplement sport-specific training programs has been widely accepted for many years. Adding variety to a training program will likely ensure high motivation to engage in the program (Heyward, 1991). Adherence to a training regimen, or an exercise program for that matter, is dependent upon making the program as enjoyable as possible for the participant. Also, the crosstraining done by the participant must be designed to help them improve in the sport for which they are training.

According to the American College of Sports Medicine (ACSM), an exercise that involves the use of large muscle groups over a prolonged period of time will result in the greatest improvement in cardiorespiratory fitness (ACSM, 1995). Some modes of exercise that meet these guidelines are running, walking, cross-country skiing, hiking, stair climbing, and possibly sport/rock climbing.

Rock climbing as an activity or sport has gained increased popularity over the last few years by becoming more than a hobby or an alternate for training in other sports (Jacobs, 1993; Kascenska, DeWitt, & Roberts, 1992; Maitland, 1992; Shirer, 1990). Maitland (1992) described various wall climbing competitions which have attracted veteran and new climbers throughout the world. Not only was this due to greater advancements in equipment safety, but also to the advent of indoor climbing facilities (Bollen, 1988; Kascenska et al., 1992; Maitland, 1992; Shirer, 1990). These facilities included treadwalls, laddermills, or even artificial climbing walls. Climbing walls alone have increased in popularity throughout the world during the past decade.

Another factor that has contributed to the growth of climbing is the use of climbing as a form of exercise training (Bannister & Foster, 1986; Bollen, 1988; Cole, 1990; Maitland, 1992). Climbing has been described by some researchers as a vigorous activity that demands power and strength along with flexibility and aerobic endurance (Kascenska et al., 1992; O'Shea, 1976). Some experts have claimed climbing should be considered as one of the best training modes available to improve overall fitness (Jacobs, 1993).

Williams, Taggert, and Carruthers (1978) concluded that rock climbing produces a specialized type of fitness that enables great improvement in the realm of climbing performance, but not necessarily improvement in overall body fitness. In contrast to this claim, Westcott (1992) found that climbing on a regular basis elicited definite physical benefits in maximum oxygen consumption and body composition.

Hardy and Martindale (1982) discovered that rock climbing compared favorably with other activities like walking, cycling, canoeing, tennis, and swimming in terms of similar rates of energy expenditure.

Although some studies have described the aerobic and strength adaptations necessary to improve climbing performance at altitude, few have addressed the physiological responses that occur during climbing (O'Shea, 1976). Further investigation is needed to determine the physiological demand that climbing places on the individual.

The purpose of this study was to determine if the heart rate (HR) and rating of perceived exertion (RPE) responses differed between beginner and recreational sport climbers who climbed selected routes on an artificial climbing wall.

MATERIALS AND METHODS

Subjects

Thirty-four volunteers were recruited from an indoor rock climbing class and the general student body at the University of Wisconsin-La Crosse. All subjects completed an informed consent form (see Appendix A) prior to participating in the study. The subjects were categorized into 2 groups of beginner or recreational climbers based on overall experience. The recreational climbers had climbed in a class 7 weeks prior to testing and also had varied experience climbing before attending the class. The beginner climbers had no prior experience climbing.

Procedures

Each subject completed 2 climbing trials that were performed within 20 minutes of each other. The subjects were asked to not eat, drink (except water), or smoke for at least 3 hours prior to the testing session. The routes that were used in the climbing trials were previously selected by the investigator.

On the day of the testing session, each subject's height, weight, and age were determined. Shortly thereafter, subjects were given proper instruction on safety precautions and on the use and meaning of the 15 point Borg (1970) RPE scale (see Appendix B). Any questions that the subjects had were answered at that time.

After the initial instructional session, each subject was asked to begin the climbing trials. Each route on the climbing wall was represented by a number that pertained to the grade of difficulty. According to the International Sport Climbers Federation, the first route (route 2) was represented by a difficulty rating of 5.6 and the second route (route 4) was given a difficulty rating of 5.8. These routes were considered as being achievable by novice climbers. Every subject climbed the routes in the same exact order with route 2 being the first route climbed.

Prior to each climbing trial, the subjects were allowed to rest for 1 minute and study the route after they tied the rope to the safety harness. After this initial rest period, a standing, resting HR (HRrest) was recorded. Final instructions, testing reminders, and thoughts were also briefly discussed at this point. The subjects were required to reach the halfway point on each route (determined by the investigator). The subjects were asked not to remain stationary for more than 5 seconds in order to make each climb as uniform as possible. This was closely monitored during each climb performed.

Other than the 5 second restriction, each climber was allowed to climb at a self-selected pace. All subjects completed at least half of each required route. After the halfway point, subjects varied as to how much of each route was completed. This was most evident during route 4 in which only 2 subjects completed the route, whereas all subjects completed route 2.

