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Analysis of Gender and Success-Related Kinematic Differences of Elite Sport Rock Climbers During Competition

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ANALYSIS OF GENDER AND SUCCESS-RELATED KINEMATIC DIFFERENCES OF ELITE SPORT ROCK CLIMBERS DURING COMPETITION

by

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ABSTRACT

Analysis of Gender and Success Related Kinematic Differences

of Elite Sport Rock Climbers During Competition

by

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This study compared differences in kinematically based performance success characteristics of elite sport rock climbers during competition both within and across the variable of gender. The purpose of this study was to identify kinematically based performance success and gender differences in elite sport rock climbers for the development of further studies and gender-specific training procedures. The dependent variables included the kinematics of the dynamic grasping hand (DGH) and the center of mass (CM) and the timing of these variables.

The participants included both the men and women competitors registered for the 1997 American Sport Climbing Federation's Fall National competition held at the Boulder Rock Club in Boulder, Colorado. Analysis was performed on the top five placing participants in each respective gender category (N = 10). For comparison within gender, the first through third place finishers were classified as the top performers with a higher degree of performance success than the bottom performers who placed fourth and fifth (n = 5).

Adjusted R-squared values were computed by way of multiple regression for the kinematic variables; variables providing adjusted R-squared coefficients greater than .24 were selected for further analysis. A one-way repeated measures ANOVA was computed for the selected kinematic variables and finish place of the participants. Standardized mean difference effect sizes were computed to determine practical significance.

No statistical significance was found at or below the .05 level of probability for finish place and any of the kinematic variables. Effect size differences were found for the DGH and CM kinematics with the top-performing men and women exhibiting more controlled horizontal movements, and more powerful but still controlled vertical movement. The control of the vertical CM motion indicated by the tops was evident from lesser distances the CM traveled. The kinematics of the CM show the top men and women with less vertical distances traveled, indicating a more efficient movement. Gender differences included the males performing the route segment with slower times but with faster DGH events. The top men provided greater event vertical velocities while the women provided greater horizontal velocities and accelerations. These differences provide considerations for the development of specific training protocols to address performance success based requirements that are gender-specific.

(75 pages)

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Russell Slaugh

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The sport of rock climbing has seen many changes over the past several years. One of these changes is the introduction of indoor artificial rock climbing environments for training in inclement weather. The use of these artificial climbing environments for training during the off season, and the general recreation use by the public have assisted in the rapid growth of the sport. Since the first commercial facility in the United States opened in 1987 in Seattle, Washington, there are now over 120 facilities currently operating in the U.S. with new facilities opening weekly (Attarian, 1989; Widdekind, 1995). The relatively small country of England, for example, has been reported as having over 2,000 such facilities, demonstrating the large potential for growth in the U.S. (Attarian, 1989).

The increasing popularity of indoor rock climbing has developed into a thriving competitive sport setting. The national organization that controls and coordinates these events on the professional level is the American Sport Climbing Federation (ACSF). This organization schedules and coordinates the national and regional competitions and promotes sport climbing in general. The most recent advancement in the sport has been its consideration as an exhibition event for the Winter Olympic Games. The consideration by the International Olympic Committee is due largely to the immense popularity of sport climbing throughout Europe (Raleigh, 1995).

The advancements in the sport of rock climbing have opened a window for the application of scientifically sound training techniques by professionals. Knowledge of the movement requirements imposed on competitive sport climbers could be valuable information when developing training procedures for these elite-level athletes. By identifying patterns of successful movement in the world's top level athletes, such as triple jumpers and freestyle swimmers, researchers have been able to provide useful recommendations for improving technique (Yu & Hay, 1995; Cappaert, Pease, & Troup, 1995).

There has been very little literature published concerning research studying the biomechanics of competitive sport climbing and no studies were found which considered kinematically based gender differences. There is also a deficit in the research concerning the kinematic analysis and description of the performance of sport climbers classified as elite. These elite climbers also should be studied performing in their actual climbing environments performing voluntary movements rather than in a clinical or laboratory setting performing imposed movements. This knowledge base is needed by the sport-climbing community if some type of generalized training and conditioning principles are to be created to efficiently develop lesser climbers to this elite level. Comparing differences in the kinematics of these elite climbers across the variable of gender will allow for more accurate training principles to be developed that are gender specific. The limited research that has been completed on the biomechanics of sport climbing lacks comparative data on which to base further experimental research training studies.

The purpose of this study was to describe kinematically based performance success and gender differences in elite-level sport rock climbers during competition. The analysis measured the effects of two variables: (1) gender and (2) performance success during competition. The dependent variables were analyzed from the movement of the climber's center of mass, and the wrist of the dynamic hand during grasping events. These variables included the following kinematic parameters: (1) linear distances and displacements, (2) velocities, and (3) accelerations. The timing of these variables, as well as the rest events, and the safety factor involving clipping of protection were also addressed.

The hypothesis of this study was that there would be no statistically significant kinematically based gender-related, or performance success-related differences observed. This study provides a basis on which further research can be developed to analyze sport rock climbers during competition.

The following definitions are included to provide explanation of terms used in this study which involve common terminology from the field of biomechanics and the sport of competitive rock climbing. These definitions are consistent with the terminology recommended by the International Society of Biomechanics, or the ACSF where applicable.

Biomechanics: An area of study dealing with the mechanics of biological systems.

Kinematic parameters: Variables that describe spatial movement or derivatives of spatial movement, such as displacement, velocity and accelerations.

Velocity: The time rate of change of position. A vector quantity.

Acceleration: The rate of change of velocity. A vector quantity.

Vector: A quantity having both magnitude and direction.

Displacement: The difference between the position coordinates of the body in its final and initial position.

Distance: Magnitude of a traveled path.

Center of mass (CM): The point about which the mass of all particles of the body are evenly distributed.

Dynamic grasping hand (DGH): The hand which is released from the initial hold and moved to the target hold which is next in the sequence of movements and performs the task of prehension.

Prehension: The act of grasping the target hold.

American Sport Climbing Federation (ACSF): Governing body that coordinates sport rock climbing competitions, sponsors, and competitors into organized sactioned events.

Climbing route: A set of plastic climbing holds placed in a certain pattern ascending an artificial climbing wall. The climber starts using the first designated hold and then may use the remaining holds in any sequence desired. All of the holds need not be used but all pieces of protection must be clipped. When the last piece of protection, referred to as anchors, is clipped, the climbing route is completed.

Protection: Hardware called bolts that are similar to eye bolts are placed every three to four feet; these bolts have a carabiner (quick clip) attached to a one foot piece of webbing with another carabiner attached to the free end of the webbing. The climber must clip the safety rope attached to their harness through the free end carabiner without weighting the rope or the carabiner. Any unweighting of the climbers mass during this process results in immediate disqualification. Once the protection is properly clipped, the climber can only fall as far as the last piece of protection clipped, hence the name protection.

Holds: Molded pieces of plastic and resin which are attached to artificial climbing wall to simulate rock holds on which the hands and feet are placed to apply force in order to displace the climber's body.

Elite climbers: The very top ability level that sport climbers are categorized into for competition purposes. Also referred to as the open category.

Performance success: Based on the subjects' performance during the competition resulting in their final placing. First place is the highest performance success and fifth place is the lowest performance success.

Finish place: Based on the number of holds climbed to, or passed while completing the climbing route. Point values are assigned to each hold, whether the participants attempt to grasp, actually grasp, or actually use the hold after grasping determines the number of points given to the participant. The participant with the highest point score is placed first, with the others placed according to their respective point scores.

Shaking: An activity performed as a rest procedure to increase blood flow to a an appendage after sustained use. Usually occurs in a rest position where one hand can be released from the hold. During this time gymnastic chalk is often applied to the hand by dipping into a small bag secured to the climber's waist, and then the hand is also shaken to remove excess chalk. The chalk absorbs moisture, thereby increasing the coefficient of friction between the hands and the holds.

Redpoint: A term used to classify the type of ascent of a climbing route. A redpoint ascent is an ascent in which the climber climbs from the starting hold to the anchors without falling or weighting any piece of equipment. Often completed after prior attempts of the route. Competition climbing involves attempted redpoints of the climbing routes without any prior attempts, kinesthetic knowledge, or feedback from other climbers on the route. This type of ascent is referred to as a flash or on-sight redpoint attempt.

CHAPTER II

REVIEW OF LITERATURE

Research on the sport of climbing has covered a diverse range of subjects. In the past, research has been conducted in such subjects as the psychophysical aspects of difficulty ratings, analysis of posture and movement in relation to testing of climbing boots, and many studies concerning the injuries related to the sport of rock climbing (Addiss & Baker, 1989; Bannister & Foster, 1986; Caron & Rougier, 1993; Delignieres, Famose, Mathieu, & Fleurance, 1993; Haas & Meyers, 1995).

Rock Climbing Physiology

The area of physiological characteristics of rock climbers has received moderate attention in research in the past. The study by Grant, Hynes, Aitchison, and Whittaker (1993) concluded that aspiring rock climbers should focus training programs on enhancing finger strength, shoulder strength and endurance, and hip flexibility .

Physiological characteristics of the energy specificity and aerobic capacities of competitive sport rock climbers were assessed by Billat, Palleja, Charlaix, Rizzardo, and Janel (1995). The findings suggest that oxidative metabolism plays a secondary role in competitive rock climbing practice.

In her thesis, Russum (1989) assessed the strength in four muscle groups, anthropometric measurements, anaerobic power and capacity, body composition, and maximum volume of oxygen consumed (VO2 max) and ventilatory threshold of 40 male rock climbers. The findings were similar to those found by Billat et al. (1995), which were that the anaerobic energy pathways play a more crucial role in the activity of rock climbing than do the aerobic pathways.

