Mapping Center of Pressure During Standing Reach Tasks

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Abstract. Postural stability and balance during manual material handling and industrial tasks are important issues in ergonomic assessment of workplace tasks. Previous work has determined accurate prediction of a person's balance maintenance strategy is one of the most important parameters affecting the accuracy of posture prediction algorithms. Digital human modeling has the potential to provide designers with accurate tools to represent human posture, but current software is typically lack empirically-derived models of center of pressure (CoP) excursion. This paper presents an overview of a study that systematically quantifies CoP excursion behavior through a standing workspace across a range of anthropometry. Participants CoP displacement increased with the kinematic constraint of the task, but the CoP excursion was greatly affected by foot placement and target location. The overall goal is to develop a quantitative model of center of pressure (CoP) excursion that can be integrated into DHMs to improve prediction of standing kinematic reach tasks typically observed in industrial tasks and ergonomic assessments.

Keywords: Standing balance; Postural control; Reach capability.

Introduction

Determining whether a standing operator is able to reach a target hand location is one of the most common assessments made using digital human models. Previous work has determined that the requirement to maintain balance is one of the most important parameters affecting the accuracy of posture prediction algorithms (Zhou and Reed, 2009).

Balance is maintained through a complex interaction of the various components of the vestibular, nervous, and musculoskeletal systems (Horak et al. 2006). Many factors can affect standing balance-maintenance capability. Balance has being quantified experimentally in terms hand loads statically held at varying location with respect to the body, constrained foot placements and reaching capability (Holbein and Chaffin 1997; Holbein and Redfern 1997; Lee and Lee 2003; Row and Cavanagh 2006). Certain neurological impairments, such as multiple sclerosis and stroke, have been found to reduce standing balance capabilities (Karst et al. 2005; Chern et al. 2010). Age has been shown to impact dynamic balance and postural instability during reaching tasks made from standing (Tanaka et al. 1999; Kozak et al. 2003; Holbein et al. 2007; Huang and Brown, 2013; Huang and Brown, 2015).

In standing, quasi-static tasks, the balance-maintenance strategy can be characterized by the location of the center of pressure (CoP) within the base of support defined by the polygon spanning the perimeters of the foot/ground contact regions. When hand forces are minimal, the CoP is coincident with the location of the whole-body center of mass projected into the ground plane. Typical foot placements result in a large range of potential CoP locations. The posture of a DHM can vary widely depending on the desired location of the CoP. Many digital human models (DHMs) govern balance by heuristic tuning parameters (Reed et al. 2006). Tuning parameters are based upon observations from experimental data that quantify CoP during functional capability assessments or prescribed test conditions. Alternatively some physics-based DHMs use a Zero-Moment Point (ZMP) formulation for static balance and to approximate support reaction forces/moments, which are derived from the resultant reaction loads (i.e. gravity and externally applied loads) (Yang, Xiang and Kim, 2009). However, because a large range of potential CoP locations is usually consistent with external constraints, additional information is needed to obtain accurate postures.

A systematic quantification of center of pressure (CoP) excursion behavior for reaches throughout a standing workspace across a range of body sizes has not been previously reported. Some previous research suggests that stability zones or stability limits, regions defined relative to the feet, describe the base of support within which the CoP must reside for static balance to be maintained. The objective of this work was to obtain normative data on CoP excursion behavior through a series of standing submaximal and maximal reaches.

Methods

Participants

Data were gathered from 14 women and 17 men participants, all right-hand dominant and with no history of musculoskeletal disorders of functional mobility impairments. Participants' age ranged from 19 to

66 years, stature ranged from 155.7 to 185.3, and body mass index (BMI) ranged from 18.3 to 42.6 kg/m^2. Figure 1 shows the size distribution of the participants. The University of Michigan's Institutional Review Board approved this research protocol.

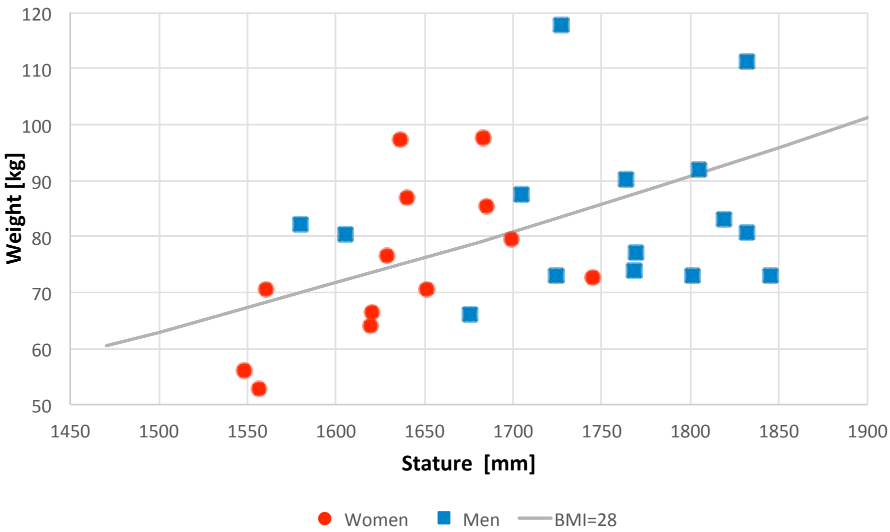


Figure 1. Weight versus stature of participants.