A climbing HR (HRclimb) was recorded at the moment the climber reached the top of the wall or at failure. After each successful or failed climb, the subjects were immediately returned to the ground at which point the RPE value was recorded. A standing, recovery HR (HRrecv) was recorded following a 10 minute rest period after each climbing trial.

Data Collection

The HR was measured with the use of a Polar Advantage XL HR monitor. The monitor consisted of a belt that was worn on the chest which contained electrodes. This belt transmitted the HR, monitored by the electrodes, to a watch worn on the wrist. The HR was obtained from the watch.

An indoor climbing wall was used for the climbing trials in this study. The climbing wall contained routes with varied degrees of difficulty. The routes were set upon a strictly vertical wall and an overhang portion of the wall. The routes also contained various types and sizes of hand and foot holds which added to the overall difficulty of the routes. The height of the wall was 33 1/2 feet.

Statistics

Standard descriptive statistics were used to evaluate the characteristics of the male and female climbing groups (see Tables 1 and 2).

Table 1. Subject characteristics of beginner (n = 7) and recreational (n = 7) female climbers

	Beginner	Recreational
	Mean±SD	Mean±SD
Age (yr)	21.4 ± 1.1	21.0 ± 0.8
Height (in)	64.4 ± 2.0	65.3 ± 0.8
Weight (lbs)	139.1 ± 20.0	136.3 ± 14.8

The physiological and psychological responses to climbing among beginner and recreational female and male climbers were analyzed using a two-way ANOVA.

Table 2. Subject characteristics of beginner (n = 10) and recreational (n = 10) male climbers

	Beginner Mean±SD	Recreational Mean±SD
Age (yr)	20.9 ± 0.6	21.4 ± 0.7
Height (in)	71.7 ± 2.1	70.4 ± 1.7
Weight (lbs)	184.5 ± 27.3	181.4 ± 22.3

The physiological responses within climbing groups were compared using paired t-tests. Alpha level was set at .05 to achieve statistical significance.

RESULTS

The HR and RPE responses to climbing in beginner and recreational climbers are presented in Tables 3 through 8. The two-way ANOVA revealed no interaction between male and female climbing groups for all HR and RPE values.

However, it was discovered that female climbers had higher HRclimb and RPE values than male climbers, thus physiological and psychological values for males and females are presented in separate tables in this study.

HR and RPE Responses to Climbing in Females

The mean HR and RPE responses to climbing in beginner and recreational female climbers are presented in Table 3.

The HRrest values were significantly ($p < .05$) different between the recreational and the beginner group

Table 3. HR and RPE responses to climbing in beginner (n = 7) and recreational (n = 7) female climbers

	Route 2		Route 4	
	Beginner	Recreational	Beginner	Recreational
HRrest (bpm)	87 ± 7.1	80 ± 4.1*	93 ± 8.8	85 ± 5.6*
HRclimb (bpm)	169 ± 10.1	156 ± 9.9*	182 ± 11.2	166 ± 12.9*
HRrecv (bpm)	82 ± 10.6	78 ± 9.2	86 ± 11.1	84 ± 9.5
RPE	12.6 ± 0.9	12 ± 0.8*	15.9 ± 0.5	14.8 ± 0.4*

HRrest: resting heart rate; HRclimb: climbing heart rate; HRrecv: recovery heart rate; RPE: rating of perceived exertion.
All values represent mean ± standard deviation.
*Beginner different than recreational ($p < .05$).

for routes 2 and 4. HRrest values were 8.1 and 8.6% higher in beginner versus recreational climbers for routes 2 and 4.

The HRclimb data for both routes were significantly ($p < .05$) different between the climbing groups. These HR values were 7.7 and 8.8% higher in beginner versus recreational climbers for routes 2 and 4. No significant ($p > .05$) differences were found in HRrecv between the female climbing groups for either route.

The RPE values were significantly ($p < .05$) lower in the recreational versus the beginner group (1.1 and .5 RPE units) for routes 2 and 4.

Comparisons between HRrest and HRrecv within the female beginner and recreational climbing groups are presented in

Table 4. HRrest and HRrecv in beginner (n = 7) and recreational (n = 7) female climbers

	Route 2		Route 4	
	HRrest	HRrecv	HRrest	HRrecv
Beginner	87 ± 7.1	82 ± 10.6	93 ± 8.8	86 ± 11.1
Recreational	80 ± 4.1	78 ± 9.2	85 ± 5.6	84 ± 9.5

HRrest: resting heart rate; HRrecv: recovery heart rate.
All values represent mean ± standard deviation.
*Beginner different than recreational ($p < .05$).

Table 4. Although mean HR values were higher at rest versus recovery for both climbing groups, these HR values were not significantly ($p > .05$) different.

HR and RPE Responses to Climbing in Males

The mean HR and RPE responses to climbing in beginner and recreational male climbers are presented in Table 5. It was found that HRrest values were significantly ($p < .05$) different between the beginner and recreational male climbing groups for routes 2 and 4. HRrest values were 6.7 and 7.7% higher in beginner versus recreational climbers for both routes.

