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Climbing-Specific Fitness Profiles and Determinants of Performance in Youth Rock Climbers

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Abstract: With the recent decision by the International Olympic Committee to include rock climbing in the 2020 Olympic Games, climbers and coaches are seeking information to enhance training methods and improve performance. The purpose of this study was two-fold: (1) to evaluate climbing-specific fitness and establish percentile rankings among youth climbers; and (2) determine the relationship between fitness and climbing performance. Anthropometrics, fitness, and performance on three indoor bouldering problems ranging in difficulty from V0-V8 were assessed in 64 youth climbers (35 girls, 29 boys) aged 7-17 from the United States. Data are reported by age groups (7-11; 12-17 y) and gender. Percentile rankings of fitness scores were computed for girls and boys separately. Analysis of variance was used to compare fitness by age groups and by gender. Regression analysis evaluated the association between climbing performance and fitness. Fitness scores were generally higher among boys than girls, and older vs. younger climbers. Multivariable linear regression revealed that, after adjusting for age, gender, and anthropometrics, fitness variables explained 49% of the variance in performance. Climbing-specific fitness measures previously established on adults are associated with bouldering performance in youth climbers, and therefore may be useful for monitoring progress in training.

Key words: Rock climbing, children, climbing-specific fitness, performance.

1. Introduction

The sport of rock climbing has markedly grown in popularity over the past 20-25 years as both a recreational activity and competitive international sport. Improvements in safety equipment and techniques, and the construction of indoor climbing walls in fitness centers and other recreational facilities have increased participation across a wide range in age and ability of men, women, and youth. In light of the recent decision by the International Olympic Committee to include rock climbing in the 2020 Olympic Games, coaches and researchers are seeking information to enhance training methods, evaluate climbers' training status, and monitor their progress.

Much of the early research on rock climbers' fitness described traditional measures of muscular and aerobic fitness. For example, maximal aerobic power (VO_2max) has been assessed in climbers during treadmill running [1, 2], arm ergometry [1], or, in one study, a rowing ergometer bolted vertically on a wall that required subjects to perform double-arm pulling motions to exhaustion [3]. This latter study [3], conducted on a small sample of elite rock climbers, compared peak VO_2 and heart rate (HR) values from the upper body ergometry test to those obtained during traditional treadmill testing, and found that although the treadmill test yielded higher VO_2 and HR values, only the upper body protocol was associated with climbing performance of the participants.

Similar to the use of mostly standardized laboratory

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measures of aerobic fitness, muscular fitness of climbers has been assessed most often using handgrip dynamometry to determine absolute strength and/or endurance of the forearm and hand [4-6], with muscular endurance assessed by reporting repetitions to failure at a given percentage of maximum force output [7]. Whereas both hand-grip dynamometry and rock climbing involve isometric contractions of the forearm, hand and fingers, hand and finger holds during rock climbing differ greatly from that used in handgrip dynamometry, as illustrated by Watts [8]. This difference has been suggested to partially explain the lack of difference in absolute grip strength between climbers and non-climbers [8, 9], as well as its poor association to climbing performance [10].

The need for climbing-specific measures of fitness was addressed by a group of climbing researchers and coaching experts that assembled at the 2014 International Rock Climbing Congress in Switzerland. A year later that group, all members of the International Rock Climbing Research Association (IRCRA), published a comprehensive manual on climbing-specific tests, largely based on previous research on adult climbers [11]. Further, while research on rock climbing has greatly increased over the past decade, very few published studies exist on youth climbers, yet it is from this group that future Olympians will be selected. Thus, there appears to be a gap in evidence on what constitutes fitness in young climbers, how best to measure it, and how it relates to performance in youth competition. Thus, the purpose of our research was two-fold: (1) to evaluate climbing-specific fitness and establish percentile rankings among youth climbers using the 2015 test battery developed by IRCRA on adult climbers; and (2) determine the association between fitness and climbing performance in bouldering. We hypothesized that the selected sport-specific measures would be positively associated with performance in a bouldering task.