Non-Climbing Biomechanical Inquiries and Gender Differences

Rapid movement kinematic and electromyographical (EMG) control characteristics in males and females were investigated by Ives, Kroll, and Bultman (1993). This study examined the gender differences in performance of an elbow flexion test. The result indicated that overall the males were 30-40% faster in the movement time variables. The males provided significantly higher peak velocities, and a shorter period of acceleration with nearly double the peak acceleration. When pre-motion resistance was increased to create a quick release, only the males were able to use this quick release to move faster throughout the entire range of motion, resulting in the higher peak velocities. The higher kinematic measurement results for the males can be attributed to being able to provide higher antagonist breaking resistance as seen by the EMG results.

Several other researchers have found similar results of gender differences concerning muscle exertion, tension development, twitch contraction rates, speed of neural firing rates, and biomechanical coordination (Bell & Jacobs, 1986; Bemben, Clasey, & Massey, 1990; Lenmarken, Bergman, Larson, & Larson, 1985; Thomas & French, 1985; Thomas & Marzke, 1991). These measured differences in ability to create speed of movement have been shown to have little association with differences in strength in unweighted tests (Lagasse, 1979). This could also hold true for the kinematic gender differences observed in the unweighted movements of sport climbing.

The effects of grip and forearm position on the performance of a flexed arm hang were studied by Gabbard, Gibbons, and Elledge (1983). Their results show that the supinated flexed arm hang performance was best in the thumb-over-bar position. This result was recognized as being due to the differences incurred mechanically in changing the posture of the humerus and forearm into a flexed position. These results confirm the importance of posture and postural adjustments on joint motion, and sustained muscle contractions similar to those found in rock climbing.

Motor Control and Biomechanics in Rock Climbing

The effectiveness of basic instruction on technique improvements in rock climbing skills was investigated by Marino and Kelly (1988). This was accomplished by measuring force exertion of both the upper and lower body during the execution of a simulated rock climbing skill. The subjects consisted of 11 males and five females with no previous rock climbing experience. Thus the independent variables included:

1. Males versus females.
2. Slope and difficulty.
3. Instruction versus no instruction.

The results suggest that instruction caused significant changes in the efficiency of rock climbing technique. The variable of gender provided no significant difference in technique acquisition, or learning, between novice male and female subjects. The slope difficulty proved to be a significant variable in the efficiency of rock climbing technique (Marino & Kelly, 1988).

In the study by Cordier, France, Bolon, and Pailhouse (1993), the kinetics of the optimization process were studied by examining the changes in entropy over time for a set of trajectories created by the learning of a simulated climbing route. The learning process occurred over 10 successive repetitions of the climb. The subjects consisted of a group of four highly skilled climbers and a group of three climbers of average skill. The trajectories were defined by the movement of a light emitting diode placed at the lower back. The movement was recorded by videotape and processed by computer to digitize trajectory and compute degrees of entropy.

The results indicated successive trajectory entropy decreasing due to postural adjustments during a series of attempts at the climb. This translates to more efficiency in movement with practice of that same movement. It was found that expert climbers process information much faster than novice climbers. In the initial trials the greater entropy and the greater the constraints of the environment, the fewer the degrees of freedom that were presented to the climber. This can be taken to the point of extreme entropy and zero degrees of freedom resulting in a cessation of movement and eventually a fall (Cordier et al., 1993)

The compensatory action of remaining limbs that accompanies a voluntary or imposed movement of one lower limb during a quadrupedal climbing task was analyzed biomechanically by Rougier (1993). The subjects were eight expert and seven beginning rock climbers. The subjects were tested on a specific instrument called a climbing ergometer. The climbing ergometer measured timing, sequences of application of pressure to the remaining holds, and tracked the trajectory of center of pressure distributed between those holds. The subjects were asked to either voluntarily displace one foot towards a randomized target or to counteract the disequilibrium due to the imposed loss of a foot support.

The results show discrepancies in the sequences of anticipatory postural adjustments causing a reinforcement of the hand supports and a positive acceleration of center of gravity (CG). This reaction was also to counteract the backward perturbation due to the strict vertical plane. The contralateral hand (CH) functional role was primarily to displace laterally and to accelerate the center of gravity. The homolateral hand (HH) would counteract the "flag effect," which is the rotation around the vertical axis running through the contralateral support line. The expert climbers would displace their center of gravity more laterally, resulting in a decreased arm level between CH and CG. The results indicated that the expert climbers more readily accepted the more evident backward unbalance than would the beginners (Rougier,1993) .

Gelat (1993) conducted a quasi replication of Rougier's (1993) study in which he examined the influence of the difficulty of the task on initial posture (distribution of weight on each support) and posturo-kinetic coordination while climbing. The subjects were five experienced male rock climbers. The tests were conducted on the same climbing ergometer referenced by Rougier. The difficulty of the task was modified for four conditions (C1-C4). C1 was the reference condition in which the subject was provided with handholds which allowed a grip with all four fingers and flat horizontal foot supports. C2 was characterized by the modification of the left hand hold to a single grip. In C3, the left foot hold was modified with an inclined surface. In C4, both the left foot and hand holds were modified as n C2 and C3 (Gelat, 1993).

Strategies were analyzed in terms of latencies in respect to time of decreasing force under the displacing limb. Two indexes, lateral (Li) and high-low (HLi), were combined to provide the position of the resultant force point. Only the results of right foot displacement were analyzed in this study. Results show that the LH was loaded first in all conditions. The latency of the anticipatory force change increased with the difficulty in both LF and LH. This anticipatory force change also increased under the RH when the LH was modified. The resultant force point variation was measured greater on the HLi and less on the Li with right foot displacement. It was concluded that only when the biomechanical conditions become too demanding that the combinations of motion become more complex in the climbing task (Gelat, 1993).

Studies of posturo-kinematics have shown significant functional correlations between postural activity and the control of motion (Dufosse & Massion, 1992; Massion & Dufosse, 1988; Nashner & McCollum, 1985). Marteniuk, Leavitt, MacKensier, and Athens (1990) found that the kinematics of the grasping motion was influenced mostly by the functional finality of the motion; that is, the state of disequilibrium experienced by completing the movement.

Nougier, Orliaguet, and Martin (1993) studied five male climbers on the climbing apparatus used in the previous two studies (Gelat, 1993; Rougier, 1993). This study examined the temporal modifications of the reaching to a given climbing hold, according to three variables:

1. The posture, easy or difficult.
2. The manual hold to reach, simple or complex.
3. The sequence of movements, right hand movement alone, before, or after left hand movement.

The test involved the subjects completing a movement with feet stationary on climbing holds, moving the right hand from the starting position hand (SPH), to the final position hands (FPH). The holds were modifiable to permit the difficulty of the initial position and the difficulty of the manual hold to be grasped. The feet could be modified to be more (difficult) or less (easy) inclined, the hand holds could be modified to either a 2 cm depth (easy), or a 1 cm depth (difficult). Hand motion was recorded two dimensionally by tracking the motion of three infrared emitting diodes placed on the hand. The beginning of movement was used to synchronize each trial to maintain a constant initial reference. The following kinematic parameters were analyzed:

1. Total duration of the movement.
2. Time to maximum positive acceleration.
3. Time to maximum velocity.
4. Time to maximum negative deceleration (Nougier et al., 1993).

The results demonstrated the mean movement time was longer in the easy initial posture than in the difficult posture by 365.05 ms. To determine where in the velocity profile the differences in time occurred, the times to maximum velocity, to positive acceleration, and to negative acceleration were analyzed. Of the three variables examined, only posture had a major effect (Nougier et al., 1993).

The movement time was always shorter in the difficult posture conditions regardless of the conditions of the other two variables: complexity of the manual hold, and composition of the motor sequence. In the difficult posture it was as though the motion was preprogrammed, which resulted in the faster movement (Nougier et al., 1993).

When the initial posture was difficult, the higher the state of disequilibrium experienced, resulting in a suppression of the motor controls. The reaction of the climber, to the difficult posture creating a state of disequilibrium, would cause the climber to make anticipatory postural adjustments automatically without the use of the on-line controls seen in easier postures (Nougier et al., 1993). These data are similar to those found by Rougier (1993) on anticipatory postural adjustments.

A kinematic and strength comparison of novice to elite sport rock climbers was the objective of the study by Abendroth-Smith and Slaugh (1997). This study collected data on eight females and 21 males over a multitude of strength, anthropometric, and kinematic variables correlated with the performance measure of redpoint level. The kinematic variables were collected with a manually digitizing two-dimensional motion analysis system by way of video taken of the participants performing a predetermined movement on an artificial climbing wall.

The strongest correlation with performance for the males include a one-arm hang impulse measure, lat pull down strength normalized with weight, averaged left and right normalized grip strength, ape index (negatively), which was calculated as the difference between arm length and height, the timing of the maximum vertical acceleration of the center of gravity (negatively), and angular trunk displacement. For the female participants, as with the males, the variables of averaged normalized grip strength and angular trunk displacement displayed high levels of correlation with performance as well as height (negatively), flexibility, normalized peak leg force, maximum velocity and acceleration of the center of gravity, and maximum wrist velocity of the dynamic grasping hand (Abendroth-Smith & Slaugh, 1997).

