

Physical Intensity of Movement along Horizontal, Vertical, and Lateral Climbing Planes

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Abstract The purpose of this study was to determine the physical intensity levels and differences between the horizontal, vertical, and lateral planes of movement during indoor climbing for high school students. Subjects were 27 adolescents (male=22, female=5) aged 14-18. Participants wore an ActiGraph GT3X accelerometer during two different 5-minute climbing sessions that took place on a vertical/horizontal climbing wall. The intensity of their climbing was determined using the ActiLife 6 software, as well as the Freedson (2005) cut-points. The data revealed that the subjects performed moderate to very vigorous exercise 56% of the time during climbing, and that there were statistically significant intensity differences between the three planes examined. Subjects of this study worked harder during lateral movement than during vertical or horizontal movements. The lateral plane refers to the climber's movements towards and away from the wall, typically for stabilization. These results suggest that a large portion of intensity while climbing did not come from how fast or how far subjects climbed, but rather by simply staying on the wall.

Keywords: climbing, accelerometer, exercise intensity levels, youth, physical activity

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1. Introduction

Today more than one-third of adults in the United States are obese, and obesity-related conditions are considered the leading causes of preventable death [1]. Adults continue to fail to meet the Physical Activity Guidelines for Americans, which recommends 60 minutes of moderate exercise daily. Sadly, these unhealthy trends appear to develop early in life as health-related problems such as childhood obesity and Type II diabetes are becoming increasingly prevalent [2]. In fact, obesity among children and adolescents has become one of the most serious public health concerns in the 21st century [3]. Evidence continues to show that a majority of children and adolescents fail to attain the physical and mental health benefits that could be acquired through regular physical activity [4]. If the current trends continue as they are, it is projected that there will be a significant burden on health-related services in the future [5].

Physical education (PE) settings provide a unique environment for developing healthy habits in children and adolescents. Because children participate in PE classes throughout the early years of their lives, typically for 12

or more years, PE can significantly aid in the development of positive physical self-perceptions, self-esteem, and physical activity in and beyond the school setting [2]. Unfortunately, many programs still rely on implementing traditional, ineffective practices, designed simply to keep students busy. This has led many students to loathe PE and physical activity [6].

Indoor climbing is a physical activity that has many promising benefits for a PE setting. Many students do not enjoy traditional sports, such as football and basketball. Climbing on the other hand, which requires muscular strength and endurance, coordination, balance, and a sense of adventure, can appeal to students [7] including in elementary students [29]. Climbing walls can challenge a student's problem solving abilities as well as their physical strength [8]. Physical education programs that focus on lifetime physical activities such as lifetime recreational and adventure selections are much more likely to make a lasting impression [6].

A survey by Costanzo, Legaspi, and Mak [9] of over 450 students revealed that 80% were interested in participating in rock climbing in a PE class. Indoor climbing is a great alternative choice to other traditional workouts that are less engaging [8]. Climbing, if managed effectively, can provide a lifelong recreational experience that is safe, educational, and beneficial [10].

Climbing has been described as a vigorous activity that demands muscular power, muscular strength, flexibility, and aerobic endurance [11]. In the 1990's public schools, gyms, universities, and health clubs began building artificial rock walls. Today, many of the rock walls located in public schools are not being used. Teachers report not incorporating rock wall climbing in their programs, due to the belief that rock climbing does not significantly improve physical fitness [12]. However, muscular strength, muscular endurance, cardiorespiratory fitness, and flexibility have all been identified as benefits of rock climbing [12].

Some of the first climbing studies evaluated upper body strength. Baláš and Bunc [13] examined the possible influences of climbing on young children. They evaluated the influence by measuring static strength, muscular endurance, and balance. The study reported a significant strength and endurance effect from climbing [13]. Statistical analyses indicated that there was a significant impact on forearm and bent arm static strength [13]. Results also indicated that physical improvements in strength and muscular endurance were greatest in students participating during out of school activities for at least 60 minutes a week. This indicates that climbing has a more significant impact when paired with other physical activities [13].

