Original Research

Geometric Entropy for Lead vs Top-Rope Rock Climbing

Phillip B. Watts‡, Scott N. Drum‡, Matthew A. Kilgas†, and Kevin C. Phillips†

Exercise Science Laboratory, School of Health and Human Performance, Northern Michigan University, Marquette, Michigan, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 9(2): 168-174, 2016. The complexity of movement of a rock climber's center of mass during an ascent has been described as geometric entropy (GE). It has been proposed that lower geometric entropy could represent more fluid and economical movement during climbing. The purpose of the present study was to measure GE during rock climbing ascents under a lead condition (LD), where the climber connects a safety rope to several intermediate anchors during the ascent and under a top-rope condition (TR), where the safety rope is always anchored above the climber. Six experienced rock climbers volunteered to participate in the study. Each participant ascended a route on natural rock outdoors under three conditions. The first ascent was performed in a top-rope condition as an accommodation trial. The two remaining ascents were performed as LD and top-rope (TR2) in random order. Each LD and TR2 ascent was recorded via digital video at 30 Hz. A single point at the back center of each climber's waist harness was manually digitized from the video images at 6 Hz and interpreted as the climber's center of mass (CM). The displacement of CM was expressed as the line of motion (LM). Geometric Entropy (GE) was calculated as GE = $\ln((2 \cdot LM)/CH)$, where CH was the value of the convex hull about the LM. A within subjects, repeated measures ANOVA with Bonferroni post hoc testing was utilized to test for differences among ascent conditions with significance set at $P < 0.05$. Mean (±s.d) values for LM and GE were 81.5±11.3 m vs 77.6±7.3 m and 1.021±0.133 vs 0.924±0.062 for LD and TR2 respectively. There were no significant differences for LM and GE between ascent conditions. It was concluded that LM and GE do not vary between LD and TR ascent conditions.

KEY WORDS: Movement economy, rock climber, video analysis

INTRODUCTION

A primary objective during rock climbing is to ascend specific route terrain with an economy of motion. The complexity of movement of a climber's center of mass has been described as geometric entropy (2). Geometric entropy (GE) is calculated from the trajectory or line of motion (LM) of a climber and the perimeter, or convex hull, of the line of motion path. GE is higher when a climber's trajectory, or LM, deviates from a direct straight path from the start to the end of a specific route. Part of a climber's GE will be dictated by the terrain of the rock and part by the body positions and movement sequences selected by the climber. It has been proposed that lower

geometric entropy (GE) could represent more economical movement (11). Recently, Watts et al. (13) found changes in energy expenditure to be related to changes in GE that occurred with repetition of a specific climbing route.

There are two fundamental ascent styles practiced in difficult rock climbing; top-rope (TR) and lead (LD). In the TR ascent style, an anchored safety rope is always above the climber to protect against falls. The TR style is mostly employed for practice climbing and climbing-specific training. In the LD style, the climber must connect the safety rope to a series of anchors while moving over the route. There are two sub-forms of LD style climbing; traditional and sport. In traditional leading, the climber must locate openings in the rock in which to place anchor devices for the rope as the ascent is made. In sport leading, anchors are pre-existing along the route and typically are permanently installed bolts. The sport LD ascent style is usually standard for competitive climbing whether indoors or outdoors.

Whether GE varies between LD vs TR styles is not known. The purpose of this study was to compare the measured line of motion (LM) and degree of GE for climbers during ascents under TR and LD conditions.

METHODS

Participants
Six experienced rock climbers, four male and two female, mean (±SD) age = 34.5±15.8 yr, volunteered and signed informed consent to participate in the study. Participants completed a self-administered physical activity readiness questionnaire (Par-Q; Canadian Society for Exercise Physiology, 2002). All participants had a minimum of three years rock climbing experience and were currently active in rock climbing and other recreational physical activity. Lead climbing ability ranged 5.8-5.11, 5a-6c, or 15-22 on the Yosemite Decimal System (YDS), French and Ewbank difficulty rating scales respectively (5). These difficulty rating scales reflect the average perceived difficulty of a specific climbing route with current maximums ranging from 5.0-5.15b, 1-9b, and 11-37 on the YDS, French and Ewbank scales respectively. Subjects were selected from a limited sample of climbers who were available to participate during a specific time period at the location of the study. The study design and methods were approved by the University Institutional Review Board prior to commencement of the study.

Protocol
Data were collected at an established outdoor sport climbing area with sandstone rock type. All participants had climbing experience at the specific area of the study although none had climbed at the specific area within a one year period. All routes were equipped with pre-installed bolt anchors to enable sport style LD as well as TR climbing. Estimated direct-line route lengths were 14-20 m based on information in the published guidebook for the area (7). No practice ascents were performed on a test route prior to data collection.

