BELAY TECHNIQUES ON STOP FALLING OF A CLIMBER

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The purpose of the present study was to identify the kinematic differences between two popular rock climbing belay techniques used in the United States: brake, under, slide (BUS) and slip, slap, slide (SSS) and their efficiency in stopping the fall of a climber. Five male subjects with no previous belaying experience from two different beginning rock climbing classes were recruited to participate in the study (n = 10). Each subject passed a practical belay test before participating in the study. Data of time to stop the fall of a climber, vertical displacement of the falling climber, maximum negative vertical velocity of the falling climber, and percentage of time each belayer was in the braked position were collected. Results showed that the climber had significant greater falling displacement, longer time to stop, and higher maximum negative velocity when SSS was performed.

KEYWORDS: rock climbing, belay technique, BUS, SSS.

INTRODUCTION: The global popularity of rock climbing has soared as it has evolved from a competitive sport in extreme outdoor landscapes to trendy recreational activity with indoor climbing gyms (Long, 2003). Over the last decade in the US alone, the number of individuals involved in rock climbing is rapidly approaching nine million individuals (Outdoor Industry Foundation, 2006). The research has surged in this area, with the biomechanical literature in particular, concentrating mostly on the climber's physiology exertion, technique of climbing, and climbing equipment such as belay device and dynamic rope (i.e., Bourdin, Teasdale, Nougier, Bard, & Fleury, 1999; Noẻ, Quaine, & Martin, 2001; Quaine & Martin, 1999; Vogwell & Minguez, 2007).

Since rock climbing presents with natural risks and is drawing an ever diverse population of individuals ranging both in age and experience, professionals in the field are constantly vigilant for new technology and techniques to reduce the possibility of injury. According to Nelson and McKenzie (2009), tens of thousands of individuals were hurt over a span of two decades with falls accounting for over 75% of total injuries. Falling, of course, cannot be eliminated from climbing, it is an accepted risk; however, the manner in which a fall is safeguarded can be managed and changed to reduce the risk of injury. Belaying is a method used to slow and arrest a fall in climbing. In a climbing situation, a rope is tied to the climber and to the person belaying – the belayer. A safe belay incorporates an anchor to hold the belayer in place, a body position that anticipates the direction of force applied to the belayer, good communication and the climber and belayer, and friction applied to the moving to slow and stop the falling climber (Powers, 2009).

Several aspects of belaying may be able to neutralize the negative consequences of a climber's fall: 1) the dependability of the equipment, 2) the belayer's skill level, and 3) the belay technique. Due to technological advances in equipment, the first variable can be considered to be constant. Differences within any particular skill level can also be stabilized through instruction, practice, and proficiency testing. The two common rock climbing belaying techniques are the brake, under, slide (BUS) and the slip, slap, slide (SSS). Both methods of belaying are very similar in that the slack is managed with the use of the hands and the belay device; however, they differ in the movements of the belayer's hands after taking in the slack. The SSS technique requires moving the brake hand with the rope upwards to meet the guide hand. The guide hand then "slaps" the two portions of rope together to allow the brake hand to slide along the rope toward the belay device (Stiehl & Ramsey, 2005). In contrast, the BUS method involves the guide hand letting go of the rope and moving underneath the brake hand so that the brake hand can slide along the rope toward the belay device (Stiehl & Ramsey, 2005). In both methods, the brake hand never lets go of the rope. The BUS technique, in theory, provides longer duration of braking phase of the rope when compared to the SSS technique.

Although there is no evidence that connects climbing injuries to the type of belay method, some climbers and some organizations teach one method over the other claiming that it is safer. A search through Accidents in North American Mountaineering for the past ten years shows no evidence of climbing accidents that can be attributed to the type of belay method used (Williamson, 2009). Accidents have been ascribed to failed belay anchors, or improper belaying techniques, but there is no empirical evidence to suggest that either the SSS of the BUS is a superior method of belaying (Williamson, 2009; Nelson & McKenzie, 2009). According to impulse-momentum relationship and gravity, the greater falling distance of a climber, the greater changing velocity the climber has. Therefore, if one method can arrest a fall faster, thus decreasing the distance of a fall the chances of injury would certainly be minimized (Nelson & McKenzie, 2009) such as injury from hitting a ledge. In addition, the dynamic rope has its mechanical property to elongate due the force applied. It is important to minimize the fall distance and duration within the dynamic rope's safe limits. Therefore, the purpose of the present study was to identify the kinematic differences between two belay techniques: BUS and SSS and their efficiency to stop the falling of a climber.

METHOD: Ten male subjects were recruited from two different rock climbing classes. Five participants were from a climbing class that taught the BUS and the other half were from a class that taught the SSS. All of the subjects received informed consent and all policies and procedures of using human subjects was followed and approved by the Human Subject Review committee at the local university. None of the subjects had any previous rock climbing or belay instruction. One month of instruction (one 2-hour class per week) in the university climbing gymnasium), and practice were given to learn either the BUS or SSS belay techniques. All subjects passed a practical belay exam given by their instructors before they could participate in the study.

Before data collection, all subjects were instructed to perform the technique in the plan of motion (POM) and markers were placed at the following joint axis on the right side of the body: shoulder, elbow, wrist, hip, knee and ankle. All subjects performed the belay techniques with the same climber, on the same climb using the same rope and belay device. In order to determine the fall of the climber, one marker was placed on the 4th lumbar vertebra and the climber was instructed to climb straight up and fall any time after point A and before point B (1 meter from the top of the camera view) (Figure 1). The belay performer was not informed that when and where the climber would fall.