The gender and performance differences noted for the participants were attributed to the advanced males greater upper body strength, and the advanced females greater flexibility and ability to create the higher peak leg forces. These reported strength differences are believed to result in the higher accelerations and velocities of the center of gravity, and the greater angular trunk displacements displayed. The importance of the timing of the maximum acceleration of the center of gravity was explained as allowing more time towards the end of the movement for a more controlled grasping action (Abendroth-Smith & Slaugh, 1997).

Summary of Review of Literature

The studies reviewed in the previous section provide some interesting variables and concepts for consideration in this study: the ability to create speed of movement in unweighted conditions as investigated by Lagasse (1979); gender differences in elbow flexion speed test (Ives et al., 1993); speed of processing information and the efficiency of movement and its relationship to level of expertise in climbing as discussed by Cordier et al. (1993); kinematic variables of accelerations and velocities of the center of mass and the wrist of the dynamic grasping hand and the timing of these variables as discussed by Abendroth-Smith and Slaugh (1997).

Kinematic analysis has been performed on a multitude of other competitive sport performances, including the quarterbacks throw, water polo throwing, boxing, and freestyle swimming, just to name a few (Capaert et al., 1992; Rash & Shapiro, 1995; Whiting, Gregor, & Finerman, 1988; William et al., 1985). These studies have provided useful information for use in further research, applied technique enhancement, and injury prevention.

In conclusion it is believed that the biomechanical analysis of the sport of rock climbing will provide useful information on which to base further research, and for the application to training methods and principles.

CHAPTER III

METHODOLOGY

Approach to the Problem

The research design used in this study was descriptive in nature. To meet the objectives of the study, men and women elite professional sport rock climbers were recorded while performing in competition. The selected competition was the Fall National sport climbing competition held in Boulder, Colorado, sanctioned by the American Sport Climbing Federation (ASCF).

Participants

The participants consisted of both the male and female elite contestants entered in the Fall National competition sanctioned by the ASCF. The performances of all the men and women were recorded on their respective separate routes that were climbed. These included the quarterfinals, semifinals, and finals routes. Of these, only the recordings of the top five male and female finalists, on the finals route, were analyzed to determine the important kinematic elements of performance and possible gender differences. Only these top five placing male and female finalists' performances were analyzed to ensure that the movement events chosen for analysis were performed by all of the subjects. The climbers who did not place in the top five generally fell off the climbing route relatively low and therefore did not perform all of the movement events that were to be analyzed.

Authorization for the recording was obtained from the director of the ASCF. Permission was also obtained from the private establishments hosting the event. Written permission was collected from each contestant in the way of a signed waiver by the establishment hosting the event.

Instrumentation and Data Collection

The performances were recorded using two Super-VHS video cameras, a Panasonic AG450 and 577OU, with shutter speeds set at 1/500 seconds. The sampling rate was at 60 Hz (60 fields/second). Calibration frames were taken from the horizontal and vertical positioning of a red and white striped calibration rod, marked in 1-foot increments, within the plane of movement of the participants.

The selected segments of the climbing routes chosen for analysis from the recorded performances were captured, digitized at a rate of 15 Hz (every other frame), and kinematically analyzed using the 2-D Motion Measurement System (Liao, 1996) on an IBM compatible personal computer. All digitized coordinates were digitally filtered using a low pass Butterworth type digital filter with a pre-selected cutoff frequency of 2.8 Hz (2-D, 1996). This frequency was selected in keeping with Winter's (1990) recommendations for minimum cutoff frequencies of digitally filtered kinematic data.

The figure definition used in the digitization process is shown in Figure 1, and consisted of the following points:

1) left toe	2) left ankle
3) left knee	4) left hip
5) right hip	6) right knee
7) right heel	8) right toe
9) left wrist	10) left elbow
11) left shoulder	12) right shoulder
13) right elbow	14) right wrist
15) mid-back	16) mid-head

Points formed by connecting the above points into segments included:

17) mid shoulder	18) mid hip

The center of mass of each formed segment was estimated at distances as defined by Winter (1990, p.56) as well as the inertial parameters of each segment to be used in the kinematic analysis.

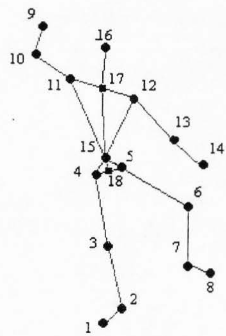

Figure 1. Figure definition showing posterior view.

The selected segments of the climbing routes analyzed were standardized to an initial reference frame. For the men, this initial reference frame of the route segment was identified as the first vertical displacement of the left wrist following the successful clipping of the third piece of protection. This route segment ended after the clipping of the fourth and fifth caribiner, with the participants grasping of the first hand hold on the head wall. The fifth male participant fell just prior to the final movement but did complete all events analyzed in this study.

The initial reference frame for the route segment analyzed for the women was identified as the first horizontal displacement of the right wrist following the successful clipping of the second piece of protection. This segment of the climbing route ended with the grasping of the last hand hold on the vertical head wall just prior to the roof section.

In each of the male and female route segments analyzed, three dynamic grasping hand (DGH) events were identified. These DGH events involved the displacement of the grasping hand from the initial hold to the target hold that was next in the sequence of moves. Figure 2 displays a side-by-side comparison of the separate genders climbing route segments and the events analyzed utilizing the figure defined in Figure 1. During these events the other points of contact (static hand and feet) remained primarily stationary. For all the males the first event was a left-hand displacement, and the second was a right-hand displacement. For the third event, the top two male participants performed right-hand displacements while the other three participants chose to perform left-hand displacements to execute the movement. Of the female events selected for analysis, all involved right-hand displacements. These three DGH events were also standardized to an initial reference frame which was the first observed positive velocity (in the direction of the target hold), and an ending reference frame which was when both horizontal and vertical velocities came closest to their zero point. This ending reference frame indicated successful grasping of the target hold.

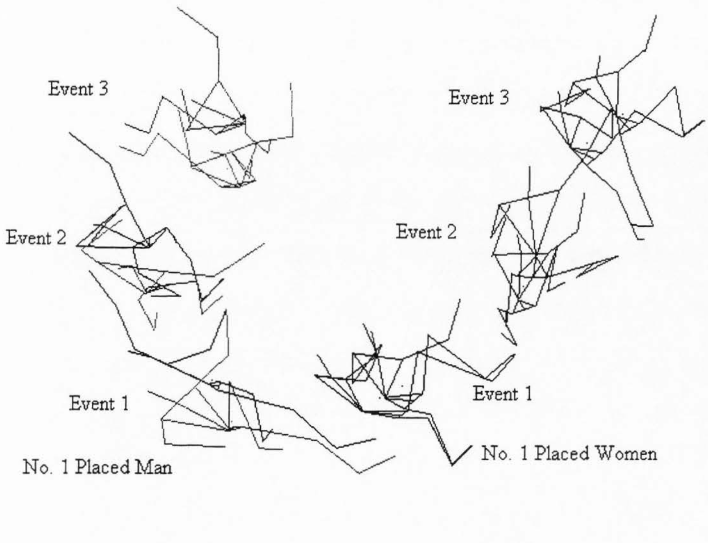

Figure 2. Side-by-side comparison of the men's and women's separate climbing route segments and events analyzed.

Analysis

The participants were placed into the category of gender and a performance success category of finish place (first through fifth). The category of finish place was divided by placing the top three male or female finishers into the top category (tops), and the bottom two male or female finishers into the bottom category (bottoms). The cutoff between the top (first through third) and bottom (fourth and fifth) performers for the performance success category of finish place was chosen due to a qualitative comparison of the performances of the male participants. The top males (first through third) all attained positioning on the head wall following the last event analyzed, but both of the bottom males (fourth and fifth) fell immediately after the last event analyzed and did not perform the movement sequences which lead to the head wall. The female participants were also divided between the third and fourth placed finishers for the purpose of direct comparison.

Descriptive statistics including means, standard deviations, and ranges were computed to compare the kinematic results of the male/female differences, and the within- gender performance comparisons for each of the variables. Correlations were calculated via multiple regression techniques examining the kinematic variables, across the three events, to the category of finish place for all participants combined. For the dynamic grasping hand, the kinematic variables included: maximum and minimum horizontal and vertical velocities and accelerations, timing of the previously stated variables standardized to the initial reference frame of each separate event, and the averaged positive horizontal and vertical velocities of each separate event. For the participants' center of mass (CM), the variables included: maximum and minimum horizontal and vertical velocities and the timing of these occurrences standardized to the initial reference frame of each event, and averaged horizontal and vertical velocities of each separate event. The adjusted R-squared values of these variables were used to identify trends in associations of the variables for further analysis.

Vertical, horizontal and resultant displacements and resultant velocities were calculated for the CM over the entire climbing route segment. The vertical distance all participants moved their CM was computed by noting the vertical displacement of the CM between consecutive frames that displayed velocities of the same vector (positive or negative) indicating movement in one direction only (up or down). The distance was computed as the difference between the first frame in this sequence and the last. This resulted in distances with both positive and negative values, depending on the direction of the movement for that sequence of frames. The negative distances were then rectified and summed with the positive distances to result in a net vertical distance value for the CM. This vertical distance value was then used for performance success comparisons within gender. Displacements of the CM for the same gender participants were not analyzed because all participants of the respective genders started and ended the climbing route segment with roughly the same positioning of their CM. For comparisons between genders and due to the different lengths of the respective genders' route segments, this distance was normalized by dividing the vertical distance of the CM by the vertical displacement of the CM (dY/lY). This resulted in a value representing the displacement as a percentage of the distance or the amount of vertical distance traveled in excess of the displacement required.