The HRclimb values were also found to be significantly ($p < .05$) different between the climbing groups for routes 2 and 4. These HR values were 6.1 and 6.8% higher in beginner than in the recreational subjects for both routes. There were no significant ($p > .05$) differences in HRrecv values

Table 5. HR and RPE responses to climbing in beginner (n = 10) and recreational (n = 10) male climbers

	Route 2		Route 4	
	Beginner	Recreational	Beginner	Recreational
HRrest (bpm)	91 ± 8.2	85 ± 5.0*	91 ± 6.1	84 ± 6.7*
HRclimb (bpm)	155 ± 8.6	145 ± 9.9*	178 ± 8.2	166 ± 11.1*
HRrecv (bpm)	84 ± 4.1	83 ± 7.8	83 ± 8.2	87 ± 10.1
RPE	12.1 ± 0.5	11 ± 0.7*	14.4 ± 0.6	13.9 ± 0.8*

HRrest: resting heart rate; HRclimb: climbing heart rate; HRrecv: recovery heart rate; RPE: rating of perceived exertion
All values represent mean ± standard deviation.
*Beginner different than recreational ($p < .05$).

between beginner and recreational climbers concerning routes 2 and 4. The RPE values were significantly ($p < .05$) lower (.6 and .8 RPE units) in the recreational versus the beginner group for both routes.

Comparisons between HRrest and HRrecv within male climbing groups are presented in Table 6. Significant ($p < .05$) differences were found between HRrest and HRrecv in beginner climbers for routes 2 and 4. No differences ($p > .05$) were found between HRrest and HRrecv in the recreational group.

Table 6. HRrest and HRrecv in beginner (n = 10) and recreational (n = 10) male climbers

	Route 2		Route 4	
	HRrest	HRrecv	HRrest	HRrecv
Beginner	91 ± 8.2	84 ± 4.1*	91 ± 6.1	83 ± 8.2*
Recreational	85 ± 5.0	83 ± 7.8	84 ± 6.7	87 ± 10.1

HRrest: resting heart rate; HRrecv: recovery heart rate.
All values represent mean ± standard deviation.
*Beginner different than recreational ($p < .05$).

DISCUSSION

The purpose of this study was to determine if the HR and RPE responses differed between beginner and recreational climbers. In the current study, HR and RPE responses were found to be significantly different between beginner and recreational climbers in most conditions for both male and female climbing groups.

In the current study, HRrest was significantly lower in recreational climbers compared to beginner climbers. This finding was in disagreement with Hardy and Martindale (1982) and Keener, Uttech, and Gilbertson (1996). Keener and colleagues found no difference in HRrest values among novice, intermediate, and experienced climbers. However, Hardy and Martindale reported higher HRrest values in the expert subjects compared to the beginner subjects. The methodology of this study was designed in order to control for anxiety as a possible extraneous variable.

The elevated HRs were attributed to increased psychological arousal that the expert subjects experienced to prepare themselves for climbing.

The beginner climbers in the present study expressed apprehension when questioned about how they felt before beginning the climbing tasks, whereas the recreational climbers did not. The anxiety expressed by the beginner climbers may have influenced HRrest to produce a difference between beginner and recreational climbing groups.

There were no current studies found in a search of the literature that compared HRrest and HRrecv within climbing groups. In the present study, a comparison was made between HRrest and HRrecv within subject groups to explore the possible influence of anxiety on HR. Significant differences were found between HRrest and HRrecv in the male beginners for both routes. However, no differences were found between HRrest and HRrecv in either male or female recreational groups, or in the female beginner group. In general, HRrecv may have more accurately reflected the true baseline "resting" HR value because it was measured after a 10 minute rest and recovery period. Also, the climbers were not expected to climb immediately after HRrecv was taken, whereas HRrest was measured 1 minute before the climbers began the climbing trials.

Landers (1980) found that techniques or tasks become less difficult and more familiar with learning. This allowed the learners, in this case the recreational climbers, to concentrate more on the activity to be done and not on outside stimuli such as fear or anxiety. Experience and wall/route familiarity may explain why the male recreational HRrest and HRrecv values were similar and male beginner HRrest and HRrecv values were not. Anxiety may have played a role in producing a difference between HRrest and HRrecv values in the male beginner climbers.

The activity of climbing can impose physical and psychological stress on the person doing the climbing (Keener et al., 1996). In the present study, HRclimb values were on average 6.5 and 8.3% higher in the beginner climbing group.