One 60 Hz high speed camera (Panasonic, model: 5100 HS) was set up 10 meters away from the POM and 1.63 meters above the floor. Each subject was required to perform three successful belay trials using the technique on which he had been trained. All successful trials included the belay performer staying in the POM and performing the proper technique during the climber's fall. The video was analyzed from the 10th frame before the falling of the climber to the 10th frame after the lowest falling position of the climber.

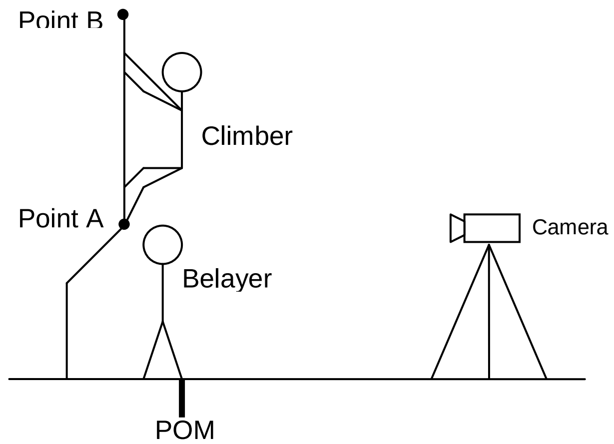

Figure 1. Experiemental setup (Note: Figure not drawn to scale).

Vertical displacement of falling includes the free fall period and the vertical displacement due to the elastic property of the dynamic rope. Time of falling was calculated from the beginning of the vertical downward movement to the lowest position of the fall. Time for belayer to reach the locking position (e.g., the angle between the dynamic rope on either side of the belay device is equal to or greater than 90 degrees) when he first sees the falling, which includes reaction time and motion time. Multiple t-tests were performed to examine the statistic significance between two types of belay techniques. In order to avoid type I and II error, the level of significance was readjusted according to the number of the comparisons using Holm's correction (*P*-value $= \alpha/(n - i + 1)$), where *n* is the total number of comparisons and *i* is the order of comparison (Knudson, 2009; Lundbrook, 1998).

RESULTS: Results indicated that the climber in SSS belay technique group had significant greater vertical displacement, maximum velocity, and a longer falling period with *P*-value less than the new adjusted *P*-value of 0.05. However, due to some discrepancies in the belayers' hand positions at the time of the fall, the percentage of the time in the braked position could not be measured. In addition, the performance in arresting the fall had large variations from trial to trial which resulted in the difficulty of identifying the beginning and the end of belay performance to catch the falling climber. Though the cycles of pulling slack from both techniques are different, belayers failed to complete a whole cycle of pulling slack of dynamic rope during the fall and in some trials, belayers started a new cycle of pulling slack. In other trials, the belayer assumed the locking position after finishing only part of the pulling cycle for both techniques. Therefore, this issue of pulling cycle resulted in the difficulty to compare times for the belayer to get into lock position. Due to the timing of getting into lock position varied from each individual belayer, the displacement and the time of the falling climber were also varied.

Table 1. Kinematic variables of the climber

Techniques	Displacement (m) *	Maximum velocity (m/s) *	Time to stop (s) *
BUS	.73 ± .04	2.17 ± .12	.51 ± .02
SSS	.90 ± .10	2.61 ± .44	.57 ± .01

Note: An * indicates significant difference with newly adjusted *P*-value.

DISCUSSION: The use of belaying techniques is an essential safety feature for rock climbers, especially for beginners. Therefore, two frequently utilized belaying techniques, BUS and SSS, were compared in terms of the efficacy of arresting a climber's fall. The main objective of belaying is to arrest a climber's fall quickly with as little vertical distance and velocity as possible. When the fall distance increases, the fall velocity, of course, will increase due to gravity before the elastic component of the dynamic rope starts to elongate and transfer the kinetic energy to strain energy and arrest the fall. One notable study showed that one of the most common injuries from rock climbing is back strain which is due to a sudden stop from the suspension of the rope (Hohlrieder, Lutz, Schubert, Eschertzhuber, & Mair, 2007). Although with better technology, the dynamic rope can be lengthened to absorb the shock from a sudden stop, the greater displacement of a fall still increases the risk of injury.

For novice belayers, the BUS technique appeared to be more effective in reducing the amount of displacement. In theory, belay performance can be separated into two phases of braking and pulling slack. As the climber moves upward, there is a period when the brake hand has to be repositioned while the belayer is taking in slack. This is a vulnerable period since the dynamic rope is not in a braked position. When the BUS technique applied, this vulnerable phase is shortened and the rope remains in a braked position for a longer duration. Therefore, it is more advantageous for the belayer to get into the braking position when using the BUS technique, which may have accounted for the findings that BUS has shorter amount of time to stop the falling in the present study.

Since there were difficulties to examine the time to assume locking position, it is hard to explain if BUS technique has less range of motion during a cycle so which resulted in higher efficiency when pulling the slack of the dynamic rope as the climber is ascending. Therefore, in order to analyze the belay techniques kinematically, the suggestions for future study are: 1) capturing three cycles of pulling slack of the rock until the locking position occurred, 2) using skilled belayers for both techniques to see if the same results of falling occur, and 3) separate the falling distance into free fall and the displacement due to elastic component of the dynamic rope.

CONCLUSION: The purpose of the present study was to investigate two common belay techniques (BUS and SSS) that are used to catch the falling of a climber. The findings suggested that after one month of instruction for all the beginners, the BUS group showed greater efficiency of catching the fall of a climber with a shorter period of time to arrest the climber with less vertical displacement and smaller maximum vertical velocity of the climber's fall when compared to SSS technique. Therefore, the BUS technique is suggested for beginners at the entry level since it is more efficient to stop the fall of a climber. However, this may not apply to skilled belayers who may be used to performing either technique.

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