2. Materials and Methods

2.1 Study Design and Participants

The present study was designed as a single sample observational study. Inclusion criteria included: boys and girls between 7-17 years of age who were enrolled in the youth program at a large urban indoor rock climbing center in southern California, U.S.A; physically and emotionally healthy and able to participate in the study, as determined by family physician approval to participate; English language skills sufficient to understand the assent form and verbal instructions during testing; signed parental consent. Study participants had been enrolled in the youth climbing program between 1-6 years (mean = 2 yr). They trained in indoor bouldering and sport climbing 2-6 d/wk for an average of 2 hours per session and 6 hr/wk, and competed in local (90% of sample), regional (45%), divisional (15%), and/or national (5%) competitions. Training duration at each coached session was divided approximately equally between bouldering and sport climbing. The study was approved by the University of California, San Diego Institutional Review Board. Participants and their parents provided written consent to participate.

2.2 Measures and Procedures

Anthropometric and climbing-specific fitness measures were conducted according to procedures reported in the *IRCRA Performance-Related Test Battery for Climbers* (Version 1.6) [11]. Measures were conducted on 2 non-training days separated by 1-2 weeks. Most of the assessments each required no more than several seconds up to 10 minutes to complete, for a total of approximately 45-60 minutes of actual exertion time by participants, excluding a 10-minute warm-up led by an instructor before testing began. However, children were at the climbing center for up to two hours at each of the two sessions, as multiple 5-minute recovery periods were enforced periodically. Water was provided during the measurement period, and a light snack afterward. Climbing performance was assessed twice beginning approximately two weeks after completion of the fitness measurements.

Anthropometric measures included body weight (kg), height (cm), arm and leg length (cm), and arm-span (cm). Weight was measured on an Eat Smart Precision Digital scale (Model HCG-R7), and recorded to the nearest 0.1 kg. Limb lengths and arm span were assessed using a tape measure, and were recorded to the nearest 0.1 cm. Arm length was measured on the dominant arm as the distance from the acromion process to the tip of the middle finger, with the arm extended by the side, fingers extended and palms of hand facing the torso. Leg length was measured on the dominant leg (foot used to kick a ball), in the standing position, as the distance from the greater trochanter to the center of the lateral malleolus at the ankle. Arm-span was measured as the distance between the tips of each middle finger as the participant stood facing a wall with feet together and arms and hands fully extended horizontally and touching the wall.

Climbing-specific fitness measures included the bent arm hang (left, right, and both arms), pull-ups, finger strength (left and right hands), and power slap (left and right arm). The testing procedures for these measures were followed as described in the IRCRA manual [11]. In addition, we included a vertical jump test for leg power (Just Jump System; Probotics, Huntsville, AL), dead/straight arm hang (metal bar, 3 cm diameter) (in anticipation of having a high number of zero scores on pull-ups), and the Y-Balance Test (YBT) for both upper and lower body [12, 13], which assesses core strength, dynamic balance and agility, as well as shoulder strength (YBT-upper body), and leg strength during a single leg squat (YBT-lower body) (Fig. 1). The YBT upper body test is performed from the prone push-up position, and consists of upper limb movements of each arm tested in three directions (medial, superior lateral, and inferior lateral). The YBT-lower body is performed from a single-leg standing position with movements of the non-weight-bearing leg in three directions (anterior, posterolateral, and posteromedial). These are illustrated on videos for the upper and lower body, respectively:
https://www.youtube.com/watch?v=P0W3ffLVE14.
https://www.youtube.com/watch?v=2HH6ZXqcAJ0.
Participants performed three familiarization trials followed by a brief rest before beginning the test. The three directions of movement on left and right sides were tested three times each for both upper and lower body. A trial was scored as zero if the participant lost balance and touched either foot or either hand on the floor before returning to the starting position. The absolute reach distance to the closest 0.5 cm was scored as the best of three trials in each direction. A composite score normalized to limb length (%) was calculated for right and left sides separately using the following equation [14]:

Fig. 1 Y-balance test for lower body (left) and upper body (right).

Sum of the 3 directions (cm) / 3 times limb length (cm) * 100

The YBT has been shown to have very good to excellent intrarater and test re-test reliability, with intraclass correlation coefficients (ICC) ranging from 0.84-0.87 for the three directions of the YBT-lower [15], and ICC > 0.90 for the YBT upper body test [13]. Poor scores on the YBT have been associated with sports injury in high school [16] and college athletes [17]. The YBT is used frequently by physical therapists and athletic trainers as part of a screening algorithm to determine an athlete's readiness for sport participation and to assess left-to-right lower limb imbalances that may increase one's risk of injury [17, 18]. A licensed physical therapist familiar with these testing procedures as well as with the sport of rock climbing conducted the YBT assessments.