Laboratory Set-Up

A laboratory fixture enabled the presentation of a target throughout the standing workspace in such a way that a wide range of postures were obtained. Participants' motions were captured using a 13-camera VICON optical motion capture system and an AMTI force plate was used to record CoP as participants performed one-hand reach tasks.

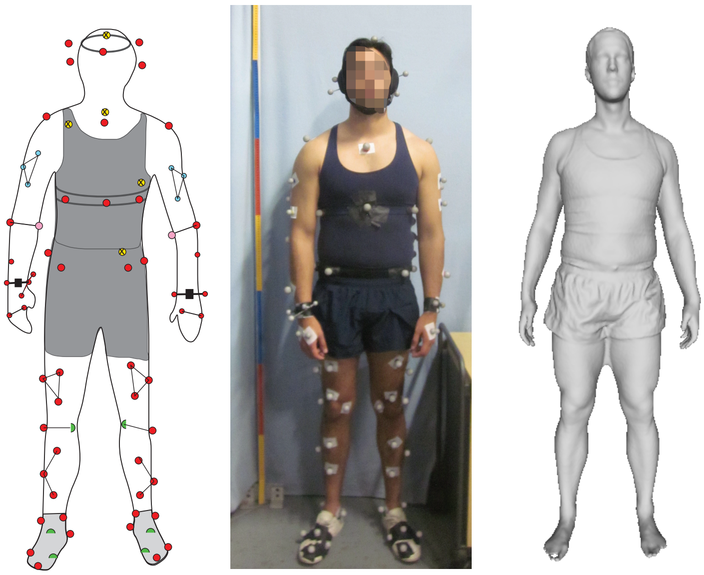
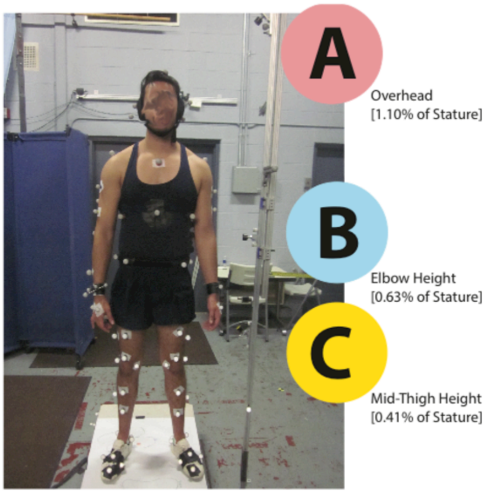


Figure 2. Marker placements and 3D body shape captured by a laser scanner.

Test Conditions

The standing workspace was characterized by a series of reach targets presented through a range of azimuth angles (Figure 3). Reach targets were located at approximately -90° (right, lateral) to + 45° (left, cross-body), at 45° interval increments, relative to the reference mid-sagittal plane (0°). Vertically, targets were presented at three task heights chosen to span the range of working heights common in industry. Target heights were defined as a percentage of the participant's stature: low (41% of stature), medium (63% of stature) and high (110% of stature). Target reach distances, the horizontal location of the target pole, were scaled using initial measurements of each participant's maximum reach performed at each vertical height and azimuth angle. Horizontal target distances were set at 50%, 80%, 85%, 90%, 95%, 97.5%, 100% and 102.5% of the individual participant's demonstrated maximum reach capability in the particular foot placement.



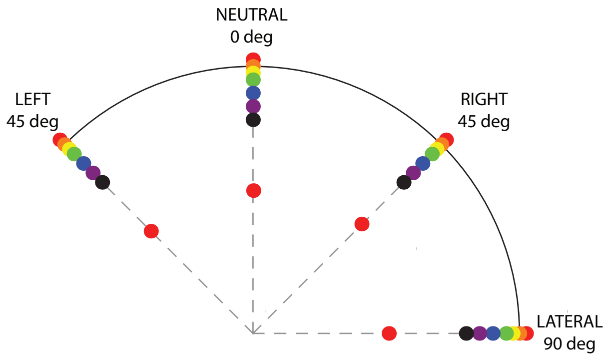


Figure 3. Target locations presented through a range of azimuth: i) Vertical Reach Targets: low (41% of stature), medium (63% of stature) and high (110% of stature); ii) Horizontal Reach Targets: 50% (red), 80% (black), 85% (purple), 90% (blue), 95% (green), 97.5% (yellow), 100% (orange), and 102.5% (red) of individual maximum reach distance (100% max).