Each participant ascended a specific route under three conditions. For each participant, the first ascent was performed as top-rope (TR1) where the rope was

anchored above the climber prior to ascent. This initial top-rope ascent served to provide an initial familiarization of the route terrain for the participants in a manner to maximize safety. It also ensured the specific route was within the capability of the participant. The second and third ascents were performed as LD and top-rope (TR2) in random order. Each ascent was recorded via high-definition digital video at 30 Hz. Data for TR2 and LD were used for subsequent analysis. The camera was placed in a fixed position approximately 15 m from the base starting point of the route. The camera position and angle enabled the entire route to be in the field of view during each ascent. A single marker point at the back center of each participant's waist harness was manually digitized by two independent investigators using MaxTRAQ 2D software (Innovision Systems Incorporated, version 2.2) and interpreted as an estimate of the participant's center of mass (CM). The behavior of this estimated CM point represented a global description of a climber's movement along the specific route. A 2.44 m rod was placed in the video field of view to calibrate distance via the MaxTRAQ software. Due to the necessity for manual digitization of the video images, and the relatively slow nature of the climbing movement, a digitization rate of 6 hz was used. The use of a single point for the CM estimation was necessary due to the impossibility of observing multiple anatomical markers during the wide range of body movement required for these ascents on natural rock outdoors. Previous studies have employed this single-point assessment for ascents of full climbing routes (2,10). The total movement distance of the CM point was expressed as the length of the line of motion (LM).

Geometric Entropy was calculated according to the method described by Cordier et al. (2) and Sibella et al. (11):
GE = ln((2•LM)/CH)), where CH is the value of the convex hull about the LM.

Statistical Analysis
Interclass Correlations were calculated between digitizers A and B for LM and GE for the LD and TR2 conditions. A within subjects, repeated measures ANOVA with Bonferroni post hoc testing was utilized to test for differences among ascent conditions with significance set at $P < 0.05$. All statistical analyses were performed using IBM SPSS Statistics 21; 2012).

RESULTS

Mean (±sd) climbing times in minutes were 2.41 ±0.71 for LD and TR2 respectively. No falls occurred for any climber in any ascent condition. Interclass correlations between digitizers for LM values for LD and TR2 were 0.95 (confidence interval 0.733 to 0.993, F=38.549, p<.001) and 0.933 (confidence interval 0.656 to 0.990). Interclass correlations between digitizers for GE values for LD and TR2 were 0.797 (confidence interval 0.194 to 0.968) and 0.889 (confidence interval 0.480 to 0.983). Since interclass correlations were high, data for the two digitizers were averaged for subsequent analyses.

Figure 1 presents example LM plots for two climbers under both LD and TR2 conditions. For climber A, GE was less for LD vs TR2 (0.878 vs 0.910 respectively). For climber B, GE was greater for LD vs TR2 (1.054 vs 0.965 respectively).
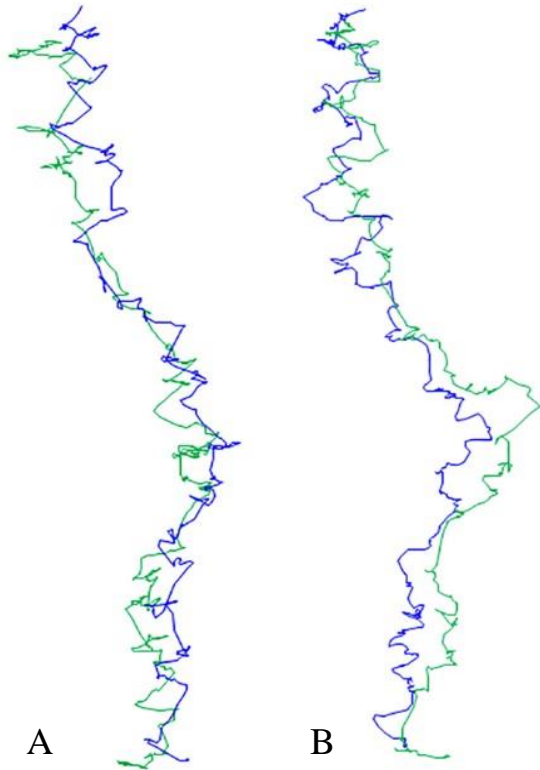
Figure 1. LM plots for two climbers for LD (green) and TR2 (blue) ascent conditions.