Climbing performance was determined on an indoor bouldering wall at the climbing center. Participants were assessed twice over a 2-3-week period in which they attempted three different bouldering problems of increasing difficulty ranging from V0-V8. They were scored from 0 to 7 on the basis of highest grade completed. The three routes were designed to challenge a wide range of climbing ability as well as age and body size. For the present study, the bouldering routes restricted the climber to a maximum height of 10-12 feet (3.0-3.6 m) from the landing surface. To ensure safety and prevent injuries when landing, the landing surface consisted of a 1-m thick pad that has been tested to absorb forces far greater than an adult's body mass would generate from a fall of 5 m (Flashed Flooring: http://www.flashed.com/permanent-bouldering-flooring/). The courses were set by a nationally recognized course setter. Climbers began with the least difficult course and proceeded until they were unable to negotiate a hand or foot hold that resulted in a fall. The score used for data analysis was the best/highest score achieved of the 2 test sessions.

2.3 Statistical Analyses

Descriptive statistics, including means, standard deviations (SD), and range of scores were computed for girls and boys separately and for age groups (7-11 and 12-17 years). Analysis of variance (ANOVA) was used to compare fitness by age group and by gender. The size of the sample was too small to further divide age groups by gender. Percentiles in 10 percentage point increments were computed separately for girls and boys, and for younger (7-11 y) vs. older (12-17 y) participants. Multiple linear regression was used to determine the contribution of fitness measures to climbing performance of the total sample. Three models were tested on individual and combined variables, including anthropometrics (height, leg length, arm span), demographic (age and gender) and fitness measures. To reduce the number of fitness variables for this analysis, measures conducted on right and left limbs were averaged. The final number of fitness variables used in regression analysis was thereby reduced from 14 to 9. Age, gender, and anthropometrics were evaluated as possible covariates in the regression. For all statistical analyses, the alpha level was set a priori at $p < 0.05$. All analyses were conducted using SPSS (version 24.0; SPSS Inc., Chicago, IL).

3. Results and Analysis

Descriptive data and ANOVA results of group comparisons by gender and age group are shown in Table 1. A total of 64 youth (n = 35 girls, age 11.3 ± 2.6 y; 29 boys, age 13.7 ± 2.7 y) participated in the study. As expected, boys were taller and heavier, and had longer legs and arm span than girls ($p < 0.05$), but similar body mass index (BMI) as the girls. Fitness scores were generally higher among boys than girls ($p < 0.05$). However, there were no statistically significant differences between girls and boys for the YBT upper body test on both right and left arms ($p > 0.05$). YBT lower body scores on the left leg were

Table 1 Mean and (SD) of anthropometric and climbing-specific fitness scores by gender and age group.

	Gender		Age group	
	Girls (n = 35)	Boys (n = 29)	7-11 yr (n = 32)	12-17 yr (n = 32)
Anthropometrics	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Weight (kg)	35.4 (11.4)	45.6 (12.9)**	29.9 (6.6)	49.3 (10.2) ##
Height (cm)	141.9 (14.8)	157.2 (16.5)**	135.5 (9.9)	160.8 (13.0) ##
BMI (kg/m^2)	17.1 (2.5)	18.1 (2.4)	16.1 (1.8)	18.9 (2.3) ##
Arm span (cm)	140.9 (15.8)	159.2 (18.7)**	56.3 (4.4)	69.8 (5.8) ##
Leg length (cm)	76.1 (10.1)	84.6 (10.6)**	72.2 (5.9)	86.9 (10.0) ##
Fitness measures				
Bent arm hang-L (sec)	2.0 (3.0)	5.9 (8.2)*	2.3 (4.4)	5.3 (7.4)
Bent arm hang-R (sec)	2.1 (2.9)	5.8 (8.5)*	2.4 (4.6)	5.1 (7.4)
Bent arm hang-both (sec)	21.6 (16.4)	34.4 (21.3)**	21.3 (15.2)	33.2 (22.0)#
Vertical jump (cm)	39.0 (6.2)	49.0 (9.5)**	39.4 (6.9)	47.5 (9.7) ##
Pull-ups (4-count/repetition)	4.0 (3.3)	6.9 (4.7)	3.6 (3.6)	7.2 (4.1)##
Dead arm hang (sec)	37.8 (23.9)	54.1 (25.2)*	40.2 (30.9)	49.9 (18.6)
Power slap-L (cm)[a]	49.0 (18.8)	71.6 (17.9)**	46.9 (18.1)	71.6 (17.4)##
Power slap-R (cm)[a]	50.3 (18.9)	71.5 (17.8)**	48.5 (18.9)	71.4 (16.8) ##
Finger strength-L (%)[b]	60.4 (24.7)	68.7 (17.2)**	61.2 (26.1)	65.9 (18.3)
Finger strength-R (%)[b]	66.1 (23.9)	72.0 (16.2)	66.7 (26.0)	69.9 (15.9)
Y-balance Upper-L (cm)	114.0 (10.3)	115.2 (10.7)	114.8 (11.5)	114.2 (9.5)
Y-balance Upper-R (cm)	115.3 (11.1)	113.9 (9.3)	115.8 (11.7)	114.0 (9.3)
Y-balance Lower-L (cm)	101.0 (11.1)	105.8 (9.8)*	101.1 (9.5)	104.9 (11.8)
Y-balance Lower-R (cm)	102.2 (11.8)	106.5 (9.4)	102.2 (9.5)	105.9 (12.4)

