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ORIGINAL RESEARCH

REPEATABILITY OF SWAY MEASURES IN UPPER EXTREMITY WEIGHT-BEARING

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ABSTRACT

Background: Analysis of upper extremity weight bearing ability is important for athletes as some function largely in a closed chain capacity (e.g., wrestling, football, gymnastics); also, all require closed chain upper extremity function during strength and conditioning. Additionally, in a rehabilitation setting, closed chain upper extremity functional testing is often used as a return to play criterion. Lower extremity sway measures (biomechanical and clinical) have been published widely and have established reliability and validity; however, the reliability of upper extremity sway biomechanical measures has not been investigated to date.

Hypothesis/Purpose: The purpose of this study was to determine the repeatability of a variety of force plate measurements during an upper extremity task in an athletic population. It was hypothesized that variables measuring upper extremity sway in a closed kinetic chain position would have excellent reliability.

Study Design: Cross-sectional.

Methods: All data were collected using a force plate system with commercially available software. Four hundred and ninety healthy Division I athletes were tested for both their dominant and non-dominant upper extremity at one of two testing sessions. Subjects were instructed to stay as still as possible while maintaining a full plank position with one upper extremity on the force plate and the contralateral upper extremity behind their back. Two, 20-second trials were performed for each extremity. Variables measured included average sway velocity (ASV), sway velocity in medial-lateral (SVML) and anterior-posterior (SVAP) directions, sway velocity at 1st and 2nd time intervals for AP (VAP1 and 2) and ML (VML1 and 2) directions, and sway frequency in the AP direction for 1st and 2nd time intervals (FreAP1 and 2). Intraclass correlation coefficients ($ICC_{(2,1)}$) and their 95% confident intervals were calculated for all force plate variables for 980 limbs.

Results: No difference was seen between left and right extremities for any measure ($p > 0.05$). ICC's ranged from 0.61-0.90 for all variables, indicating moderate to excellent reliability for all variables.

Conclusion: Upper extremity sway biomechanical variables using a force plate system have moderate to excellent reliability. These results are important prior to validation and clinical utilization of these measures including baseline testing, return to play guidelines, and injury prevention parameters.

Level of Evidence: 3.

Keywords: biomechanical testing; movement system; reliability, upper extremity

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Conflict of Interest: No conflicts.

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INTRODUCTION

Biomechanical analysis of lower extremity postural sway variables has been found to be reliable and valid to quantify balance performance for both healthy individuals and individuals with an injury.[1-3] Upper and lower extremity postural control is controlled by integrated information from the visual, somatosensory, and vestibular systems. The integrity of the postural control system is typically evaluated with static or dynamic posturography. Postural steadiness, or static posturography, characterizes the performance of the postural control systems in a static position. In the lower extremity, this is often evaluated in both eyes open and eyes closed trials to estimate the role of the visual system while maintaining balance. This postural steadiness or sway is quantified biomechanically by the displacement of the center of pressure on a force platform. These variables can further be quantified into displacement variables, such as mean deviation from center of pressure or path length, or other variables which express the magnitude that the center of pressure moves during a trial. Additionally, velocity-based variables can be utilized to express how quickly the center of pressure is moving during a trial, indicating how quickly this subject is adjusting to maintain their balance. The center of pressure variables reflect the orientation of the body segments as well as the movements of the body to keep the center of gravity over the base of support.[2,4] Correspondingly, these measures can be used to assess upper extremity stability and proprioception, quantified by variables measuring the ability of the upper extremity to remain still in a weightbearing position.[4,5]

Despite extensive work utilizing sway data in the lower extremity,[1-4] there is a paucity of literature describing its use for upper extremity testing. In 2007, Pontillo and colleagues investigated the demands of upper extremity weight-bearing exercises on shoulder musculature by electromyographic analysis.[5] The authors found that triceps, serratus anterior, and anterior deltoid muscles activity significantly increased as each trial progressed, irrespective of stability condition, indicating that fatigue should be considered when using this position for the assessment of stability. Closed kinetic chain (CKC) upper extremity assessment is necessary for several reasons. First, certain diagnoses occur most often in closed chain positions, such as posterior glenohumeral instability and posterior labral tears; elbow dislocations; triangular fibrocartilage complex tears, and ulnar impaction syndrome.[6,7] Additionally, certain sports require athletes to function largely in a closed chain position(s), such as football, gymnastics, and wrestling. However, even in the absence of sport-specific CKC skills, most athletes require CKC function for strength and conditioning activities (e.g., planks, push-ups). Thus, assessment of upper extremity function is necessary to mimic sport-specific demands. Upper extremity CKC positions test several facets of function simultaneously; the positions require co-contraction of the upper quarter musculature, the ability to withstand both sheer and compressive forces, and core stability.[8] These systems must work in a synchronized manner to stabilize the upper extremity; ergo, postural stability measures in upper extremity weight bearing can be used to assess these facets.

