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JOINT ANGLE CHANGES WITH VARIED FOOT POSITIONING IN ROCK CLIMBING

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Eleven experienced climbers performed a climbing movement known to climbers as a *high-step* on a vertical indoor wall using different foot positions 1) with the inside edge of the foot or 2) with the front part of the shoe/toe against the wall. Subjects self-selected the rate of movement and specific body positioning, other than the right foot, during each trial. Reflective markers identified elbow, shoulder hip, knee, and ankle joints. Minimum and maximum joint angles were found via 3D kinematic analysis. With the exception of the elbow, Maximum joint angles were different ($p < 0.05$) between the two foot positions, however, there were no differences ($p > 0.05$) in the Minimal angles for any of the studied joints. Results indicate that when foot position is altered the climber adjusts maximum angles of other joints to perform the movement.

KEYWORDS: KINEMATICS, LOAD CARRIAGE, CLIMBERS

INTRODUCTION: Sport rock climbing transports the individual by using a series of complex movements and body positions. Often times the climber has the option of using different types of holds and positions for the same overall movement (de Geus, et al., 2006; Watts, 2004). To minimize the load of the body during these movements the climber may change the configuration of the hand or foot, which will likely require alteration of different parts of the body (Noe´, 2006; Quaine et al. 1995). This is akin to what happens in many other types of activity, e.g. the positioning of the body during high jumping when using a flop versus a straddle technique (Dapena, 2002).
Although more researchers have begun to study physiological responses (Watts, 2004) and kinetic measures (Jensen et al., 2005; Noe´, 2006; Quaine et al., 1995); only Sibella et al (2006) have reported kinematic data of actual climbing. Their study examined center of mass movement, but did not address joint angle changes, or how the angles of the joint might change with variations in the rock climbing technique of a specific movement. The purpose of the current study was to compare the minimum and maximum angles of the major joints of the body during a rock climbing movement with the foot positioned using two different techniques.

METHODS: Eleven experienced rock climbers volunteered as subjects (mean ± SD: 31.6±13.9 years; height = 177.5±8.6 cm; body mass = 73.8±10.7 kg). All subjects had prior experience in performing the moves examined in the current study. Subjects completed a Physical Activity Readiness Questionnaire and signed an informed consent form prior to participating in the study. Approval for the use of Human Subjects was obtained from the institution prior to commencing the study.
Each Subject completed two trials of a climbing movement sequence on a vertical indoor wall (see Figure 1). The specific movement sequence is known to climbers as a high-step. Climbers performed two randomized conditions according to foot placement where the foot was positioned either (1) Inside edge = where the area on the inside of the shoe near the base of the great toe is used for contact and support; or (2) Toe-in = where the front part of the shoe at the toe is used for contact and support. During the movement sequence, a point was attained at which all weight was supported by the right foot on one hand hold, and the right hand on a second hand hold. Subjects self-selected the rate of movement and specific body positioning, other than the right foot, during each climbing trial. Malin et al. (2008) have reported the reliability for joint angle measurements to be high ($r > 0.8$) for repeated climbing moves.
Three Canon Optura 20 cameras were synchronized and positioned as follows: from directly behind the climber, on the right sagittal side, and approximately 50º from the sagittal camera. Reflective markers were placed on the following landmarks of the right side of the body:

acromial process; humeral epicondyle of the elbow; ulnar stylus; greater trochanter; proximal fibular head; lateral malleolus; and above the first metatarsal. The markers used to define each joint were as follows: Elbow = ulnar stylus, humeral epicondyle and acromial process; Shoulder = humeral epiconndyle, acromial process, and greater trochanter; Hip = acromial process, greater trochanter, and fibular head; Knee = greater trochanter, fibular head, and lateral malleolus; Ankle = fibular head, lateral malleolus, and first metatarsal. The anatomical position was considered to be zero, with flexion of the joint resulting in increasing values.
Kinematic data were collected at 60 Hz using a 1/500 shutter speed. Video data were then digitized using Peak Motus 8.5 (Vicon/Peak, Centennial, Co, USA) and a 2nd order Butterworth filter with a cut off of 3-6 Hz was used to smooth the data (Winter, 2005).
Maximal and minimal joint angles were the dependent variables studied. Statistical treatment of the data was performed using a Paired T-test, across the foot positions, for minimal and maximal joint angles of the elbow, shoulder, hip, knee and ankle joints (SPSS v.15.0). Alpha was set *a priori* at $p < 0.05$.