[a] Scored as “slap” reach minus standing reach.

[b] Finger strength (preferred grip) scored as percent of body weight lifted from a digital scale and held for 3 sec.

* $p < 0.05$, ** $p < 0.01$ compared to girls. # $p < 0.05$, ## $p < 0.01$ compared to 7-11 year old group.

significantly greater among boys compared to girls, and trended toward significance on the right leg ($p < 0.10$). Age group comparisons showed higher values among older participants compared to younger for all anthropometric measures ($p < 0.01$), as well as for the power slap, pull-ups, vertical jump, and bent arm hang, both arms. However, there were no significant differences between age groups in single bent arm hang, dead arm hang, finger hang, or any of the YBT measures ($p > 0.05$). Percentile scores by gender and age group are reported in Tables 2 and 3, respectively.

The results of the multiple linear regression analysis are shown in Table 4. In the unadjusted model (Model 1), the combined fitness, demographics, and anthropometric variables explained 86% of the variance in bouldering performance ($p < 0.001$). In the model adjusted for age and sex (Model 2), fitness variables collectively explained 49% of the variance in bouldering performance. Because anthropometrics alone, including height, leg length and arm span, was not a significant covariate after adjusting for age and sex (p = 0.52-0.83), further adjusting for those anthropometric variables (Model 3) did not change the variance attributable to the combined fitness measures.

4. Discussion

The most important finding of the present study was that several measures from the IRCRA Test Battery were predictive of climbing performance among youth rock climbers. To our knowledge, this is the first study to report reference data on climbing-specific fitness in young climbers using these measures. Given that measurement procedures strictly adhered to IRCRA’s standardized procedures previously reported for adult climbers [11], additional

Table 2 Percentile rankings of fitness variables for girls (*n* = 35) and boys (*n* = 29).