Other variables examined separately included the timing variables of total time for all participants to complete their respective route segment, overall average time of the three events, average time spent clipping protection, total time spent shaking, total combined time spent clipping and shaking, and ratios of total time clipping and shaking to total time separately and combined.

Statistically significant differences between top and bottom place finishers, and between genders were assessed by way of a one-factor ANOVA for the selected kinematic variables. The null hypothesis stated that there would be no statistically significant differences found between these groups. Statistical significance was determined at the $p = .05$ level for all comparisons.

Standardized mean difference effect sizes (SMD) for the selected kinematic variables were computed by dividing the difference of the means of the top to bottom males and females separately, top males to top females, bottom males to bottom females, males to females, and combined tops to combined bottoms, by the standard deviations of the males and females, combined tops, combined bottoms, and pooled, respectively. For the purpose of determining practical significance, effect sizes were considered small in magnitude if less than .4, moderate if between .4 and .7, and large in magnitude if greater than .7. These effect size values are in keeping with Jacob Cohen's recommendations as cited in Thomas and Nelson (1996), suggesting that effect sizes of .2 represent small differences, .5 moderate differences, and effect sizes greater than or equal to .8 as large differences.

CHAPTER IV

RESULTS

The purpose of this study was to describe kinematic performance and gender differences in elite-level sport rock climbers during competition. The analysis examined the kinematics over three separate dynamic grasping events.

Kinematic variables examined for the dynamic grasping hand (DGH) included: maximum and minimum horizontal and vertical velocities and accelerations of the separate events, these variables averaged over the three events, and the timing of the previously mentioned variables.

The movements of the participant's centers of mass (CM) were analyzed through the following variables: maximum and minimum horizontal and vertical velocities of the separate events, averaged over the three events; the timing of these occurrences; vertical, horizontal, and resultant displacements and velocities of the CM for the entire segment; a vertical distance for the CM; and a normalized value of the vertical displacement divided by the vertical distance (dY/lY). This equation dY/lY resulted in a unit-less value for comparisons between the different length climbing routes of the males and females. Timing variables analyzed included: total time of each participant to complete each respective route segment, overall average time of the three events, average time spent clipping protection, total time shaking, total combined time clipping and shaking, and ratios of total time clipping and shaking to total time, both separately and combined.

Multiple regression equations were computed on all of the kinematic variables, and the timing of the occurrences of these variables, for the dynamic grasping hand, and for the CM movement, excluding those regarding the CM vertical distance and the vertical displacement/distance relationship. Tables 1 and 2 display the R, R-squared, and adjusted R-squared values from these regression equations for the DGH and CM, respectively. From these multiple regressions the variables with reported adjusted R-squared values ≥ .24 were then analyzed through ANOVAs and standardized mean difference effect sizes.

A two-way ANOVA was computed on the selected kinematic and timing variables to determine the presence of statistically significant differences between genders and within gender between top and bottom place finishers. The results of these ANOVAs are presented in Tables 3 and 4 for the dynamic grasping hand and the center of mass, respectively. Statistical significance was set at the .05 level of probability.

The kinematic variable of the CM vertical distance and displacement/distance relationship was examined, without qualification by acceptable adjusted R-squared values, due to the relationship shown between the entropy of a climbers movement and the difficulty of the climbing movement being attempted, which was noted in previously completed research by Cordier et al. (1993).

For the determination of practical significance, standardized mean difference effect sizes (ES) were calculated for all DGH and CM kinematic variables which displayed acceptable adjusted R-squared values, the variables concerning the CM displacement/distance relationship, and the variables regarding time spent in other events (shaking and clipping). The standardized mean difference effects sizes were calculated as the difference between the means (pooled, males, females, tops, bottoms) divided by the respective standard deviation. Practical significance, calculated as standardized mean

Table1

Multiple Regression Coefficients of the Dynamic Grasping Hand with Finish Place for thePurpose of Identifying Trends and Associations

Dependent variable	R	R-squared	Adj. R-squared
Max vertical velocity	.86	.74	.61[a]
Timing max vertical velocity	.43	.19	-.22
Max horizontal velocity	.55	.30	-.06
Timing max horizontal velocity	.55	.30	-.05
Max vertical acceleration	.80	.64	.45[a]
Timing max vertical acceleration	.52	.27	-.10
Max horizontal acceleration	.22	.04	-.43[a]
Timing max horizontal acceleration	.70	.49	.24[a]
Min vertical velocity	.61	.38	.06
Timing min vertical velocity	.66	.43	.15
Min horizontal velocity	.61	.38	.07
Timing min horizontal velocity	.56	.31	-.03
Min vertical acceleration	.40	.15	-.27[a]
Timing min vertical acceleration	.26	.07	-.40[a]
Min horizontal acceleration	.65	.43	.14
Timing min horizontal acceleration	.46	.21	-.18

[a] Denotes variables selected for further analysis

Table 2

Multiple Regression Coefficients of the Center of Mass with Finish Place for the Purpose of Identifying Trends and Associations

Independent variable	R	R-squared	Adj.-R-squared
Max vertical velocity	.82	.67	.51[a]
Timing max vertical velocity	.60	.36	.04
Max horizontal velocity	.34	.12	-.38[a]
Timing max horizontal velocity	.49	.23	-.15
Min vertical velocity	.80	.64	.45[a]
Timing min vertical velocity	.52	.27	-.10
Min horizontal velocity	.77	.60	.39[a]
Timing min horizontal velocity	.68	.46	.19

[a] Denotes variables selected for further analysis

difference effect sizes (ES), was considered to be small if less than .4, moderate if between .4 and .7, and strong if greater than .7.

No statistical significance at or below the .05 level was found across the independent variable of finish place and the selected dependent kinematic variables for the DGH or CM, justifying the acceptance of the null hypothesis. This was attributed mainly to the small sample size (n = 10, pooled) (n = 5, separate genders) analyzed during this study.

Table 3

One-Factor Repeated Measures ANOVA for Finish Place and Selected Kinematic Variables of the Dynamic Grasping Hand over the Three Analyzed Events

Source	df	Between group SS	Mean square	F	p value
Finish place (A)	4	5.06	1.265	.736	.605
Repeated measure maximum vertical velocity (B)	2	2.208	1.104	.942	.422
AB	8	5.775	.722	.616	.748
Error	10	11.72	1.172		
Finish place (A)	4	439.573	143.036	1.627	.300
Repeated measure maximum vertical acceleration (B)	2	511.707	255.853	4.769	.035
AB	8	453.869	56.734	1.058	.458
Error	10	536.461	53.646		
Finish place (A)	4	80.364	20.091	.765	.591
Repeated measure maximum horizontal accel. (B)	2	30.861	15.431	.299	.748
AB	8	121.714	15.214	.294	.952
Error	10	516.685	51.668		

(table continues)

Source	df	Between group SS	Mean square	F	p value
Finish place (B)	4	152.2	38.05	1.2	.414
Repeated measure timing max horizontal accel. (A)	2	121.867	60.933	3.543	.069
AB	8	122.8	15.35	.892	.555
Error	10	172.0	17.2		
Finish place (A)	4	102.780	25.695	.873	.539
Repeated measure minimum vertical accel. (B)	2	50.427	25.213	.39	.687
AB	8	170.135	21.267	.329	.936
Error	10	647.063	64.706		
Finish place (A)	4	415.2	3.8	.356	.831
Repeated measure timing min vertical accel.(B)	2	0	0	0	0
AB	8	70.0	8.75	.559	.790
Error	10	156.667	15.667		

Table 4

One-Factor Repeated Measures ANOVA for Finish Place and Selected Kinematic Variables of the Center of Mass over the Three Analyzed Events

Source	df	Between group SS	Mean square	F	p value
Finish place (A)	4	1.281	.320	3.74	.090
Repeated measure maximum vertical velocity (B)	2	.79	.396	5.197	.028
AB	8	.800	.100	1.312	.337
Error	10	.763	.076		
Finish place (A)	4	.073	.018	.732	.608
Repeated measure maximum horizontal velocity (B)	2	.059	.029	.43	.662
AB	8	.255	.032	.465	.855
Error	10	.686	.069		
Minimum vertical velocity (A)	2	.004	.002	.08	.924
Finish place (B)	4	.189	.047	1.721	.281
AB	8	.049	.006	.229	.976
Error	10	.269	.027		

(table continues)

Source	df	SS	Mean square	F	p value
		Between group			
Finish place (A)	4	.013	.003	.253	.896
Repeated measure minimum horizontal velocity (B)	2	.029	.014	2.824	.107
AB	8	.102	.013	2.536	.085
Error	10	.050	.005		

Female Practical Performance Success Differences

The women's performances varied on several kinematic variables. Those with effect sizes of small (but $\geq$ .21) to strong in magnitude are presented below. All effect sizes along with means and standard deviations computed for the variables concerning the movement of the dynamic grasping hand (DGH) and CM of females are presented in Tables 5 and 6, respectively.

The movement of the dynamic grasping hand DGH, averaged over the three events was analyzed with the following results. The tops overall maximum vertical accelerations mean was slightly higher than that of the bottoms by 0.09 m/s/s (ES = .25). These higher maximum accelerations translated to slightly higher overall max vertical velocities for the tops with a mean difference of 0.07 m/s (ES = .21). The difference between overall maximum horizontal accelerations of the DGH top to bottom was .53 m/s/s with the bottoms reporting the much higher accelerations (ES = .84).