Mean (±sd) data for all climbers under both ascent conditions are presented in Table 1 and graphic plots in Figure 2. LM means were 81.5±11.3 m vs 77.6±7.3 m for LD vs TR2 respectively and not significantly different between ascent conditions (p=0.375, F=0.947, 1 df, power=0.126 and effect size=0.159). GE means were 1.021±0.133 vs 0.924±0.062 for LD vs TR2 respectively and not significantly different between conditions (p=0.096, F=4.201, 1 df, power=0.383 and effect size=0.457). Although mean values for both LM and GE were higher for LD than TR2 ascent, and GE was higher for LD for four of six participants (Figure 2), there were no significant differences between conditions for either LM or GE.

Table 1. Individual climber values and group means (± sd) for LM and GE under LD and TR2 conditions.

Climber	LM (m)		GE	
	LD	TR2	LD	TR2
1	99.7	75.8	1.154	0.929
2	89.9	70.8	1.184	0.984
3	77.0	78.8	0.873	0.858
4	68.9	72.6	0.878	0.877
5	74.2	76.0	1.054	0.884
6	79.5	91.4	0.982	1.012
Mean	81.5	77.6	1.021	0.924
±sd	11.3	7.3	0.133	0.062
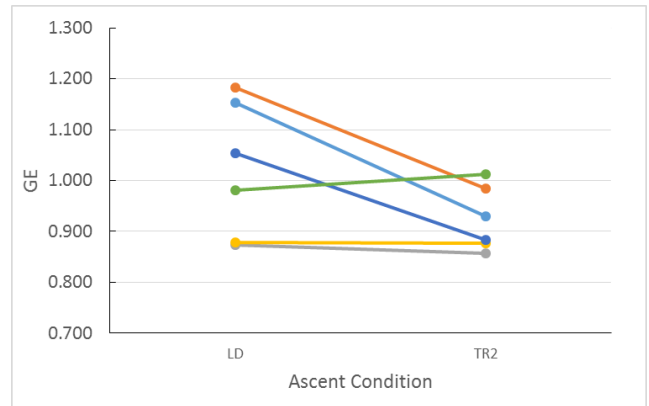
Figure 2. Individual participant GE values for LD and TR2 conditions.

DISCUSSION

Most previous research has typically employed either TR or LD climbing but not made comparisons between the two styles. To our knowledge, ours is the first study to compare GE between these two styles of rock climbing.

A common perception among climbers is that LD climbing incurs a higher energy expenditure and greater movement

demands than TR climbing. During Sport LD ascents, the climber must stop at intervals to connect the rope to pre-installed anchors. Typically there would be eight or more such anchors along the route depending on the total distance. During a TR ascent the climber would not be required to pause and attain a body position that allowed support as the rope was connected to the anchor. The perceived smoother movement flow during TR would result in lower entropy and seem to be more economical.

Fryer et al. (8) recorded physiological data from a group of advanced level climbers for LD and TR ascents of an indoor route (rated 5.11a/6c/22). Eighteen climbers were matched for gender, age, height and weight and divided into two groups for TR and LD conditions. Heart rate was higher for LD than TR, however the difference did not reach significance until the last third of the route ascent. Mean oxygen uptake was not significantly different between conditions at any point during ascents.

Draper et al. (4) suggested the physiological demand during lead climbing was greater than during top-rope climbing. This group studied nine intermediate level climbers who ascended the same route under LD and TR conditions on different days and in random order. Ascent time was significantly longer for LD than TR. Blood lactate was significantly higher immediately after the LD ascents and similar to values presented in earlier studies (9, 12). There were no significant differences in peak or average oxygen uptake, average heart rate, or rating of perceived exertion between LD and TR.

While the studies of Fryer et al. (8) and Draper et al. (4) compared LD versus TR ascents, neither of these studies attempted to calculate total energy expenditure or characterize a climber's movement via assessment of LM and/or GE during the ascents.

The early research of Cordier et al. (2) reported changes in GE with repeated ascents of the same climbing route. In their study, a decrease in GE occurred with the initial ascents and appeared to plateau after ascent three. Sibella et al. (11) interpreted lower GE to be reflective of a higher fluency of movement and greater economy of climbing. Cordier et al. (2) described "complex nodes" in the trajectory, or line of motion, of a climber that could indicate a degree of searching for a movement or movement sequence that would enable further progress along the climbing route. Such complex nodes would increase GE and possibly be reflective of less economical movement.

Work by España-Romero et al., (6) found energy expenditure to decrease with repeated TR ascents of the same climbing route on an indoor wall. In a follow-up study, Watts et al. (13) have presented data on changes in GE for the ascents reported in 2012 by España-Romero et al. and found the lower energy expenditure to be associated with lower GE. This is supportive of the suggestion of Sibella et al. (11) that lower geometric entropy reflects a higher economy of climbing.