Girls	Bent arm hang-left (sec)	Bent arm hang-right (sec)	Bent arm hang-both (sec)	Vertical jump (cm)	Dead arm hang (sec)	Power slap-left (cm)	Power slap-right (cm)
%							
10	0.0	0.0	3.7	31.0	10.0	23.6	23.6
20	< 0.1	< 0.1	7.0	33.9	16.1	29.6	28.2
30	< 0.1	< 0.1	9.2	35.2	21.1	39.4	40.8
40	0.1	0.1	13.7	36.9	33.2	42.4	45.0
50	0.6	0.4	19.0	38.6	36.9	45.0	51.0
60	1.3	0.8	23.0	42.1	39.6	52.2	55.0
70	2.5	2.6	28.3	43.7	46.2	60.2	63.2
80	3.7	5.7	36.8	44.1	56.8	70.0	69.4
90	7.0	7.1	46.7	47.1	65.2	77.8	77.0
100	12.4	9.6	70.6	50.8	123.0	84.0	84.0
Boys							
10	0.0	0.0	13.6	37.4	21.5	47.7	48.8
20	0.1	0.01	15.0	39.6	34.1	56.6	55.4
30	0.3	0.4	18.8	42.2	36.7	59.7	57.7
40	0.6	0.7	23.0	47.3	43.9	63.6	32.0
50	2.0	0.8	24.9	50.4	47.1	66.5	69.0
60	3.7	4.3	34.9	52.1	59.9	76.6	70.4
70	6.1	7.0	44.8	54.8	65.5	87.0	87.6
80	15.3	13.5	63.9	57.5	77.2	91.2	93.2
90	19.1	20.0	70.7	58.5	88.8	99.1	97.2
100	27.2	31.9	72.4	74.9	121.0	100.0	100.0
Girls	Y-balance Upper-L	Y-balance Upper-R	Y-balance Lower-L	Y-balance Lower-R	Pull ups (4-count)	Finger St (L) % body wt	Finger (R) (% body wt)
%							
10	97.3	98.7	86.5	85.3	0.3	30.6	35.5
20	105.3	106.9	89.5	91.3	0.5	34.1	42.4
30	108.1	109.6	94.1	95.6	1.2	41.8	50.5
40	113.5	112.6	97.9	97.7	2.5	48.6	55.1
50	116.0	115.2	99.8	102.5	3.5	57.7	58.6
60	118.0	117.3	104.1	106.6	4.5	63.1	71.0
70	119.7	123.2	106.2	109.7	6.0	76.0	90.0
80	122.7	125.3	111.9	112.3	7.4	91.7	96.0
90	127.4	131.3	116.4	116.0	9.0	98.0	98.5
100	133.3	133.9	128.0	133.3	10.5	100.0	100.0
Boys							
10	100.6	101.8	94.8	94.5	1.2	44.8	45.4
20	105.3	102.5	98.1	99.5	1.5	49.4	62.9
30	108.4	108.0	98.6	102.3	3.8	58.6	64.7
40	111.1	1112.3	100.4	103.5	5.0	64.7	65.1
50	112.5	114.1	104.6	105.8	6.5	66.6	71.3
60	116.0	117.4	108.5	106.5	7.9	73.2	75.9
70	122.7	118.6	109.2	109.6	10.1	78.7	79.1
80	128.5	121.0	114.5	112.5	11.0	86.0	87.2
90	131.3	128.6	118.4	121.0	15.0	96.2	98.3
100	131.9	134.8	134.8	133.8	16.5	100.0	100.0

Table 3 Percentile scores of fitness variables by age group (7-11 y, *n* = 32; 12-17, *n* = 32).

7-11 y	Bent arm hang-left (sec)	Bent arm hang-right (sec)	Bent arm hang-both (sec)	Vertical jump (cm)	Dead arm hang (sec)	Power slap-left (cm)	Power slap-right (cm)
%							
10	0.0	0.0	3.6	30.0	9.9	23.3	23.3
20	< 0.1	< 0.1	7.2	34.5	16.3	28.2	27.2
30	< 0.1	< 0.1	10.0	36.1	18.3	36.7	39.5
40	0.1	0.1	16.2	37.5	26.0	42.2	43.4
50	0.2	0.4	22.6	38.9	35.0	45.0	49.0
60	0.6	0.5	23.5	40.0	39.0	52.2	54.8
70	1.2	0.8	26.1	43.0	45.1	57.2	61.1
80	3.4	4.6	31.0	45.3	62.6	60.0	62.4
90	11.1	9.3	43.6	47.6	90.2	66.0	69.4
100	16.7	18.7	67.1	59.0	123.0	96.0	94.0
12-17 y							
10	0.0	0.0	8.6	33.0	25.0	45.0	47.6
20	0.1	0.1	13.8	38.8	35.1	54.2	53.8
30	0.5	0.3	15.0	42.6	38.8	63.0	60.4
40	1.5	0.8	19.6	44.3	43.4	66.6	66.8
50	2.9	2.4	24.1	47.4	47.1	72.0	70.0
60	3.7	5.0	37.4	51.0	55.8	77.4	72.6
70	4.8	6.1	43.5	52.3	61.3	83.4	82.8
80	9.1	7.5	58.1	56.0	67.8	87.6	89.4
90	17.2	13.7	70.6	57.9	74.7	97.6	96.8
100	27.2	31.9	72.4	74.9	88.5	100.0	100.0
7-11 y	Y-balance Upper-L	Y-balance Upper-R	Y-balance Lower-L	Y-balance Lower-R	Pull ups (4-count)	Finger St (L) (% body wt)	Finger (R) (% body wt)
%							
10	98.6	101.8	87.7	86.2	0.25	31.3	34.5
20	105.1	105.2	94.1	93.6	0.30	34.1	38.3
30	106.6	109.8	97.3	97.4	0.75	41.0	42.7
40	108.5	111.6	98.8	100.0	1.5	47.7	55.3
50	116.0	114.3	100.4	102.6	3.25	54.3	61.7
60	121.1	117.4	103.6	104.0	4.0	68.3	77.9
70	121.7	123.5	105.8	108.3	5.0	81.6	93.8
80	126.5	129.9	108.8	112.3	5.75	95.7	96.5
90	130.9	133.2	116.1	115.4	8.75	99.0	99.0
100	133.3	133.9	117.1	116.8	16.5	100.0	100.0
12-17 y							
10	99.1	99.9	89.5	90.8	1.5	41.8	50.0
20	106.4	103.2	93.8	93.6	2.5	49.4	50.7
30	110.7	109.4	98.2	99.4	3.75	58.7	61.1
40	112.3	114.0	98.9	105.6	6.0	61.1	64.6
50	113.8	114.8	105.0	106.5	7.0	64.7	65.9
60	117.5	117.3	108.5	107.9	8.75	67.4	72.5
70	118.5	119.1	110.1	110.5	10.25	73.2	77.0
80	121.8	120.9	115.3	112.7	11.0	86.0	87.2
90	128.5	123.9	121.5	125.7	13.0	94.1	96.0
100	131.9	134.8	134.8	133.8	15.0	100.0	100.0