Table 5

Descriptive Statistics and Effect Sizes for the Female Dynamic Grasping Hand Kinematics

Dependent variable (units)	Range	Mean		SD	ES
		Tops	Bottoms		
Max vertical velocity (m/s)	.235	.628	.553	.095	.21
Max vertical acceleration (m/s/s)	.901	3.509	3.422	.312	.25
Max horizontal acceleration (m/s/s)	1.50	5.055	5.585	.631	.84
Timing max horizontal acceleration (s)	.491	.618	.927	.199	1.56
Min vertical acceleration (m/s/s)	1.06	-3.617	3.30	.458	.69
Timing min vertical acceleration (s)	.201	.722	.726	.093	.04

Table 6

Descriptive Statistics and Effect Sizes for the Female Center of Mass Kinematics

Independent variable (units)	Range	Mean		SD	ES
		Tops	Bottoms		
Max vertical velocity (m/s)	.265	.259	.169	.109	.83
Max horizontal velocity (m/s)	2.665	5.50	6.00	1.043	.48
Min vertical velocity (m/s)	.036	.018	-.017	.016	1.66
Min horizontal velocity (m/s)	.044	.018	-.009	.020	.90
Vertical distance/vertical displacement (unit-less)	.422	.570	.508	.160	.39

The timing of the overall maximum horizontal accelerations provided the strongest effect size calculated for the females at 1.56. This translates to a mean difference of .309 seconds, with the tops reaching their maximum horizontal accelerations, with much lower values, much sooner during the event. The tops females produced overall minimum vertical accelerations which were moderately lower than the bottoms, and negative (ES = .69). The mean difference in minimum vertical accelerations was 6.91 m/s/s. No practical difference was found concerning the timing of the minimum vertical accelerations of the DGH (ES = .04).

The overall movement of the female CM during the analyzed events also varied considerably on certain kinematic variables. The maximum mean vertical velocities for the tops were much faster with a mean difference of 0.09 m/s (ES = .83). Maximum horizontal velocities indicate moderate differences (ES = .48), but opposite of that found with the maximum vertical velocities, with a mean maximum horizontal velocity for the bottoms 0.50 m/s faster than the tops (ES = .48). The minimum vertical velocities provide an interesting contrast, with the bottoms showing a much lower and negative mean minimum velocity at -0.036 m/s than the tops at 0.018 m/s (ES = 1.66). The negative velocity indicates a movement in the opposite direction of the grasping movement or in this case downward. The minimum horizontal velocities displayed the same effect as the minimum vertical velocities. The negative mean minimum velocity of -0.066 m/s for the bottoms was much lower than the mean of 0.002 for the tops, again with the negative velocity indicating movement in the opposite direction of the grasping action (ES = .90).

The vertical distances the participants moved their CM varied between tops and bottoms. The calculations describing the CM vertical distance traveled show that the tops moved their CM through a slightly less vertical distance with a mean difference of .260 m when compared to the distance traveled by the CM of the bottom females (ES = .37).

The variables describing the time spent in certain activities provided some of the strongest effect sizes analyzed for the females. The ranges, means, standard deviations, and effect sizes for these timing variables are reported in Table 7. The total time used to complete the analyzed segment was much lower on average for the tops with a mean time difference of 12.5 seconds (ES = 1.21). The overall average time spent completing each event shows the tops with much shorter times with a mean time difference of 0.153 seconds (ES = 1.51). The tops spent moderately more time clipping protection than the bottoms with a mean time difference of 0.622 seconds (ES = 1.51), which proved to be an even stronger difference when compared as a ratio to the total time used for the entire segment (ES = 1.21). Times spent chalking or resting indicate that the tops spent moderately less time chalking with a mean time difference of 4.366 seconds. This also held true when comparing the times as a ratio to the total time used for the entire segment (ES = .66).

Male Practical Performance Success Differences

The kinematic performance differences analyzed for the males all provided moderate to strong effect sizes. Tables 8 and 9 display the ranges, means, standard deviations, and effect sizes computed for the kinematic variables analyzed for the movement of the DHG and CM, respectively.

The male kinematic differences in movement of the DGH were as follows. The

Table 7

Descriptive Statistics and Effect Sizes for the Female Timing Variables in Activities Other Than the Kinematics of the Events Analyzed

Dependent variable (units)	Range	Mean Tops	Mean Bottoms	SD	ES
Total time (s)	27.939	44.466	56.983	10.381	1.21
Overall event average time	.268	.953	.931	.101	1.51
Average clipping time	1.333	3.755	3.133	.502	.62
Time clipping:Total time ratio	.12	.113	.055	.048	1.21
Total time shaking	14.133	5.198	7.266	6.602	.66
Time shaking:Total time ratio	.24	.083	.145	.117	.53
Total time other:Total time ratio	.20	.203	.195	.091	.09

top performers displayed moderately faster maximum vertical wrist accelerations than the bottom performers with a mean difference of 1.917 m/s/s (ES = .42). These higher accelerations resulted in much higher maximum vertical velocities for the tops' DGH with a mean difference of 0.365 m/s (ES = 1.03). While the mean values of the maximum horizontal accelerations of the DGH did not vary significantly top to bottom, the timing of this variable did (ES =.11). The tops reached their maximum horizontal accelerations moderately sooner in the event with a mean difference of 0.127 seconds (ES = .42). On the variable of minimum vertical acceleration, the tops and bottoms both show negative values; the tops, however, provided negative mean values that were much lower in magnitude with a mean difference of 1.52 m/s/s (ES = .42). The tops also

Table 8

Descriptive Statistics and Effect Sizes for the Male Dynamic Grasping Hand Kinematics

Dependent variable (units)	Range	Mean Tops	Mean Bottoms	SD	ES
Max vertical velocity (m/s)	.880	1.203	.838	.759	1.54
Max vertical acceleration (m/s/s)	11.65	4.891	2.975	9.099	.42
Max horizontal acceleration (m/s/s)	1.330	4.555	4.500	.490	.11
Timing max horizontal acceleration (s)	.558	.789	.916	.226	.56
Min vertical acceleration (m/s/s)	4.425	-4.18	-5.70	1.986	.77
Timing min vertical acceleration (s)	.335	.648	.704	.92	.45

displayed these lesser minimum vertical accelerations moderately sooner during the event with a mean time difference of 0.056 seconds (ES = .45).

For the variables describing the movement of the CM, no practically significant differences were found in the timing of these variables, but strong effect sizes were found with the overall maximum and minimum values. The male tops attained much higher maximum vertical velocities with a mean difference of 0.117 m/s (ES = .89). The minimum vertical velocities varied with a strong effect size at ES = .42, with the tops displaying a mean vertical velocity of 0.265 m/s and the bottoms with a mean velocity of -0.094 m/s. As was observed with the female results, this negative minimum vertical velocity indicates movement of the CM in the opposite direction of the grasping movement, or downwards in this case. A similar effect was seen with the variable of minimum horizontal velocity, producing the strongest effect size reported for these kinematic variables at ES = 1.54. Again, as seen with the minimum vertical velocities, the bottoms displayed negative minimum horizontal velocity values indicating movement of the CM in the opposite direction of the grasping action. The vertical distances the males moved their CMs varied greatly from top to bottom by a difference of 1.928 m (ES = 1.16).

Table 9

Descriptive Statistics and Effect Sizes for the Male Center of Mass Kinematics

Independent variable (units)	Range	Mean Tops	Mean Bottoms	SD	ES
Max vertical velocity (m/s)	.358	.373	.256	.132	.89
Max horizontal velocity (m/s)	11.330	3.333	15.665	9.195	1.34
Min vertical velocity (m/s)	.194	.265	-.094	.078	1.54
Min horizontal velocity (m/s)	.087	-.045	.008	.032	1.47
Vertical distance/vertical displacement (unit-less)	.325	.475	.373	.131	.78

As was observed with the female participants, the variables concerning time spent in certain activities during the segment analyzed provided some of the strongest effect sizes overall. The ranges, means, standard deviations, and effect sizes for the timing variables analyzed are presented in Table 10. The total average time the tops used to complete the climbing route segment was moderately longer, with a mean time difference of 5.875 seconds (ES = .67). The time spent completing each event on average was much less for the tops than the bottoms, with a mean time difference of .209 seconds (ES = 1.57). For the factor of time spent clipping protection, the tops clipped much more slowly for a mean time of 2.128 seconds slower than the bottoms (ES = 1.43), and when compared as a ratio of the total time spent climbing the segment, the tops spent 4% more of their time clipping protection (ES = 1.18).

Table 10

Descriptive Statistics and Effect Sizes for the Male Timing Variables in Activities Other Than the Kinematics of the Events Analyzed

Independent variable (units)	Range	Mean		SD	ES
		Tops	Bottoms		
Total time (s)	20.974	65.103	59.22	8.726	.67
Overall event average time	.335	.908	1.117	.113	1.57
Average clipping time	.666	5.711	3.583	.489	1.43
Time clipping:Total time ratio	.111	.177	.130	.04	1.18
Total time shaking	10.729	6.262	6.031	4.022	.06
Time shaking:Total time ratio	.150	.097	.085	.056	.21
Total time other:Total time ratio	.150	.273	.215	.054	1.07

The factor of total time spent shaking, and this time spent shaking when compared in ratio to the total time spent climbing the segment, produced only small effect sizes of 0.06 and 0.21, respectively, with tops spending slightly more time. When time shaking was combined with time clipping, and compared as total time other to total time climbing the segment, the tops spent 6% more time in the other activities than the bottoms (ES =

1.07).

Gender Practical Performance Success Differences

The top-performing male and female participants varied across several of the analyzed variables and these differences will be presented in this section. The differences between the bottom performer on these variables will be presented where an interaction between the genders is noted with an opposite effect.