Most studies reporting muscular strength and endurance of climbing have focused on the upper body, forearm, and handgrip [14,15]. While these studies have provided some valuable insight into the area of muscular strength used during climbing, it is too restricted. Good climbing technique requires the use of legs as the primary means of progress while rock climbing [16]. Therefore, measuring only upper body strength and endurance of climbers delimits the proper examination of total muscular physiology necessary for rock climbing.

To make matters worse, some studies have reported the physical intensity levels of rock climbing by studying subjects' heart rates (HR) [17,18]. Monitoring HR is often used to determine physiological exertion when exercising because it is simple, cost effective, and convenient. However, there are well-established factors other than exertion, which increase heart rate such as anxiety, excitement, stress, drugs, and caffeine. Therefore, simply measuring the HR of subjects while climbing would not be a reliable measure of physiological intensity [20]. For instance, it is not uncommon for some students to experience an anxiety-manifested "fear factor" when climbing, which increases HR. Therefore, it is impossible to discern how much of the HR increase was due to anxiety or physical exertion [20].

While rock climbing is an engaging and exciting activity, the physical intensity levels incorporated with climbing among adolescence is largely unknown. Accelerometers are a promising tool for measuring the physical intensity of climbing, and have provided substantial evidence of being a valid and reliable method for the assessment of physical activity [21]. If students are going to participate in climbing in PE as a way of meeting the Physical Activity Guidelines, it is important to understand how vigorous it actually is.

The purpose of this study was twofold: First, to determine the physical intensity levels of lateral, horizontal, and vertical indoor climbing for high school aged students. Second, to determine whether there is a significant difference of energy requirement between the three planes of movement.

2. Methods

2.1. Sample Selection

Twenty-seven students (22=male, 5=female) from a rural high school in Washington State were used as subjects in this study. The subjects' ages ranged between 14 to 18 years old (Mean=16.5). Before the study began all students in multiple PE classes received a recruitment packet containing information about the study, a consent form, and health-screening questionnaire. Any student who handed in a signed parental consent form were allowed to be subjects, and subsequently screened for safe participation using a health history appraisal. Those subjects who were approved then completed a demographics questionnaire. This questionnaire was used to acquire information on each subjects age, gender, ethnicity, activity participation, and climbing experience. Prior to any data collection, the study had been approved by a Human Subjects Review Committee.

2.2. Instruments

The weight of each subject was measured without shoes using a calibrated physician beam scale to the nearest tenth of a pound. Subjects' height were measured without shoes using a nylon measuring tape to the nearest quarter inch. Four Actigraph GT3-X triaxial accelerometers, which measure movement on three axes (Axis 1=Vertical (X), Axis 2=Horizontal (Y), Axis 3=Lateral (Z)), were used to assess movement intensity. The GT3X has been validated in multiple studies examining the intensity levels of various physical activities across all ages [22,23]. Researchers have concluded that the GT3X is a valid and reliable tool for measuring energy expenditure/exercise intensity in youth and adults [22].

The activity monitors were placed at the anterior axillary line of the right hip secured by a non-invasive elastic band. Intensity was measured every one second (300 seconds total). The data collected by the accelerometers was downloaded into the ActiLife 6 data analysis platform. ActiLife is Actigraph's premier data analysis software platform, which features analysis tools and data management options that support a broad range of research objectives, and uses independently developed and validated algorithms

Data collection was completed on a vertical climbing wall measuring 32 feet tall and 32 feet wide, and a horizontal wall measuring 10 feet tall and 40 feet wide. The vertical wall had an average of .49 holds per square foot, and the horizontal wall had .53 holds per square foot. Both climbing walls were designed and installed by Everlast Climbing Industries. Protective climbing pads were located beneath each wall to minimize injury in the event of a fall.