Table 4 Regression analysis of the association of fitness measures to bouldering performance.

	Model 1		Model 2		Model 3	
Variables	β coefficient	*p*-Value	β coefficient	*p*-Value	β coefficient	*p*-Value
Fitness						
Single bent arm hang (mean of right/left arm)	0.29	< 0.0001	0.25	< 0.0001	0.25	< 0.0001
Double bent arm hang	0.09	0.0015	0.07	0.005	0.07	0.008
Vertical jump	0.14	0.0006	0.07	0.21	0.07	0.23
Finger strength (mean of right/left hand)	0.06	0.0008	0.04	0.01	0.05	0.004
Pull-ups	0.36	< 0.0001	0.27	0.001	0.31	0.0006
Dead arm hang	0.05	0.0005	0.04	0.003	0.04	0.002
Powerslap (mean of right/left arm)	0.08	< 0.0001	0.07	0.01	0.08	0.002
Y-balance upper body	0.07	0.11	0.07	0.06	0.08	0.06
Y-balance lower body	0.03	0.4	0.02	0.57	0.11	0.04
Anthropometrics						
Height	0.06	0.006	0.009	0.83	-0.05	0.67
Arm span	0.06	0.003	0.01	0.72	0.03	0.79
Leg length	0.09	0.01	0.03	0.52	0.05	0.53

Model 1: unadjusted.

Model 2: adjusted for age and gender.

Model 3: adjusted for age, gender and anthropometrics including arm span, leg length and height.

data could be added to our existing database with confidence on their fidelity, assuming the same procedures were followed. While the sample size limits generalizability, we believe the data provide a framework for coaches of youth climbers to detect strengths and weaknesses of individual climbers, and thereby tailor their training to achieve optimal results. We have displayed the percentile rankings separately for girls and boys, and for younger vs. older climbers, as the ANOVA results indicated significant gender and age-group differences for most, but not all variables. The largest differences were noted for upper body strength and power tests, for which mean scores for boys were in the range of approximately 45% to 200% greater than for girls, and 50% to 130% greater among older vs. younger climbers.