The gender difference results concerning the variables calculated for the dynamic grasping hand (DGH) display effect sizes of a slight to strong magnitude for all of the variables selected for analysis. The ranges, means, standard deviations, and effect sizes for the top performer gender differences for the DGH variables are provided in Table 11.

The variable of maximum vertical velocity displayed a mean difference of 0.575 m/s with the males displaying the slightly higher velocity (ES = .38). The top males also had slightly higher maximum vertical accelerations than the top females with a mean difference of 1.382 m/s/s (ES = .34). The variable of maximum horizontal acceleration provided the strongest effect size between genders for the DGH variables at ES = 1.79. A mean maximum acceleration difference of 1.0 m/s/s with the females providing the higher horizontal accelerations is shown, which is an opposite effect as seen with the maximum vertical accelerations. The timing of these maximum horizontal accelerations shows the top females reaching the their maximum horizontal accelerations much sooner than the males, with a mean difference of .171 seconds (ES = 1.10).

Both the top-performing females and males provided negative minimum vertical accelerations with the females at slightly lower minimum accelerations for a difference

Table 11

Descriptive Statistics and Effect Sizes for the Top-Performing Female and Male Dynamic Grasping Hand Kinematics

		Mean			
Independent variable (units)	Range	Females	Males	SD	ES
Max event vertical velocity (m/s)	20.034	.628	1.203	.42	.38
Max event vertical acceleration (m/s/s)	23.356	3.509	4.891	3.985	.34
Max event horizontal acceleration (m/s/s)	3.00	10.11	9.11	.56	1.79
Timing max event horizontal acceleration (s)	.446	.618	.789	.167	1.10
Min event vertical acceleration (m/s/s)	8.85	-3.617	-4.18	1.617	.35
Timing min event vertical acceleration (s)	.201	.722	.648	.079	.94

of .563 m/s/s (ES = .35). The top females attained these minimum vertical accelerations much later on average during the event than the top males with a mean difference of .074 seconds (ES = .94). The effect of minimum vertical acceleration within gender provided an interesting interaction effect across, and is portrayed in Figure 3. The bottoms females show moderately higher minimum vertical accelerations than the tops (ES = .69), whereas the bottom males show much lower minimum vertical accelerations than the tops males (ES = .77), for a bottom performers gender difference of .447 m/s/s (ES = .49).

The variables computed for the kinematics of the CM provided moderate to strong effect sizes between genders for the top performers across all variables analyzed. Descriptive statistics including ranges, means, standard deviations, and effect sizes computed for the CM variables selected for analysis are presented in Table 12.

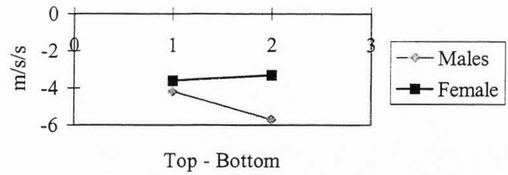

Figure 3 Women and men top-to-bottom placing performance success comparison of mean overall event minimum vertical acceleration differences of the dynamic grasping hand.

The mean maximum vertical velocity of the CM of the top-performing males was .114 m/s faster than the top females with an effect size of ES = .81. These vertical velocity, results are in contrast with the results found for the values of maximum horizontal velocity which show the top females with much higher horizontal velocities for the CM than the top males for a mean difference of 3.833 m/s (ES = 1.70). The top females displayed minimum vertical velocities much lower than those of the top males, showing a mean difference of .247 m/s (ES = 19.0).

The variable of the minimum horizontal velocity of the CM of the top males displayed a much lower and negative minimum velocity than the top females, with the negative indicating movement of the CM opposite to the direction of the grasping

Table 12

Descriptive Statistics and Effect Sizes for the Top-Performing Female and Male Center of Mass Kinematics

Dependent variable (units)	Range	Mean		SD	ES
		Females	Males		
Max event vertical velocity (m/s)	.716	.259	.370	.140	.81
Max event horizontal velocity (m/s)	10.66	5.50	1.667	2.258	1.70
Min event vertical velocity (m/s)	.074	.018	.265	.013	19.00
Min event horizontal velocity (m/s)	.175	.002	-.041	.032	1.34
Total vertical displacement	.536	1.304	1.389	.187	.45
Total horizontal displacement	.942	1.221	.811	.347	1.18
Total resultant displacement	.558	1.814	1.564	.195	1.28
Total resultant velocity	.039	.039	.026	.014	.93
Total vertical distance/vertical displacement (unit-less)	.422	.570	.475	.151	.63

movement (ES = 1.34). For this variable of minimum horizontal velocity, an effect was noted within gender providing an interaction displaying the opposite effect across genders and is portrayed in Figure 4, and the effect is opposite to that which was found with the minimum vertical acceleration of the DGH. This interaction is such that the female top performers displayed minimum horizontal velocities much higher than the bottom females (ES = .90), whereas the top males displayed minimum horizontal velocities that were much lower than those of the bottom males (ES = 1.47).

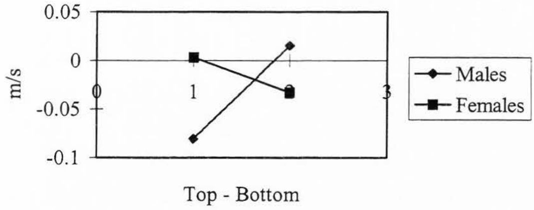

Figure 4. Women and men top-to-bottom placing performance success comparison of mean overall event minimum horizontal velocity of the center of mass.

Vertical, horizontal, and resultant displacements of the CM were calculated depicting the differences in the separate genders' route segments. The males on average displaced their CM vertically 0.085 m farther (ES = .45) and horizontally 0.41 less (ES =1.18) for a resultant displacement of 0.25 m less than the females (ES =1.28). Using the total times for the top male and female performers to calculate resultant velocities for the entire segment indicates that the top females climbed faster overall with a mean difference of 0.013 m/s (ES =.93). The variable of the CM vertical distance divided by the vertical displacement (lY/dY) shows the top males with a moderately lower value than the top females (ES = .63).

The top-performing males and females differed with moderate to strong effect sizes on five of the seven variables analyzed concerning the timing in activities other than the kinematics previously discussed for the DGH and CM. Descriptive statistics including ranges, means, standard deviations, and effect sizes computed for the selected timing variables are presented in Table 13.

Table 13

Descriptive Statistics and Effect Sizes for the Top-Performing Female and Male Timing Variables in Activities Other Than the Kinematics of the Events Analyzed

Dependent variable (units)	Range	Mean Females/Males	SD	ES
Total time (s)	37.322	44.466/65.103	13.44	1.54
Overall event average time (s)	.201	.953/.908	.073	.62
Average clipping time (s)	3.800	3.755/5.711	1.385	1.41
Time clipping:Total time ratio	.140	.113/.177	.051	1.25
Total time shaking (s)	10.140	4.134/6.262	4.147	.51
Time shaking:Total time ratio	.210	.083/.097	.077	.18
Total time other:Total time ratio	.190	.203/.273	.072	.07

The first of these variables, total time spent climbing the segment, provided the strongest effect size of these time variables at ES = 1.54, with the top males spending 20.637 seconds longer on average than the top female performers to complete the segment. The effect of total time within gender provides an interesting interaction across gender as is shown in Figure 5, with the top females spending less time than the bottom females, whereas the top males spent more time than the bottom males completing the segment. The overall average time required to complete the events analyzed was moderately longer for the top males than the females for a difference of .045 seconds less (ES = .62).

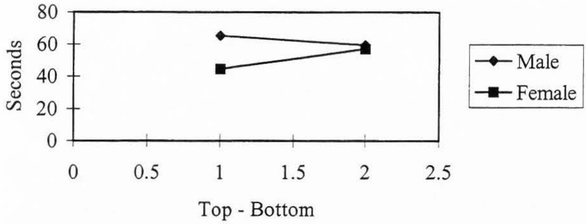

Figure 5. Women and men top-to-bottom placing performance success comparison of mean total segment time difference interaction.

The average time spent clipping the protection was much higher for the top males, with a mean difference of 1.956 seconds longer than the top females (ES = 1.41). When this time clipping is considered as a ratio of the total time to complete the segment, again the males spent much more of their time clipping protection in proportion to the top females (ES = 1.25). The top males, as with clipping protection, also spent moderately more time shaking or resting than did the top female performers, with a mean difference of 2.128 seconds (ES = 1.25). When the time shaking is examined in ratio to the total time, a very small difference was found of only 1.4% (ES = .18). With time spent clipping and time spent shaking combined and looked at as a ratio to total time, a difference of only 7% was found, which translates to a small effect size of .07.

CHAPTER V

DISCUSSION, CONCLUSIONS, AND RECOMENDATIONS

The objective of this study was to identify the presence of kinematically based performance success and gender difference in elite sport rock climbers during competition. The subjects consisted of the top five placing male and female participants in the American Sport Climbing Federation's Fall National competition held in Boulder, Colorado. The participants were filmed and then manually digitized for the purpose of kinematic analysis.

No statistically significant differences were found for the kinematic variables analyzed either across gender or performance success. As was stated in the Results chapter, this was believed to be due mainly to the low subject numbers of $\underline{n} = 5$ across performance success and $\underline{n} = 10$ across the dependent variable of gender used in this study. For the purpose of identifying practical significance in the differences identified, a standardized mean differences effect size was calculated for each of the variables selected and was computed for the performance success differences between the top three placing participants of their respective genders, and for the gender differences found between the respective top three placing participants. Gender differences between the bottom-placing participants were discussed only when a significant interaction between genders was noted for the effect of a dependent variable.