Williams and associates (1978) determined that increased HRs during climbing may be due more to anxiety-type psychological influences than physical. The climbers in their study were required to climb a route after taking a beta-blocker (oxprenolol) and a placebo tablet. Mean climbing HRs were significantly higher during the placebo trial than during the oxprenolol trial as expected. An analysis of plasma catecholamine concentrations revealed no significant increases in norepinephrine levels during either trial. Williams and associates stated that the climbers in their study expressed considerable anxiety during the climb while experiencing low physical exertion. Since increases in norepinephrine levels are associated with increases in physical activity, it was determined that increased HRclimb values were likely due to an anxiety-mediated withdrawal of vagal tone. This may explain the differences found in HRclimb values between beginner and recreational climbers in the present study.

Another possible reason for the difference in HRclimb between recreational and beginner climbers could have been that a pressor response occurred in the beginner group.

Keener and colleagues (1996) found significantly lower HRclimb values in experienced climbers compared to novice climbers. Also, the novice climbers produced significantly lower aerobic power outputs than the experienced climbers. Power output was calculated by using body weight, vertical displacement, and elapsed time. The low aerobic power outputs were attributed to increased isometric contractions which occurred when the novice climbers stopped during the climb to decide on how to continue the route.

In the present study, the subjects were instructed not to stop for more than 5 seconds in order to produce a continuous, uniform movement throughout the climb. This was also done to prevent large amounts of isometric muscle contractions from occurring.

Ballor, Becque, and Katch (1988) concluded that simulated climbing produced the same physiological responses (increased oxygen consumption and HR) as those found in treadmill running and cycling, activities that do not produce a pressor response. Brahler and Blank (1995) have attributed high HRclimb values to the need for greater perfusion to overcome the forces of gravity in the arms as they are held in an overhead position. Becque and Huber (1996) found that climbing greatly increased cardiac stress and elicited high energy expenditures to meet the energy demands of climbing.

The current study's climbing protocol may have been effective in limiting the influence of a pressor response on HRclimb. However, acknowledging the absence of oxygen pulse measurements, an indicator of the pressor response, limited this argument (Abadie, 1990).

Other factors that may have contributed to the differences in HRclimb between the climbing groups were route familiarity and overall climbing technique.

The recreational climbers in the present study had experience climbing on this wall in a class for 7 weeks prior to the study and had climbed before the class while the beginners had not. The experience gained by the recreational climbers probably aided them in choosing the best way to complete the route.

Hardy and Martindale (1982) found that experienced climbers, when compared to beginners, climbed much further on a more difficult route while using less energy. This finding suggested that skill and technique played an important role in determining the energy cost of climbing in these subjects. In the current study, the beginner climbers had a tendency to use their arms more than their legs which produced a less efficient climbing technique. It was considered less efficient because the smaller muscles in the arms fatigued more quickly than the larger muscles in the legs, which decreased climbing performance. Westcott (1992) noted that climbers who had engaged in a 7 week climbing program climbed more efficiently during a climbing test at the end of the program than they had 3 weeks into the program. Both of these studies supported the notion that good climbing technique and route familiarity could have produced the recreational groups' HRclimb responses in the current study.

Varied levels of aerobic fitness could also have produced the differences in HRclimb values between climbing groups. Westcott (1992) showed increased aerobic fitness capacities in climbers who had engaged in an 8 week climbing program. However, Williams and associates (1978) concluded that climbing produced a specialized type of fitness, one that improved climbing performance and not necessarily increased performance in other areas.

In the current study, HRrecv was not significantly different between beginner and recreational climbing groups. As mentioned earlier, HRrecv was considered the true baseline HR because it was recorded when subjects were given an opportunity to rest without being expected to climb immediately. This finding suggested that beginner and recreational climbers were similar at rest and changed only when they were faced with the task of climbing.

In the present study, RPE values were significantly greater in beginner versus recreational climbers. The RPE values varied from 11 to 12.6 for route 2 and 13.9 to 15.6 for route 4 in both climbing groups.

Keener and colleagues (1996) found similar differences in RPE values between experienced and novice groups. It was concluded that psychological stress may have contributed to the differences in RPE between subject groups in their study, but not to what degree. Bollen (1988) stated that the activity of climbing had the same demands as gymnastics with the added psychological pressure of performing further from the ground. The extent to which anxiety could have influenced the RPE values was not explored in the current study.

When the RPE values were recorded in the current study, most of the beginner subjects experienced some discomfort in the fingers and forearms which they expressed made climbing more difficult. Cole (1990) found that a static hang by a 70 kg person using only the fingers produced an enormous pressure of 1000 kPa on the fingers (20 kPa = 150 mmHg). This could have been a contributing factor to the differences observed in RPE values between the climbing groups. Likewise, Pandolf, Kamon, and Noble (1978) suggested that sensations of muscular discomfort and awkwardness may have caused elevated RPE values between subjects who used different laddermill climbing techniques.