Notably, scores on both the upper and lower YBT were not significantly different between girls and boys, or between the younger and older age groups. Because YBT scores are normalized to limb length, scores would not necessarily increase with age or linear growth, alone. We observed nearly identical mean YBT upper body scores among the older vs. younger climbers, and similar mean values for girls and boys. We speculate that possible greater shoulder joint flexibility among girls vs. boys and younger vs. older climbers could partially account for the similarities, despite the expectation that boys and older climbers would be expected to have greater absolute upper body strength, and therefore higher scores, as strength is an important component of the upper body YBT [13]. While we are not aware of any studies that have examined possible gender differences in either upper or lower YBT, previous research has reported no gender differences in measures of static balance among 6-10 year old children [19]. Additional research is needed to help explain our findings. Looking further at individual data for the lower body YBT, we observed that the better climbers, regardless of gender or age, performed a deep single leg squat ("pistol" squat) to initiate the test, and from that position extended the foot of the suspended leg to achieve a higher score than if they were unable to perform a deep single leg squat. This movement requires lower body strength and flexibility as well as dynamic balance, all of which are important qualities of climbing performance.

The multivariate regression analysis yielded a strong association between climbing-specific fitness and bouldering performance on an indoor course. We found that after adjusting for age and gender, which together explained nearly 37% of the variance in performance, the climbing-specific fitness measures with the addition of the Y-balance tests and vertical jump uniquely explained nearly half of the variance in bouldering performance in our sample of youth climbers. These fitness measures may therefore serve as useful benchmarks to monitor training and improvement as young climbers grow and develop. Interestingly, adding height, leg length and arm-span to the model did not significantly or appreciably contribute to the variance after adjusting for age and gender. Two other studies reported similar findings for adult climbers [20, 21]. Laffaye and colleagues [20] reported that climbing-specific measures of strength and power explained 46% of the variance in self-reported climbing ability, while Mermier et al. [21] found that similar climbing-specific measures of strength and power, with the addition of self-reported climbing rating, explained nearly 59% of the variance in performance on an artificial climbing wall. Moreover, similar to our findings, the addition of anthropometric variables to their regression models contributed less than 4% to the variance in climbing ability and performance. Taken together, these two studies [20, 21] and our study suggest that, among both adult and youth climbers across a wide range of climbing ability, climbing-specific fitness factors are more important to climbing ability and performance than factors such as general strength, body type, and anthropometric variables.

To date, research on youth climbers has been limited largely to reports on injuries [22-26], anthropometric or body composition characteristics [27-29], energy expenditure or heart rate responses during climbing [28, 30-32], or muscular strength measures [27, 33, 34]. These types of studies add to the existing literature on rock climbing in children and adolescents. In particular, the published reports on injuries among young climbers warrant additional research and dissemination to coaches, climbers, and parents to determine and ensure safe and effective training practices among young climbers.

A recent review of nine peer-reviewed publications evaluated rock climbing as an activity with potential to promote physical fitness and increase physical activity in children and adolescents [35]. Collectively, this review revealed that although the physiological demands of competitive rock climbing are sufficient to achieve U.S. or European national guidelines on recommended volume and intensity of physical activity to reap health benefits, data on the few recreational or school climbing programs reported in the review suggested that the total duration of activity fell short of national guidelines, largely due to long periods of waiting between climbing bouts. Thus, recreational and school-based programs need to be structured to ensure children get adequate time for actual climbing, or perhaps include additional moderate to vigorous activities to increase total exercise time.

Strengths of the Study: Our study provides new data on climbing-specific fitness measures among youth rock climbers. Coaches may find this information useful for determining relative strengths and weaknesses, and monitoring progress particularly among beginner and novice climbers. Another strength of this study was the addition of the YBT for this population, as it has been used among athletes from other sports to evaluate several musculoskeletal factors considered important to rock climbing, and to compare left to right limb imbalances that may either predispose a climber to potential injury or be monitored during rehabilitation post-injury. The YBT lower body test has been shown to identify individuals with chronic ankle instability that may otherwise go undetected until the ankle becomes injured [36]. Given that young climbers training in bouldering frequently land on their feet from heights of 3 m or more during training sessions, pre-screening these athletes using the YBT, and following up with targeted ankle strengthening and stability exercises may potentially prevent ankle injuries. To our knowledge, no studies have evaluated youth climbers' opposing limb strength and flexibility, or core stability, and how these relate to performance or injury. This, presumably, is an important area of research to explore.

Limitations: One limitation of the study was the relatively small sample size, which precluded statistical analyses by gender within each age group. However, by having standardized measurement procedures in accordance with IRCRA, the sample size could be increased with confidence, and include data from our own or other research sites.

5. Conclusion

Climbing-specific fitness measures previously established on adults are associated with bouldering performance in youth climbers.

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