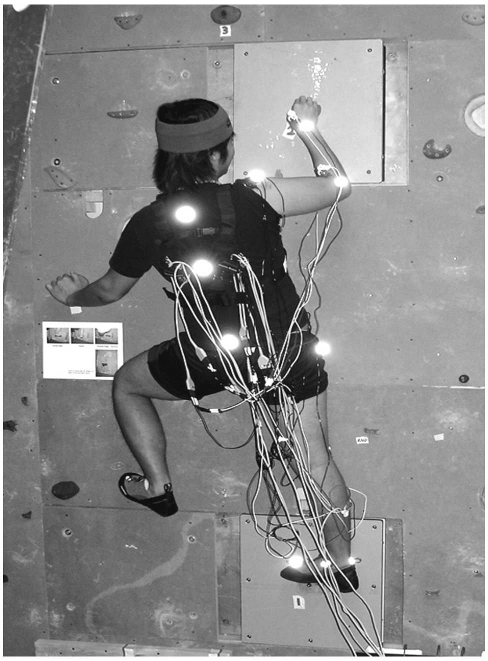

Figure 1: Subject Performing the High-Step Climbing Move.

RESULTS: As shown in Table 1, with the exception of the Elbow, Maximum joint angles were significantly different ($p < 0.05$) between the two foot positions. On the other hand, there were no differences ($p > 0.05$) in the Minimal angles between the two foot positions for any of the studied joints (see Table 1).

Table 1 Minimum (Min) and maximum (Max) joint angles (Mean ± SD) for the Elbow, Shoulder (SH), Hip, Knee, and Ankle during the two movement conditions (N=11).

	Elbow Min º	*Elbow Max º*	*SH Min º*	*SH Max º*	*Hip Min º*	*Hip Max º*	*Knee Min º*	*Knee Max º*	*Ankle Min º*	*Ankle Max º*
Inside Edge	43.5 ± 21.8	130.1 ±10.0	15.6 ±13.0	81.4 [a] ± 11.2	23.2 ± 12.6	65.0 [a] ±10.6	12.0 ± 7.8	84.5 [a] ±7.3	62.7 ± 7.5	109.5 [a] ± 6.4
Toe In	47.7 ± 22.4	130.5 ± 9.9	15.1 ± 13.9	86.2 ± 14.6	21.6 ± 12.1	72.0 ± 13.9	13.1 ± 6.2	80.8 ± 9.5	65.6 ± 7.1	105.3 ±5.5

[a] Indicates significant difference from the Toe-in foot position ($p < 0.05$).

DISCUSSION: Results of the current study indicate that when foot position is altered, maximum angles of most joints studied also changed. Conversely minimal joint angles did not change. The lack of change in the minimal joint angle was likely due to the climbers'

maintaining similar starting positions in both conditions. Lower leg joint (ankle and knee) angle increases corresponded to increased flexion of these joints during the Inside edge foot position. Increased flexion of these joints would lower the body and require other joints to be more extended in order to reach the holds. Noe´ (2006) noted that when body positioning was altered, required forces generated by the hands also changed. This may be due to a change in the climber's body position relative to the wall.
Watts (1996) has suggested that the toe-in position is often used when the feet must be secured on very small features of steep terrain. Use of the toe enables the climber to position the center of mass more away from the rock yet maintain stability over the support base. This helps the climber maintain a more vertical (erect) body position and decreases the effect of the rock "pushing" the climber's upper body away from the surface. Because the climber is likely further from the surface of the hold, it could be that the SH and Hip angles are greater due to the climber having to make more of a "reach" for the handhold (i.e. extending the length of the body) with the toe-in position. Thus, although the toe-in foot position may be better for balance and minimizing torque at the hand contact, the more extended body may be a consequence of the increased reach that is required with the body being further from the wall.

CONCLUSION: As noted by previous authors a change in body position, the increased distance from the wall as seen in the toe-in, will likely result in a change in the force required of the hands (Noe´, 2006; Quaine et al. 1995; Sibella, 2006). However, in complex situations, such as rock climbing, it may be difficult to say what is "better" since movement of one part of the body often times effects other parts ultimately resulting in a compromise. This compromise or optimization of the movement requires additional research to identify the effect of movement choices on performance.

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