In conclusion, it was determined that HRrest, HRclimb, and RPE values differed between beginner and recreational climbers. These differences between climbing groups could have been due to varied efficiency in climbing technique, a pressor response, or psychological factors, such as anxiety or route familiarity. These factors could be researched in greater depth to determine how each influences HR and RPE during climbing by including measurements of oxygen consumption in future investigations. The implications for the health and fitness industry that this study presented were fairly negligible, in that aerobic fitness benefits of rock climbing were not researched in any detail. However, in the context of instructional climbing programs, this study presented information that could be useful to physical education instructors. It provided instructors with information about how climbers at varied skill levels responded during a climbing exercise. With this information, an instructor could design a climbing program to fit the individual needs of the climber based on their overall skill.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

HEART RATE AND PERCEIVED EXERTION RESPONSES DURING CLIMBING IN BEGINNER AND RECREATIONAL SPORT CLIMBERS

Dr. Jeff Steffen 785-6535
Jeff Janot 782-9757

I, ______________________________, agree to participate in this study which will determine heart rate and perceived exertion differences between beginner and recreational sport climbers. Participation in this study requires that I perform two climbing trials on the climbing wall while my heart rate response is being monitored.

Climbing trials will consist of completing a climbing route from top to bottom or until failure. This will be done on one day of climbing. All testing sessions will be scheduled during my climbing class, or at my convenience. I also give consent to the researcher to publish the results of this test.

As with any exercise, there exists the possibility of adverse cardiovascular changes (abnormal heart rate response, dizziness, shortness of breath, etc.) during the climbing activity. I understand that with any climbing there exists the possibility of equipment failure and the danger of falling, but that all precautions have been taken by trained staff to minimize these risks to extremely rare. I am in full control of the testing procedure and can terminate the climbing trial at any point for any reason I deem fit. In addition, I will most likely feel tired or experience muscle soreness or tightness after each climbing trial.

I consider myself to be in good health and, to my knowledge, devoid of anything that would preclude my participation in these trials. I know that I may withdraw at any time without penalty.

I have read the above document and have been fully advised of the nature of the procedures and the possible risks and complications in it, all of which risks and complications I hereby assume voluntarily.

SIGNATURE OF SUBJECT____________________ DATE___________

SIGNATURE OF WITNESS____________________ DATE___________

APPENDIX B

15 POINT BORG RPE SCALE

Rating of Perceived Exertion*

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

*From Borg, G: Med Sci Sports Exerc 14:377-387, 1982.

APPENDIX C

REVIEW OF LITERATURE

REVIEW OF RELATED LITERATURE

INTRODUCTION

This review of literature relates to the physiological responses that occur during the activity of climbing. A lack of research on outdoor rock and indoor wall climbing requires the inclusion into this review of certain modes of exercise that are most similar to the climbing done in the present study. This review will examine the following areas: the physiological responses that occur during the act of climbing, the fitness benefits of climbing, the training involved with climbing, and various injuries associated with climbing.

Physiological Responses During Climbing

The majority of research studies on the subject of climbing dealt primarily with physiological effects of climbing at altitude (Hardy & Martindale, 1982). However, several studies have solely measured the physiological responses of the act of climbing itself, independent of the altitude influence.

Kamon, Metz, and Pandolf (1973) measured the oxygen consumption of subjects who exercised on a cycle ergometer and on a laddermill. Fourteen male subjects were asked to climb on a laddermill at varying speeds (7.5, 10.5, and 14 m/min) with an incline of 10%. They were also asked to pedal on a cycle ergometer at 50 and 70 rpm with and without external weights on the extremities. The training sessions were 5 minutes long, two to three times per day for a total of 21 sessions. The loading of the extremities produced little change in oxygen consumption compared to no loading while climbing the laddermill. The relative oxygen consumption was linearly related to the climbing speed only and not the loading. Comparatively, cycling with weight loaded extremities at a pedaling rate of 50 and 70 rpm elicited an increase in oxygen consumption of 1.34 and 1.44 ml/kpm, respectively.

Pandolf, Kamon, and Noble (1978) measured the physiological and exertional responses of doing positive (ascending) and negative (descending) work on a laddermill. Fifteen male subjects climbed up a 30% grade at a climbing rate of 7.5, 10.5, and 14.5 m/min for four climbing sessions that lasted 5 minutes each. Two climbing techniques were employed during this study: the foot-over-foot climb (regular climb) and the rung-by-rung climb (stepping climb). As expected, oxygen consumption was significantly greater during positive climbing than negative climbing in each successive climbing rate for similar climbing methods. The HR and RPE responses were significantly greater during positive climbing than negative climbing as well. The most interesting finding of the study involved the comparison of the RPE responses during positive (regular) climbing and negative (stepping) climbing. The RPE responses found in this instance did not differ significantly. It was generally accepted that feelings of muscular strain and discomfort reported by the subjects contributed to the choice of the RPE point. Although much less metabolically challenging than positive work, negative (stepping) climbing was reported to be just as stressful as positive climbing.