Female Performance Success Differences

The female participants displayed the strongest performance success differences between their dynamic grasping hand (DGH) maximum horizontal accelerations and the timing of these accelerations. The top women attained much lower DGH maximum horizontal accelerations much sooner during the event than did the bottom-performing women. In contrast, the results of the women's vertical motion of the DGH show the top women reaching slightly higher maximum vertical accelerations, which results in the slightly higher maximum vertical velocities of the DGH. The difference observed in DGH velocities and accelerations is attributed to the level of control of these precise DGH movements exhibited by the top climbers. Cordier et al. (1993) concluded that the higher the level of expertise of a climber, the faster the climber is able to process information pertinent to the climbing route being attempted. These findings by Cordier et al. add explanation to the performance success differences found in this study. The top women were able to process the information required to successfully perform the next movement sequence much sooner than the bottom-performing women and therefore initialize the DGH motion sooner. The smaller reported values for the DGH maximum horizontal accelerations suggest that the top women participants initiated the movement of the DGH with only the required force to complete the movement and without overshooting the hold. Overshooting the hold horizontally due to the generation of excess horizontal acceleration would require the climber then to compensate for the overshoot by generating forces in the opposite direction of the hold to bring the DGH back into proper position to grasp the hold. The greater DGH maximum vertical acceleration and resulting greater maximum vertical velocities of the DGH exhibited by the top women, while only slightly greater than the velocities of the bottom-performing women, indicate that compared to the horizontal movement the top females made a less precise but a slightly more powerful vertical movement. These findings are in agreement with previous research. Abendroth-Smith and Slaugh (1997) reported that with increasing level of ability based on redpoint level, a strong correlation was found with the females maximum vertical velocity of the DGH. The negative minimum vertical accelerations displayed only by the top-performing females seem to be a result of the slightly higher maximum vertical velocity achieved, which in turn would require the negative vertical acceleration to then slow the hand for prehension of the hold.

The movement characteristics displayed by the top-performing females' kinematic DGH variables are supported by the results reported for the top females' kinematic variables of the CM. As with the DGH, the top women also displayed greater maximum vertical velocities for the CM, suggesting that the top performers, due to these much higher vertical velocities of the CM, attained the needed vertical positioning of the CM sooner. These greater vertical velocities for the top women are again in keeping with the findings reported by Abendroth-Smith and Slaugh (1997), who noted a strong correlation of the greater vertical velocities of the CM with higher levels of ability in female climbers. The negative minimum vertical velocities shown only by the bottom-performing women indicate that they moved their CM too far vertically and then needed to lower their CM in order to be in the needed position to perform the DGH event. The lowering of the CM directly after raising it would produce a much less efficient movement, which was reinforced by the vertical distance the CM actually moved. This vertical distance the CM actually moved takes into account all vertical motion of the CM, with both negative and positive directions combined. The bottom-performing women, as depicted in Figure 6, demonstrated a much greater vertical distance traveled for the CM, even though all participants performed roughly the same total displacement of their CM to complete the analyzed route segment. This indicates that the bottom women must have performed much more negative vertical motion to attain the high vertical distances for the CM, which would result in more work and a less efficient movement. This is in keeping with the findings by Cordier et al. (1993) that with increased climbing experience and a corresponding level of expertise, a decrease was found in the level of entropy of the climbers' trajectory. The method of using the absolute values of the CM vertical distance moved is a simpler way of attaining values for comparisons similar to those used for the calculation of entropy based on degrees of freedom, which was used by Cordier et al.

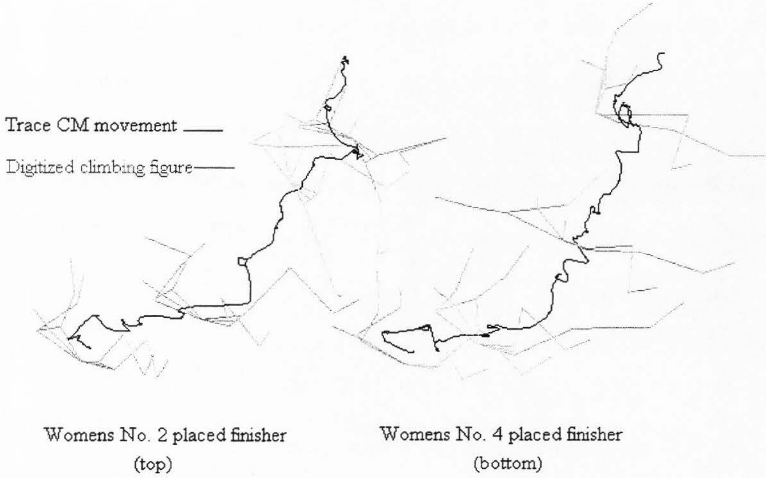

Figure 6. Side-by-side trace of the women's center of mass movement for top-to-bottom comparison.

The amount of time the participants spent completing the climbing segment and time spent in other than climbing activities such as clipping protection or shaking for rest provided some interesting results for discussion. The top-performing women completed the analyzed segments in less time on average than did the bottom-performing women. The quicker completion time is attributed to the more fluid and efficient climbing style of the female top performers. These findings are in keeping with those reported by Cordier et al. (1993) that with increased climbing expertise also comes the ability to process pertinent information faster, which would result in the top-performing climbers recognizing the next movement in a sequence sooner, and initiating that movement sooner.

This theory may also be supported by the result concerning the CM vertical distance moved, with the top-performing women performing a smaller CM vertical distance. These women were able to identify the next required movement sooner, whereas the bottom-performing women, with the larger vertical CM distances, would have raised their CM to attempt to perform what results in being the incorrect movement, only to have to lower their CM in order to figure out the correct sequence. The time spent shaking for rest reinforces this theory on the overall timing variable, showing a lesser time for the top-performing women. When compared to the total time spent climbing the segment, the top women spent only 8.3% of their total time shaking, whereas the bottom women used 14.5% of their time shaking. Not only would the top women spend less time on route requiring less time resting, but the bottom women would also require more time to process information in order to successfully complete the next move and would spend this time resting or shaking.

The time to complete each event and the average time to clip each piece of protection demonstrated that the top women spent more time on each, indicating that even though the tops are able to recognize the correct movement for the event sooner, once they begin the movement they perform the movement with care and precision. This is also supported by the result of a negative DGH minimum vertical acceleration for the tops, indicating that they were able to slow the DGH movement toward the end for more precision in prehension of the hold, and resulting in the overall longer event. The top women spending more time clipping protection may again be a matter of efficiency. While it may seem better for the climber to clip the protection faster, the possibility of missing the clip and having to try again would be more detrimental to the efficiency of the climbing sequence than spending the extra half second or so to perform the clip correctly the first time.

Male Performance Success Differences

The performance success results reported for the men were similar to those found for the women participants on several of the DGH and CM variables with the exception of the magnitudes of the differences, which varied for different variables for the separate genders. For the men the strongest effect size calculated for the DGH variables was for the difference in the maximum vertical velocities attained. The top men performed the events with much higher DGH maximum vertical velocities than did the bottom-performing men participants. The greater maximum vertical velocities of the DGH exhibited by the top men are a result of the greater maximum vertical accelerations the tops attained for the DGH. The maximum horizontal acceleration of the DGH shows a very small difference top to bottom, but the timing of this variable did provide a moderate effect size, showing the top men reaching their maximum horizontal accelerations sooner than the bottom men. This, as with the women participants, is attributed to the ability of the top performers to process the information required to properly initiate the DGH event sooner, therefore committing the required force to generate these accelerations sooner.

The horizontal movements are performed with more precision and the vertical components of the motion with more relative power. The lesser minimum vertical accelerations exhibited by the top men are attributed to the timing of these lesser accelerations occurring sooner in the event. The sooner the negative acceleration or slowing of the DGH occurs, the more time there is left to slow from the higher DGH vertical velocities, and results in more precise prehension of the hold. These minimum vertical accelerations also indicate a more constant velocity of the DGH during the event for the top men.

The analysis of the CM variables supports the efficiency of movement shown by the DGH variables for the top-performing men. As shown with the women participants, the top men attained much higher vertical velocities for the CM as well as for the DGH than did the bottom-performing men. This may be a more efficient technique because the top men with the higher vertical velocities will attain the vertical positioning of the CM sooner during the event, and allow more time for the DGH movement and easier prehension of the hold. The top men displayed the lesser maximum horizontal velocities of the CM, indicating a more controlled horizontal positioning rather than the more powerful movement executed for the vertical positioning. These higher CM horizontal velocities of the bottom men being almost five times the values reported for the top men contributed to the overall faster total segment times for the bottom men.

The CM negative minimum vertical velocities of the bottom men represent a downward motion of the CM during the event. This downward motion, as addressed with the bottom women, resulted in a much less efficient movement due to the additional energy wasted in the added work of raising and lowering the CM, and was supported by the vertical distance that the CM traveled. The opposite effect was displayed in the minimum horizontal velocity showing the top men with a negative minimum velocity, indicating excess horizontal movement of the CM by the tops. This excess CM movement is attributed to the tops attaining a horizontal position to perform the DGH movement but needing to adjust (in the negative direction) to facilitate prehension of the hold.

The distance the participants moved their CM is a major indicator of the efficiency of the movement. The top men exhibiting much lower distances traveled for the CM would result in a more direct completion of the climbing route segment without the excessive up and down motion, which resulted in the negative CM minimum vertical velocities and the greater CM distances shown by the bottom performing males. The difference in the CM vertical distance is exhibited with the more varied CM trace shown by the bottom-placing male participant in Figure 7.