Figure 1. The Actigraph GT3X accelerometer measures movement on three axes

2.3. Procedures

Subjects in the study completed five minutes of continuous climbing on both a vertical and horizontal wall. These five-minute climbs were completed in two different climbing sessions at least 2 days apart. The type (horizontal or vertical) of wall a subject climbed first was chosen at random by the investigators. At the start of each climbing session, investigators communicated climbing and safety procedures with each subject and reviewed the climbing walls and equipment. This familiarization trial was done to increase the safety and comfort levels of participants, as well as decrease variability.

Before each trial an activity monitor was initialized for each subject and synchronized to a clock on the investigators personal computer. All subjects began climbing from the same location on each wall. They were instructed to climb across or up the wall as quickly as they could while feeling under control and safe.

Before a participant began their climbing session on the vertical wall they were fitted with a harness and safety helmet, and attached to the climbing rope, anchored at the top of the wall. The vertical wall was certified for safety by Everlast Climbing industries. All subjects were belayed by one of the investigators. All basic safety protocols were followed including verbal commands of readiness, and safety checks of connection, harness, and rope.

Belayers used Grigis for belaying. The Grigri is a belay device with assisted braking that is attached to the belayer's harness. The device assists significantly in catching a fall, and also allows a belayer to hold and lower the climber safely with little effort. The Grigri is designed so that if the belayer lets go of the rope, it would immediately arrest the fall. Once subjects were harnessed and given directions, they were fitted with an Actigraph GT3-X triaxial accelerometer. The harness did not interfere with the accelerometer placement or movement as participants climbed.

When climbing the vertical wall subjects were directed to stay away from the obstacle features (e.g. overhangs or roofs on the wall). Climbing was completed strictly on the flat face of the wall and no roof or overhanging sections of the wall were used. If a subject fell off the wall they were instructed to get back on the wall, from where they fell, and keep climbing. If a subject reached the top of the vertical wall before their five minutes were up, they were belayed down the wall (at an average rate of 9.2 seconds/descent) and ascended again. This continued until the end of the five minutes.

When climbing the horizontal wall, subjects were instructed to climb across the wall using whatever route they chose. If at any point a subject fell off the wall, they were instructed to get back on, from where they fell, and continue climbing. When a subject reached the end of the wall they continued climbing by reversing the horizontal direction of movement.

Once each five-minute climbing session was completed, subjects were instructed to descend the wall and give their activity monitor to the investigator. Data were immediately downloaded to the *ActiLife 6* computer software. Once the data were downloaded the accelerometer was re-initialized for the next subject and the process repeated.



Figure 2. Participant climbing the 32-foot vertical climbing wall

3. Results

Of the 27 subjects, 24 had complete data on both climbing walls (males=20, females=4). Three subjects' data on the horizontal wall were excluded due to time synchronization errors during the data collection process. Using the cut-points available in the ActiLife software, the data were analyzed to determine the physiological intensity of the participants' climbing. Each five-minute recording of horizontal and vertical climbing sessions were calculated in the ActiLife software using the [24] cut-points. These cut points were developed, for children between the ages of 6 to 18 years old, using past published research aimed at quantifying activity levels in children using the ActiGraph products [24]. The counts per minute (CPM) recorded by the accelerometers were compared to these cut points to determine exercise intensity. "Counts" are a result of summing post-filtered accelerometer values (raw data at 30Hz) into epoch lengths. The value of the counts will vary based on the frequency and intensity of the raw acceleration. This means the harder an individual worked, the more counts they would record.

The intensity of climbing was determined for each of the recorded climbs using the [24] cut-points. The ActiLife software determined the amount of time each participant spent within each intensity level. Once these data were produced, the mean amount of time in each intensity level was determined Table 1. Results showed that participants spent the most time in the moderate exercise intensity range with the mean being 141.47 (± 39.40) seconds. Furthermore, the data revealed that the subjects were performing moderate to very vigorous exercise 56% of the time.