In another study that involved the use of a laddermill, Kamon and Pandolf (1972) compared the maximum oxygen cost of uphill running on a treadmill, cycling, and climbing on a laddermill. A group of male and female subjects (11 and 12, respectively) were tested to determine the differences between these modes of exercise. To determine maximum oxygen consumption while treadmill running, subjects were measured on consecutive days until the values obtained did not differ by more than 2.1 ml/kg/min. The cycling protocol consisted of cycling at a preset workload that was predicted to yield maximum oxygen consumption. Laddermill work was performed at a 30% grade until maximum was reached. The mean oxygen consumption for females was the greatest during climbing and the lowest during cycling. In contrast, the mean oxygen consumption for the males was greatest during uphill running and the lowest during cycling. Maximum HR was similar for climbing and running in most subjects and lower during cycling. Although climbing involves the use of upper and lower body muscles, this study showed that the use of both upper and lower body muscles to perform work does not always elicit a higher metabolic cost.

Brahler and Blank (1995) compared the maximum oxygen consumption responses during treadmill running, rowing ergometry, and simulated climbing on a VersaClimber. These modalities were chosen because treadmill running elicited the highest maximum values, rowing and climbing involved greater usage of the upper and lower extremities than does treadmill running, and the subjects were female collegiate rowers. The results of the study indicated that the greatest maximum oxygen consumption (L/min) value was obtained during VersaClimber exercise. Indeed, this may have been due to the subject population chosen who were highly trained in both upper and lower body segments. However, since the running values were higher than the rowing values, this may not have been the case. The researchers concluded that the higher climbing values might have been the product of good climbing technique and an excellent climbing protocol.

In an earlier study, Ballor, Becque, and Katch (1988) examined the relationship between oxygen consumption and climbing speed using a VersaClimber climbing simulator. Eleven male subjects were asked to climb on the VersaClimber until a maximum oxygen consumption was attained. Cycle ergometer and treadmill exercise tests were also performed by the subjects. The results of this study showed that simulated climbing elicited similar metabolic responses to increased workloads as was seen in treadmill and cycle ergometry exercise. In comparison, maximum oxygen consumption was the highest during treadmill running.

The following studies used a rock climbing wall and were closely related to the current study. Von Schurch, Haas, and Diers (1986) measured the influence that differing degrees of difficulty and coordination had on hemodynamic and metabolic responses in subjects who wall climbed. The subjects in the study were asked to climb three routes with varied difficulty. In addition to these trials, the subjects were asked to climb a self-selected route once in a "speedy" manner and once in a "moderate" manner. Blood lactate concentration and HR were measured after each climb and were found to be highest after the most difficult climb and lowest after the easiest. The "speedy" climb that was performed resulted in higher HRs and lactate levels than the "moderate" climb. In this comparison, a negative correlation was shown between elapsed time and lactate. These results indicated that a better, more controlled climbing technique led to an economic rate of energy expenditure.

Williams, Taggert, and Carruthers (1978) observed the HR responses and plasma catecholamine concentrations of 11 male rock climbers during 2 climbing trials. Each subject was administered a placebo tablet 1 hour prior to the first climb and then was given a beta-blocker (oxprenolol) 1 hour prior to the second climb. Mean maximum HRs were significantly higher following the administration of the placebo tablet. The only significant difference in the plasma catecholamine concentration was observed in the adrenaline (epinephrine) measurements during the placebo trial. The subjects remarked that the routes were relatively easy physically, but harder on the psyche because of the steepness of the route. The results of this study showed that, overall, climbing challenged the climber psychologically more so than physiologically. The researchers stated that an increase in noradrenaline (norepinephrine) is associated with an increase in physical exertion. The absence of an increased norepinephrine concentration pointed to the influence of anxiety on the increased HR response. With this rationale in mind, the increased HR response during this climb may have been due to decreased vagal tone rather than increased hormonal activity.

Other physiological (and psychological) elements such as lactate concentration, caloric expenditure, power, and psycho-somatic features were measured in other studies that involved the activity of rock climbing (Becque & Huber, 1996; Hardy & Martindale, 1982; Keener, Uttech, & Gilbertson, 1996; Lefebvre, 1980; Mace, 1979).

Lefebvre (1980) and Mace (1979) studied psychological and arousal experiences during climbing. Lefebvre (1980) found that beginning climbers experienced different feelings and attitudes before climbing, while climbing, and after climbing. In general, climbers felt excited to take on the task at the beginning and felt self-assurance and positive about the experience after the climb.

Mace (1979) investigated what effect pretraining to produce task familiarity had on arousal during abseiling. The pretraining consisted of practicing smaller abseiling tasks before taking on larger abseiling tasks. The results showed that the practice abseils had no effect on reducing anxiety during the bigger abseils. Certainly through any type of practice or pretraining one develops a learning effect, be it a great or small improvement in overall performance.