The time the male participants spent in activities such as clipping protection, shaking to rest, and overall time to complete the segment demonstrated some interesting contrast to the women participants. The overall time to complete the segment was longer for the tops than for the bottoms. The strongest explanation for this difference comes

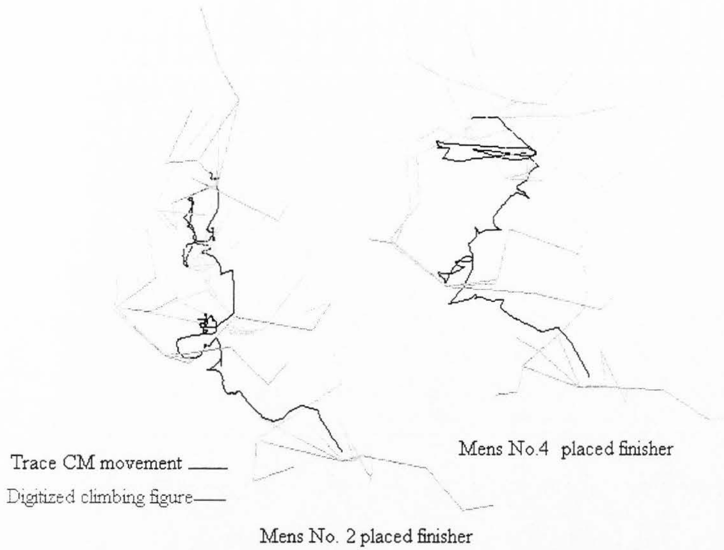

Figure 7. Side-by-side trace of the men's center of mass movement for top-to-bottom comparison.

from the maximum horizontal velocity of the CM showing much higher horizontal velocities of the CM for the bottom-performing men. These higher CM horizontal velocities reported for the bottom men also contributed to the less time the bottoms took, on average, to complete the analyzed route segments. The greater total time values reported for the top men are also evident with the variables of time spent clipping protection and time spent shaking for rest. The top men, consistent with the previous results, demonstrated precise accurate movements, in the action of clipping, taking more time than the bottom men, on average, to clip the piece of protection.

Gender Performance Success Differences

The results reported for this study indicate several moderate to strong gender differences in the kinematic and timing variables analyzed. Some of the differences between gender for the kinematic and time variables analyzed can be attributed partly to the differences in the separate female and male climbing routes analyzed in this study. The differences in the angle of the climbing walls for portions of the separate segments and the differences in the styles and the resulting unique moves required of the separate genders' segments can account for some of the differences observed. The first of these variables, the total time used to complete the segment showing the top males spending more than 20 seconds longer on average than the top females and the corresponding longer times the top males spent shaking for rest, are attributed partly to this difference in separate genders' climbing routes. The differences not accounted for by the separate genders' climbing routes are attributed to an overall slower climbing style of the top males. When an overall resultant displacement is calculated from the CM horizontal and vertical displacements, the top females performed on average a .25 m longer resultant CM displacement than the top males. Calculating a resultant CM velocity from these resultant displacements shows the top women climbing with a much greater average velocity than the top men for a mean difference of .013 m/s faster for the top women. With the exception of the variable of average event time, the top women provided overall faster times on average than the top men. The differences between the average times to complete the DGH events showing the top men with the faster DGH completion times suggest that while the overall climbing style of top men may be slower, the individual

DGH movements are performed with more speed and resultant power. An interesting interaction on the effect of the total time (Figure 5) is demonstrated across gender. The top women climbed the segment faster than the bottom women while the top men climbed their respective segment slower than the bottom men. This interaction results in the bottom men and women being separated by only 2.25 seconds on overall time, indicating to some extent the importance of speed of movement for the performance success of the respective genders.

The most evident differences found between genders for the variables examining the kinematics of the DGH and CM were the differences between the maximum vertical and horizontal velocities and accelerations of the DGH, and the maximum vertical and horizontal velocities of the CM. From Tables 11 and 12 it is evident that the top men demonstrated values in the vertical direction that were greater than the top women, and values in the horizontal direction that were less than those observed for the top women. The differences in the separate gender route segments may provide some explanation for some of the variance between these variables. The women's route segment contained, on average, .41 m more horizontal displacement than the men's segment, so the horizontal velocity and acceleration components of these DGH events for the top women would logically be greater. The top women reached their greater maximum horizontal accelerations much sooner than the top men, which is also indicative of their more horizontally inclined route segment. When the ratio between the vertical and horizontal maximum velocities for the CM are examined, a difference is found between the top women's maximum velocities of the CM with a 1:23 ratio compared to the top men's ratio of 1:9 of maximum vertical to horizontal velocity, showing the importance of the maximum horizontal velocities to the top female's more horizontally inclined route segment.

The noted gender differences in DGH and CM maximum vertical velocities and the higher maximum DGH vertical accelerations of the top males could be indicative of a more powerful climbing style for the top men as was noted with the overall faster DGH event times for the top males. Ives et al. (1993) reported in their findings that their male participants were 30-40% faster in the timed movement variables, providing overall significantly higher maximum velocities than the female participants which supports the findings of the faster DGH event times for the top males in this study. Abendroth-Smith and Slaugh (1997) reported gender-related strength differences in climbers, reporting a strong correlation of upper-body strength for males and lower-body strength for females with performance. These strength differences suggest that where the top female participants would be using more leg strength to create their movement, resulting in the reported velocities and accelerations of the CM and DGH, the top males would be utilizing more upper-body strength to perform the DGH event. Compared to the top women, the top men utilizing the greater upper-body-oriented strength could introduce a greater pre-motion resistance to the DGH prior to motion. Ives et al. found that with increased pre-motion resistance to force a quick release, only the male participants were able to use this quick release to move faster throughout the entire range of motion, resulting in the higher maximum velocities reported. These gender differences in the ability to generate speed of movement could add explanation to the top men's faster overall event times, if the upper-body predominant strength use imposes a similar pre-motion resistance resulting in an imposed quick release.

The results of the minimum CM vertical velocities showing the top women with the lower values is attributed to the slowing from the relative slower maximum CM vertical velocities. The fact that both the top women and men groups provided positive minimum vertical velocities while both the bottom men and women provided negative minimum CM vertical velocities is an important factor, indicating the relevance of how the excess vertical movement of the CM affects performance success. The CM vertical displacement divided by the CM vertical distance (dY/lY) (Table 12) depicts the top men with a lesser amount of excess CM vertical movement. This lesser excess CM vertical movement is attributed to the slower climbing style, which is becoming more apparent for the top men, allowing them to perform more controlled and decisive movements. The top women with the relatively faster climbing style would have a better possibility of performing an excess vertical motion, resulting in the female climber making an adjustment to the proper vertical position of the CM in order to perform the DGH event.

Excess horizontal motion, shown by the negative variable of minimum CM horizontal velocity, for the top men, compared to the positive value for the top women, seems to be less of an issue due perhaps to the upper-body strength differences such as those reported by Abendroth-Smith and Slaugh (1997). This theory is based on the interaction (Figure 4) that shows the opposing effect of this variable within genders. The bottom women provided negative minimum CM horizontal velocities similar to the top men, indicating the excess movement opposite to the direction of the DGH movement. This would indicate that while the excess movement indicated by the negative CM movement could be detrimental to the performance success of the women, the effect would not be so crucial to the performance success of the top men, possibly due to this greater relative upper body strength allowing the men to more easily compensate for the excess horizontal motion.

The greater rate of slowing of the DGH occurring sooner during the event shown by the top men is a result of having to slow from the higher vertical velocities produced for the DGH. The minimum DGH vertical acceleration providing the gender interaction (Figure 3) shows the opposing effect within each gender, again with the bottom women producing higher minimum DGH vertical accelerations and the bottom men producing lower minimum accelerations. The noted effect is attributed to the aforementioned differences in climbing styles between the top men and women.

Conclusions

The results of this study identified kinematically based performance success and gender differences in the elite sport climbing participants studied. The performance success analysis within each gender identified kinematic characteristics attributed to the success of the top performers that were common for both genders. These common performance success kinematic characteristics include: more controlled and precise horizontal movement of the dynamic grasping hand (DGH) and positioning of the center of mass (CM), a relatively more powerful vertical DGH motion and CM positioning, and an efficient CM movement indicated by minimum excess vertical motion.

Time usage by each gender varied across performance success. The top men participants indicated slower overall route segment times but faster DGH event times. Faster overall route segment times with slower DGH event times were attributes of the movement of the top women. Kinematically based gender differences for the top-performing participants include: greater overall resultant velocities for the route segment, and greater horizontal velocities and accelerations in the events for the top women; and the top-performing men with greater event vertical velocities.

No statistically significant differences were found for the kinematic variables analyzed either across gender or performance success. The practical significance determined by the use of the standardized mean difference effect size does provide an indication of kinematically based performance success differences both within and across the variable of gender. These identified differences provide possibilities for the generation of training protocols to meet specific gender performance-based requirements.

Recommendations

The following areas of inquiry warrant investigation and could provide additional data concerning kinematically based performance success and gender differences in elite sport rock climbers.

1. Replication of current study examining route segments of quarterfinal and/or semifinals for the inclusion of more participants across more finishing places.

2. Analysis of velocities and accelerations of the center of mass prior to the dynamic grasping hand event.

3. Replication of this study utilizing recordings of the women and men participants competing on the same climbing route.

4. Analysis by way of three-dimensional digitization procedures for examination of kinematics that occur in the transverse plane due to varying pitches of the artificial climbing wall.

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