Several clinical assessments require CKC function of the upper extremity, including the closed kinetic chain upper extremity stability test,[8-10] the upper quarter Y-Balance Test,[11-12] and the two-minute timed push-up test.[13] At this time, there is a paucity of literature investigating biomechanical measures of CKC upper extremity function. Recently, Gillen and colleagues[14] found that plyometric push-ups off a force plate were a reliable measure of strength and peak rate of force development (both demonstrated ICC's > 0.8).

There have been no large-scale studies which examine the repeatability for force plate variables for the upper extremity. Therefore, the purpose of this study was to determine the repeatability of a variety of force plate measurements during an upper extremity task in an athletic population. It was hypothesized that both the amplitude and direction variables would have good to excellent reliability, as these have been determined for similar lower extremity studies.[1-3]

METHODS

Approval was obtained from University of Pennsylvania Health System's institutional review board. All data were collected using a force plate (Kistler Inc; Amherst, NY, USA) system connected to a dedicated computer with commercially available software (Sparta Science, Menlo Park, CA), with a video monitor connected to the computer which displayed force plate center of pressure (COP) movement in real time. Force plate data were collected at 1000 Hz (a standard output per Kistler Inc).

Four hundred and ninety healthy Division I athletes were tested for both their dominant and non-dominant upper extremity at one of two testing sessions (327 males, 163 females; mean age (SD): 20.3 (1.3) years) at one location; testing occurred at the beginning of their strength and conditioning workout, in order to minimize potential fatigue from other activities. Subjects were excluded if they had any orthopedic injury or concussion which prevented the athlete from unrestricted sport participation.

The athlete was instructed to maintain their balance with as little movement as possible. They are instructed to start in a standard push up position, then when prompted, they place their contralateral arm either across their chest or behind their back. They were instructed to perform the task naturally so that they could complete the test. Should an error (shifting the weight from the weightbearing upper extremity, or touching down the opposite upper extremity) occur, the system would register this as an error and terminate the test. The trials with error(s) were repeated until a valid trial was obtained. Two, 20 second trials were performed for each extremity, alternating limbs, with a 15-second break between trials. Trial time was determined by the options the initial software provided as well as initial reliability testing that showed that 20 seconds was adequate time to capture fatigue changes, without being over taxing on the body. It also makes the test more accessible to people, as these tests are done prior to usual strength and conditioning. This also is consistent with other biomechanical UE testing in weightbearing.[5] The subjects were blindfolded during testing to eliminate the visual component of balance. The force plate filtered and smoothed the resultant output. Center of pressure data was quantified by velocity and frequency of motion. The Sparta Science software labelled and processed the data into the appropriate variables. Operational definitions of variables measured are presented in Table 1 (below).

Figure 1. *Test Position for measurement of Upper Extremity Sway.*

Statistical Methods

Independent samples T-tests were used to determine if differences existed between sides (left versus right). If no difference between sides existed, data would be averaged across the two trials by side (left, right). Intraclass correlation coefficients (ICC

Table 1. *All variables, variable definitions, ICC(2,1) values, 95% confidence intervals of ICC(2,1) values, standard error of measure (SEM), and minimal detectable change (MDC) values.*

	Definition	$ICC_{(2,1)}$	95% CI	SEM	MDC (95% CI)
ASV	average sway velocity	0.700	0.659-0.735	0.005	0.013
SVAP	sway velocity in anterior-posterior (AP) direction	0.710	0.671-0.744	0.004	0.012
SVML	sway velocity in medial-lateral (ML) direction	0.876	0.860-0.892	0.003	0.008
VML1	sway velocity at 1st time interval for ML direction	0.874	0.857-0.889	0.003	0.008
VML2	sway velocity at 2nd time interval for ML direction	0.731	0.696-0.763	0.007	0.020
VAP1	sway velocity at 1st time interval for AP direction	0.745	0.701-0.784	0.160	0.444
VAP2	sway velocity at 2nd time interval for AP direction	0.609	0.557-0.655	0.003	0.007
FreAP1	sway frequency in the AP direction for 1st time intervals	0.897	0.883-0.909	0.603	1.672
FreAP2	sway frequency in the AP direction for 2nd time intervals	0.875	0.858-0.890	0.677	1.876

$_{(2,1)}$) and their 95% confident intervals were calculated using SPSS statistical package version 25 (SPSS Inc, Chicago, IL) based on a mean-rating (k = 2), absolute-agreement, one-way mixed-effects model, for all force plate variables for 980 limbs. Standard error of measure and minimal detectable change (95% CI) were also calculated.