Hardy and Martindale (1982) compared the energy costs of climbing in beginner and expert climbers. The inexperienced climbers were required to climb for as long as possible on a route with a 4a/4b difficulty rating. The experienced climbers did the same protocol, but on a route with a 5b/5c difficulty rating. Prior to and after each climb, HR, tidal volume, oxygen consumption, and lactate concentrations were taken for each subject. Oxygen consumption and HR were measured during the climb as well. Energy costs for the climbs were converted to calories per minute (kcals/min) which allowed for a comparison to be made to other activities. The mean energy costs for the subject groups were 6.7 to 9.3 kcals/min which were similar to the energy demands of walking, canoeing, tennis, cycling, and swimming. No differences were found in the energy cost for the climb and the energy cost per minute between the two subject groups. This suggested that there was no difference between the energy costs of climbs with varying difficulties for climbers who were familiar with the difficulties. Conversely, the experienced group had a significantly lower proportional energy cost per meter than that of the beginners. In fact, the experts climbed further in the same time period on a more difficult route while using less energy than the beginners. Lactate levels indicated that the expert group had a much greater resistance to lactate buildup than the beginner group. The researchers concluded that skill and technique probably played a larger role in climbing than what had been previously thought.

Becque and Huber (1996) determined the exertional intensity and energy expenditure parameters of rock climbing. Six elite climbers climbed a vertical and an overhang route (three times each) that was categorized with a difficulty level of 5.10. Oxygen consumption, ventilation, and HR were measured during the climb and later compared to maximum values obtained prior to the climbing session. Climbing HRs were 185 bpm (93% of maximum) for the vertical climb and 190 bpm (96% of maximum) for the overhang climb. The climbing minute ventilations were 56 L/min for the vertical climb and 59.9 L/min for the overhang climb. The vertical climb elicited an average relative oxygen uptake of 41.8 ml/kg/min (62% of maximum) and the overhang climb elicited an oxygen cost of 46.9 ml/kg/min (65% of maximum). Energy expenditures for the vertical and the overhang climb were measured at 14 kcals/min and 14.7 kcals/min, respectively. The researchers concluded that, according to these results, climbing was a moderate intensity activity which produced high rates of energy expenditure that placed high stress on the cardiovascular system.

Keener, Uttech, and Gilbertson (1996) tested the hypothesis that the characteristics of low power output and high HR responses would represent inexperienced climbers in a climbing situation. Thirty-two volunteers were divided into three groups (novice, intermediate, and experienced) based on overall experience. There were no differences in the resting HR between groups, but climbing HRs were significantly lower in the experienced climbers. Power output, calculated by using body weight, vertical displacement, and elapsed time, was significantly greater in experienced climbers compared to novice climbers. In contrast, there was no difference between the experienced and intermediate groups regarding power output. These results indicated that the high HRs in novice climbers may have been the result of a pressor response and not increased aerobic activity. The researchers also concluded that stress may have contributed to the HR responses due to the higher RPE values that were collected from the novice climbers.

Fitness Benefits of Rock Climbing and Training

The physical challenge of rock climbing has been generally regarded as beneficial from a fitness standpoint. However, the magnitude to which the activity of climbing benefits one's fitness has not been studied in great detail. Several articles have been published on the benefits of climbing and the training involved with climbing (Kascenska, DeWitt, & Roberts, 1992; Shirer, 1990; Westcott, 1992).

Westcott (1992) studied the benefits of rock climbing with the use of a Treadwall climbing simulator. The subject groups were comprised of 20 climbing and 11 nonclimbing subjects. The exercise group climbed twice a week for 7 weeks and each session consisted of continuous climbing for 15 to 20 minutes. Fitness tests were completed on each subject before and after the 7 week climbing program. After 3 weeks of climbing, the climbing subjects were tested on a specific climbing protocol. The climbing level, time, and distance were recorded after the test was terminated. After 7 weeks, the subjects were tested again on the same climbing protocol. The results indicated that the exercise group significantly improved their body composition, joint flexibility, and strength after participating in the climbing program. Climbing performance also improved in the subject group with increased climbing time, level, and distance during the posttraining climbing test. The researcher concluded that climbing was an intense activity that was challenging and satisfying to the subject group.

A second study done by Westcott (1992) investigated the cardiovascular changes that occurred as a result of a climbing training program. Ten men and women participated in an 8 week training program in which they climbed twice a week, 15 to 20 minutes each session. Each subject completed a fitness test before and after participating in the training program. The results revealed that the subjects significantly improved their predicted maximum oxygen consumption from 44 ml/kg/min to 48 ml/kg/min. Coupled with the results found in the previous study by Westcott, the researcher concluded that improvements in body composition, flexibility, strength, and endurance were made by subjects who engaged in a climbing program.

Jacobs (1993) outlined several ways professional climbers trained in an article designed to advise the aspiring climber. According to the author, climbing produced better overall fitness in climbers, but having a solid cardiovascular endurance base developed outside of climbing was beneficial. The benefits of an intense weight training program were not generally accepted by most veteran climbers because they believed that enough strength was gained by just climbing. The climbers that were interviewed also agreed that flexibility was very important when climbing to overcome difficult routes. Finally, the author stated that climbing is as much mental as it is physical and that the mental part of climbing should receive more attention.