The GT3X accelerometer measured subjects' movement on three axes' (Axis 1=Vertical (X), Axis 2=Horizontal (Y), Axis 3=Lateral (Z)), while they climbed. The activity monitor tracked the participants' counts within each axis as they climbed. When downloaded into the ActiLife 6 software, investigators were able to see the counts recorded within each axis for every second of a subject's climb.

Table 1. Mean Intensity of Activity Counts in Climbing by Minutes and Seconds

Intensity Level	N	Sedentary	Light	Moderate	Vigorous	Very Vigorous
Mean Time within Intensity Level (min: sec)	51	1: 35.73 ± 50.76	0: 38.24 ± 10.25	2: 21.47 ± 39.40	0: 22.12 ± 20.34	0: 03.49 ± 3.86

Table 2. Descriptive Statistics of the Counts by Axis

Axis	N	Mean	Standard Deviation	Standard Error	Lower Bound	Upper Bound	Minimum	Maximum
1-Vertical	51	6670.71	3467.608	485.562	5695.43	7645.99	1473	16876
2-Horizontal	51	7697.43	2951.203	413.251	6867.39	8527.47	3103	15100
3-Lateral	51	9912.16	3652.040	511.388	8885.00	10939.31	4564	18851
Total	153	8093.43	3612.378	292.043	7516.44	8670.42	1473	18851

Table 3. Analysis of Variance (ANOVA)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	279925037.686	2	139962518.843	12.324	.000
Within Groups	1703564829.843	150	11357098.866		
Total	1983489867.529	152			

Table 4. Scheffe Post Hoc Analysis of Significant Difference between Axes

(I) Axis Type	(J) Axis Type	Mean Difference (I-J)	Standard Error	Significance	Lower Bound	Upper Bound
1-Vertical	2	-1026.725	667.365	.309	-2676.72	623.26
	3	-3241.451*	667.365	.000	-4891.44	-1591.46
2-Horizontal	1	1026.725	667.365	.309	-623.26	2676.72
	3	-2214.725*	667.365	.005	-3864.72	-564.74
3-Lateral	1	3241.451*	667.365	.000	1591.46	4891.44
	2	2214.725*	667.365	.005	564.74	3864.72

Table 2 describes the mean number of counts within each axis during the climbing sessions. In Table 2 it is evident that Axis 3 (lateral) had the highest mean number of counts at 9912.16 (± 3652.040). This indicates that subjects experienced more frequent and intense movement towards and away from the wall as they climbed, as opposed to their movement vertically (6670.71 ± 3467.608) or horizontally (7697.43 ± 2951.203). This lateral movement towards and away from the wall is typically a result of a climber trying to stabilize himself or herself on the wall.

All axis counts were combined and calculated by Axis to determine whether a difference in expenditure exists between the three planes. A One-Way Analysis of Variance (ANOVA) was used to determine whether there was a significant difference between the planes. As seen in Table 3, there was a significant difference ($p < .0001$) among the three axes ($F = 12.324$).

A Scheffe post hoc analysis was used to determine whether there was a significant difference in counts between the three axes when compared to each other. The Scheffe was used recognizing that it is a more conservative post hoc for this type of analysis. As seen in Table 4, the analysis showed that there was no significant difference between Axis 1 (Vertical) and Axis 2 (Horizontal) at .309. Results of the analysis did indicate a significant difference between Axis 1 and Axis 3 at $p < .0001$, and Axis 2 and Axis 3 at $p < .005$. This confirms that climbers are experiencing more frequent and intense movement in the lateral axis of movement than in their horizontally or vertically movements.