RESULTS

No differences were seen between left and right extremities for any of the measures (p < 0.05). $ICC_{(2,1)}$ values ranged from 0.61-0.90 for all variables, indicating moderate to excellent reliability for all variables. Additionally, Table 1 provides standard error of measurements and minimal detectable change values for each variable.

DISCUSSION

This is the first study to examine the reliability of a unilateral closed chain upper extremity task using force plate measures. Moderate to excellent reliability was found for all the variables assessed. In addition to average sway velocity, sway velocity was also examined in both medial-lateral and anterior-posterior directions. Typically, force plate measures of postural steadiness are either related to the magnitude or velocity of the motion. Sway velocity indicates the speed at which the center of pressure moves, indicating the subjects' ability to stabilize their upper extremity during the task. It is common to examine these variables in both the medial-lateral and anterior-posterior directions, as these are likely to be influenced by different muscle groups. Additionally, the sway velocity and frequency were examined during early and later intervals for the task; it is important to look at velocity during time intervals, as stability is usually more challenging as time increases,[5] and these had moderate to high $ICC_{(2,1)}$ values, indicating that the total task time was appropriate and not affected by fatigue. This also indicates that the length of the trial was appropriate, as the second time interval showed decreased reliability; a longer task may have decreased the reliability even more.

Lower extremity sway or postural stability measures have been investigated extensively, and show large variability, with anywhere from poor to excellent reliability.[1-4] The reported reliability values in this study are all moderate to high, indicating that this task can be easily replicated. Additionally, as it is known that there is a visual contribution to postural stability, measurements obtained in an eyes closed condition are often lower than the eyes open condition.

Upper extremity closed chain functional testing is important for several reasons. First, the position assesses several facets of function simultaneously (ability to withstand sheer and compressive forces through all upper extremity joints, co-contraction of upper quarter musculature; and core stability). The CKCUEST is performed by starting the athlete in a full plank position, which is similar to the position utilized in this study, and correlates with isometric rotator cuff strength for elevation *(r = 0.7)* , external rotation (ER) *(r = 0.7)* and internal rotation (IR) *(r =0.8)*;[11] peak isokinetic ER/IR strength *(r = 0.9)*;[10] grip strength *(r = 0.8)*;[10] isolated neuromuscular control of core *(r = 0.4)*.[8] Uhl et al (2003)[16] compared the one-arm push up position to other closed chain upper extremity positions, and found that it requires 60% of the subjects' body weight in force to maintain the position; thus, it is known that to maintain this test position, each extremity must be able to withstand compressive forces at the wrist, elbow, and shoulder joints. Also, upper extremity weight bearing positions elicit extremely high deltoid and infraspinatus activity, with fair to moderate muscle activity in the supraspinatus and pectoralis major as well.[5] This position also mimics some sports specific tasks (e.g.: blocking in football, all handstand/handspring skills in gymnastics) well as strength and conditioning demands (e.g., push-ups, planks, etc).

The results of this study have clinical implications. As these biomechanical measures have good to excellent reliability in normal subjects, they could be utilized to compare upper extremity closed chain function between the extremities. The sample showed no difference between extremities for any variable, thus limb symmetry should be expected in healthy athletes across all sports, and asymmetry in such measures could indicate an area for concern.

As athletes who participated in open chain, unilaterally dominant sports were included in the study, the absence of asymmetry finding was somewhat surprising. This can be attributed to the fact that although it is a closed chain upper extremity task, successful task completion requires core stability, and perhaps this could be considered an assessment of both upper extremity stability and core stability simultaneously.

Future directions should include validation of these measures against clinical measures of upper extremity function and/or core stability. This would be useful for incorporation of this task into upper extremity and/or trunk return to play protocols. Additionally, the same measures could be studied in populations that include injured athletes.

CONCLUSION

The results of the current study indicate that upper extremity sway biomechanical variables using a force plate system have moderate to excellent reliability. These results are important prior to validation and clinical utilization of these measures including for baseline testing, return to play guidelines, and use in injury prevention.

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