Kascenska and associates (1992) outlined fitness guidelines for students who engaged in the sport of rock climbing. The authors addressed how fitness related to climbing and what training principles and guidelines were useful to climbing students. The components of fitness were listed as muscular strength, muscular endurance, cardiovascular endurance, and flexibility. By developing these components along with the three energy systems (ATP-CP, anaerobic, and aerobic), the authors felt that climbing skill and the prevention of injuries would be increased. The authors stated that, to maximize the benefits of training, climbing techniques should be developed along with general fitness. This was done by wall climbing, which the authors agreed was the best way to train. The authors concluded that by carefully designing a training program that challenges the climber, while staying within their limitations, led to increased performance, enjoyment, and a reduced chance of injury.

In a 1990 article, Shirer described how to develop a climbing conditioning class for university students. The author outlined the objectives of a class that was developed at Montana State University. The objectives of the class were to improve overall fitness, improve mental self-discipline and confidence, provide climbers with information to be used in the future, and familiarize the climbers with fitness concepts related to climbing. The class was divided into three topics: flexibility, strength, and technique. Advice and techniques were given to achieve greater flexibility and strength training was taught in the weightroom. Climbing techniques were taught to the students with emphasis on proper balance and footwork. The author concluded that the students who participated in the class expressed that they were in better shape for the outdoor climbing season than expected.

Injuries Related to Climbing

Rock climbing is generally considered to be a high risk sport (Cole, 1990). The term high risk described the risk climbers take of experiencing traumatic injury due to a fall. The majority of climbing injury studies have focused on the traumatic types of injuries as well as altitude sickness and exposure conditions (Maitland, 1992).

However, with the growing popularity of climbing, coupled with improved safety techniques, more people have been climbing with greater frequency. With the advent of indoor climbing facilities, climbers were now training and climbing year round (Bollen, 1988). This has led to an increased prevalence of overuse injuries in climbers which had occurred less frequently than traumatic injuries in the past. Overuse injuries were categorized as occurring in the regions of the upper or the lower limbs of the body.

Upper and Lower Limb Injuries

In one of the most comprehensive studies done on climbing injuries, Maitland (1992) outlined the most common injuries that occurred in a group of 148 climbers. Traumatic injuries accounted for 18% of all of the injuries reported. The majority of traumatic injuries were reported as affecting the lower limb area of the climbers. In contrast, 82% of the injuries reported were described as being overuse injuries. Upper extremity injuries were the most common and accounted for 63% of all overuse injuries. Hand and elbow overuse injuries were the most frequently reported and accounted for 28 and 19% of all upper extremity injuries, respectively. Lower extremity injuries, more specifically the knee, were less common and accounted for 4% of all injuries reported. The results of this study clearly showed that the predominance of injuries that occurred were due to overuse. The general frequency of upper extremity injuries revealed the fact that climbing subjected the upper extremities to greater levels of stress than the lower body. Performing difficult climbs, especially on a safe and controlled indoor wall, also contributed to the frequency of overuse injuries.

Cole (1990) attributed these overuse injuries to the increased intensity of training which allowed climbers to attempt more difficult climbs. The researcher added that finger tendon injuries were a particularly problematic overuse injury. These injuries were due to the extreme pressures placed on the fingers which can reach approximately 1000 kPa (20 kPa = 150 mmHg pressure) during a static hang using two fingers.

In a study by Bannister and Foster (1986), the researchers presented four case studies of climbers with overuse injuries. The injuries in this study were attributed to intensive training done by each subject as each injury occurred in the upper extremities.

Bollen (1988) surveyed 86 climbers (76 males and 10 females) about any injuries that they had experienced. Of all the injuries that occurred, 89% involved the upper extremities and 50% of these involved the wrist and hand. To further clarify these percentages, two interesting findings were made in this study. The first was that almost half of the injuries reported occurred during training. These injuries may or may not have been attributed to overuse. The second finding was the absence of a correlation between injury occurrence or type and the difficulty of the climbing routes. Since the survey examined injury occurrence during intensive training periods, the amount or volume of training sessions may have contributed to the climbing injuries. Improper warm up techniques may have contributed to the occurrence of injury as well.

In a later study, Bollen and Gunson (1990) further expounded on climbing injury research and examined the characteristics of hand injuries. Sixty-seven competitors at a climbing competition were examined for hand injuries, both past and present. The most commonly afflicted site was the finger, more specifically the proximal interphalangeal joint. This injury was due to the high pressures placed on the fingers while the climbers gripped on to small holds. The researchers concluded that these injuries can be prevented through proper training and stretching. However, there was little research that dealt with proper training techniques and injury prevention to guide climbers in their training regimen.

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