4. Discussion

Results from this study can be used to provide a valuable insight into the intensity of climbing. Without an

understanding of the intensity levels involved in climbing, there is no way to accurately design programs to meet the daily-recommended demands for physical activities. The USDHHS [25] and Surgeon General [26] both recommend moderately intense activities for children in order to improve health. Climbing at these intensity levels demands glucose for muscle physiology, the more used the less stored, which decreases overall adiposity and the onset of type II diabetes.

The results of this study can be interpreted to conclude that horizontal and vertical climbing is a moderately intense form of exercise. Participants in the study experienced moderate to very vigorous exercise 56% of the time. This indicates that climbing can contribute to an adolescent's ability to meet the recommended level of moderate physical activity. This is important information for physical educators and climbers alike.

The intensity of indoor climbing is comparable to many of the physical activities implemented in PE. According to the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) [27] activities such as bicycling (on level terrain or stationary), walking at a brisk pace, light calisthenics, and weight training are all defined as moderate activity. Many students do not enjoy the traditional practices like calisthenics and weight training, which are often used to keep students busy during PE [6]. Climbing offers many physical benefits as well as a sense of adventure that many students enjoy [7,8].

The results of this study were used to deduce that individuals put more work into their lateral movement during climbing than their vertical or horizontal movement Table 2. This lateral movement refers to the climber's movements towards and away from the wall, typically in an effort to stabilize themselves. This suggests

that a large portion of work being done while climbing does not come from how fast or far they climb on the wall, but rather just keeping themselves on the wall. This would suggest that individuals are still working hard and experiencing intense exercise when they are seemingly resting on the wall.

When a climber is holding themselves on the wall with little movement they are actively using the muscles in their core, arms, and hands, as well as their legs, in order to stabilize themselves on the wall. Even though an individual may be moving slowly while they climb, it doesn't necessarily mean that they are not working hard. When an individual is not moving, their muscles are engaged in isometric contractions in order to hold themselves on the wall. This means that while they are not moving, their muscles are still highly engaged, which aids metabolism by using more fatty acids and glucose. In addition, moderate intensity exercise contributes to increasing insulin sensitivity, all of which is good for decreasing adipose and Type II diabetes.

While accelerometers have been identified as an accurate and objective tool for measuring energy expenditure and exercise intensity [22], it may not provide a complete understanding of the physiology involved with climbing. These results contribute to our understanding of the intensity of movements while climbing, however, further studies may be needed in order to get a more complete picture. One recommendation for a future study would be to have participants wear accelerometers on their waist and wrist to get a better measurement of their full body movement. It would also be interesting to measure changes in body composition for youth participating in a year-long climbing regime.

5. Conclusion

Being physically active is one of the most important steps to improve overall health [28]. In order for kids to pursue physical activity, they need to be introduced to activities that they find enjoyable. Indoor climbing is a physical activity that has many promising benefits for a PE setting. Many students do not enjoy traditional sports, so climbing walls, which involve upper body strength, coordination, balance, and a sense of adventure, can appeal to these students while providing a sufficient form of physical exercise [7]. Climbing walls can challenge a student's problem solving abilities while challenging their physical strength and endurance [8]. Climbing is a great alternative choice to other traditional workouts that are less engaging [8]. Research has shown that PE programs which focus on lifetime physical activities such as recreation and adventure selections are much more likely to keep their students active for life [6].

If climbing is going to be used in PE as a way to get kids active and meeting the physical activity, it is important to have an understanding of the intensity involved in the activity. By analyzing the intensity that school-aged individuals experience when climbing, this study will provide PE teachers with valuable information that they can relate to climbing in their own physical education programs. This study collected some of the first reliable and objective data on the physical intensity of

climbing in adolescents. The results of this study show that indoor climbing in children aged 14-18 is a moderate form of exercise. Results from this study can be used to provide insight into the intensity and the potential benefits for using climbing as a quality physical activity that can be used to meet the suggested daily minimum of 60 minutes of moderate to vigorous physical activity. The authors published a previous study using elementary children, which supported this study with similar results. [29].

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