The present study indicates no difference in GE between LD and TR ascents for the routes studied. Although energy expenditure and other physiological data

were not measured in the present study, the conclusions of Watts et al. (13) suggest a large difference in energy expenditure would not be observed since GE did not differ between ascent conditions. This is also indirectly supported by the previous work of Draper et al. (4) and Fryer et al. (8) in which no differences in oxygen uptake were found between LD and TR ascents.

Our research design includes a number of compromises which should be considered. Foremost, the use of a single point to represent the center of mass is a simplification. Our intent was to record data in a full rock climbing ascent on natural outdoor rock terrain. The complex movement sequence of vertical climbing over natural terrain is not conducive to multiple point digitization. This same difficulty occurs with competition route ascents on indoor structures as evidenced by Sanchez et al. who also employed the single-point methodology (10). Furthermore, the single-point measurement represents a global indication of movement and may not reflect some specific arm and/or leg movements that occur without movement of the trunk. We feel this is an acceptable compromise for the applied study of climbing on outdoor rock terrain.

The small sample of subjects could also be a factor in our final result. Three participants had higher GE during LD than TR2 (Figure 2) and one had a slightly higher GE for LD. One participant had greater GE for TR2 and one had no difference between conditions. Testing of a larger sample would be necessary to determine if these proportions hold.

It is possible that individual preference relative to ascent style exerts an effect. We feel this is not likely as all participants were active in LD and TR climbing. The participants were not specifically queried regarding ascent style preference or volume of climbing regularly performed in each style, however.

It is not known whether route difficulty relative to a climber's ability is a factor. The specific routes selected were rated one full grade (YDS scale) below each subject's best outdoor ascent route rating. We selected a route difficulty within the lead capabilities of the participants to minimize the chance of a fall and the necessity to repeat an ascent. Further research with larger samples would be necessary to determine if route difficulty relative to climber ability is a factor.

Based upon the results, we conclude that LM and GE do not differ between TR and LD styles for ascents of the same route.

ACKNOWLEDGEMENTS

REFERENCES

1. Booth J, Marino F, Hill C, Gwinn T. Energy cost of sport rock climbing in elite performers. Br J Sports Med 33:14-18, 1999.

2. Cordier P, France MM, Bolon P, Pailhous J. Entropy, degrees of freedom and free climbing: A thermodynamic study of a complex behavior based on trajectory analysis. Int J Psych Sport 24:370-378, 1993.

3. Cordier P, France MM, Bolon P, Pailhous J. Thermodynamic study of motor behaviour optimization. Acta Biotheoretica 42:187-201, 1994.

4. Draper N, Jones GA, Fryer S, Hodgson CI, Blackwell G. Physiological and psychological responses to lead and top rope climbing for intermediate rock climbers. Eur J Sport Sci 10(1):13-20, 2010.

5. Draper N, Dickson T, Blackwell G, Fryer S, Priestley S, Winter D, Ellis G. Self-reported ability assessment in rock climbing. J Sports Sci 29(8):851-858, 2011.

6. España-Romero V, Jensen RL, Sanchez X, Ostrowski ML, Szekely JE, Watts PB. Physiological responses in rock climbing with repeated ascents over a 10-week period. Eur J Appl Physiol 112(3): 821-828, 2012.

7. Frisbee C. Horseshoe Canyon Ranch Arkansas Rock Climbing. Boston Mountain Press, Springfield, MO, USA, 2013.

8. Fryer S, Dickson T, Draper N, Blackwell G, Hillier S. A psychophysiological comparison of on-sight lead and top rope ascents in advanced rock climbers. Scand J Med Sci Sports 23:645-650, 2013.

9. Mermier CM, Robergs RA, McMinn SM, Heyward VH. Energy expenditure and physiological responses during indoor rock climbing. Br J Sports Med 31:224-228, 1997.

10. Sanchez X, Boschker MSJ, Llewellyn DJ. Pre-performance psychological states and performance in an elite climbing competition. Scand J Med Sci Sports 20:356-363, 2010.

11. Sibella F, Frosio I, Schena F, Borghese NA. 3D analysis of the body center of mass in rock climbing. Hum Movement Sci 26:841-852, 2007.

12. Watts PB, Daggett M, Gallagher P, Wilkins B. Metabolic response during sport rock climbing and the effects of active versus passive recovery. Int J Sports Med 21:185-190, 2000.

13. Watts PB, España-Romero V, Ostrowski ML, Jensen RL. Change in geometric entropy and energy expenditure with repeated ascents in rock climbing. Med Sci Sports Exerc 45(S1):700, 2013.