Because workers' preferred foot placements vary with task parameters, participants were instructed to self-select foot placement within a rectangular boundary. Side by side stance was characterized as a comfortable stance at preferred width, and narrow tandem stances involved either the right/left foot forward, at modest tandem width with natural splay (foot rotation relative to the ground plane). When selecting foot placement, participants were instructed to ensure body weight was evenly distributed bilaterally.

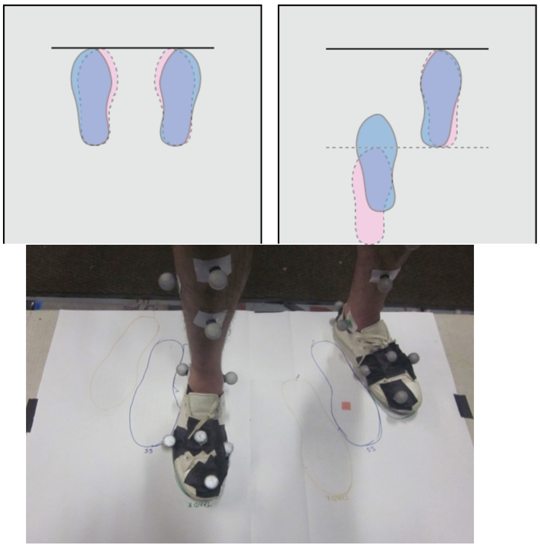


Figure 4. i) Side by side stance; ii) Narrow tandem stance (right foot forward); iii) Stance protocol.

Data Collection Protocol

Standard and 3D anthropometry, range of motion and clinical measures of functional reach (ANSUR 1989; Duncan 1990) were obtained from each participant. Prior to the start of each trial, the participant was instructed as to the target reach azimuth and height, and stance required. A maximum reach trial was completed for each target reach azimuth, height and stance configuration. Participants were required to reach out as far as possible, towards the target location, and press the button on the target structure with their right index finger, without leaning on it, while holding posture steady for three seconds. The objective was to quantify maximum reach capability for each target reach azimuth and height. The only constraints imposed on the participant was to maintain at least one of point contact for each foot at all times and to maintain a forward head position; otherwise participants were encouraged to select a preferred posture. Participants were instructed to perform a series of practice trials to explore foot placement and posture options. The research staff continued to adjust the horizontal location of the target until maximum reach capability was achieved.

All subsequent right-handed horizontal reaches to targets set at a percentage of maximum reach and presented in a randomized order across target reach azimuth and height, and stance configurations. Testing was completed in a single session and each participant completed a total of 192 trials.

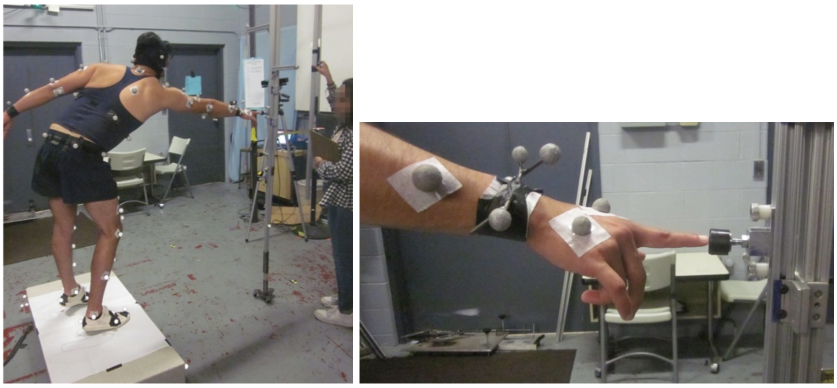


Figure 5. Participant in performing a reach task in the laboratory.

Results

Center of pressure displacement relative to relaxed standing increased with the kinematic constraint of the task imposed by moving the target horizontally and vertically and through the azimuth target directions; in general, the CoP excursion was greatly affected by target location.

For each trial, the CoP trajectory was expressed in terms of both the reach task and nominal neutral base of support. Base of support and corresponding centroids were computed by fitting a convex hull to a stream of 3D coordinates derived from markers placed bilaterally on the right and left shoes (e.g. located on toe and heel). CoP excursion was also quantified during maximal horizontal reach, defined by the maximal horizontal distance between the wrist and hip.

Figure 6 illustrates CoP excursion for all the horizontal reach targets for reach tasks performed from a side by side stance, 0-deg azimuth target and medium (63% of stature) target height for a representative participant. The range of postures and foot placement selected are also illustrated.

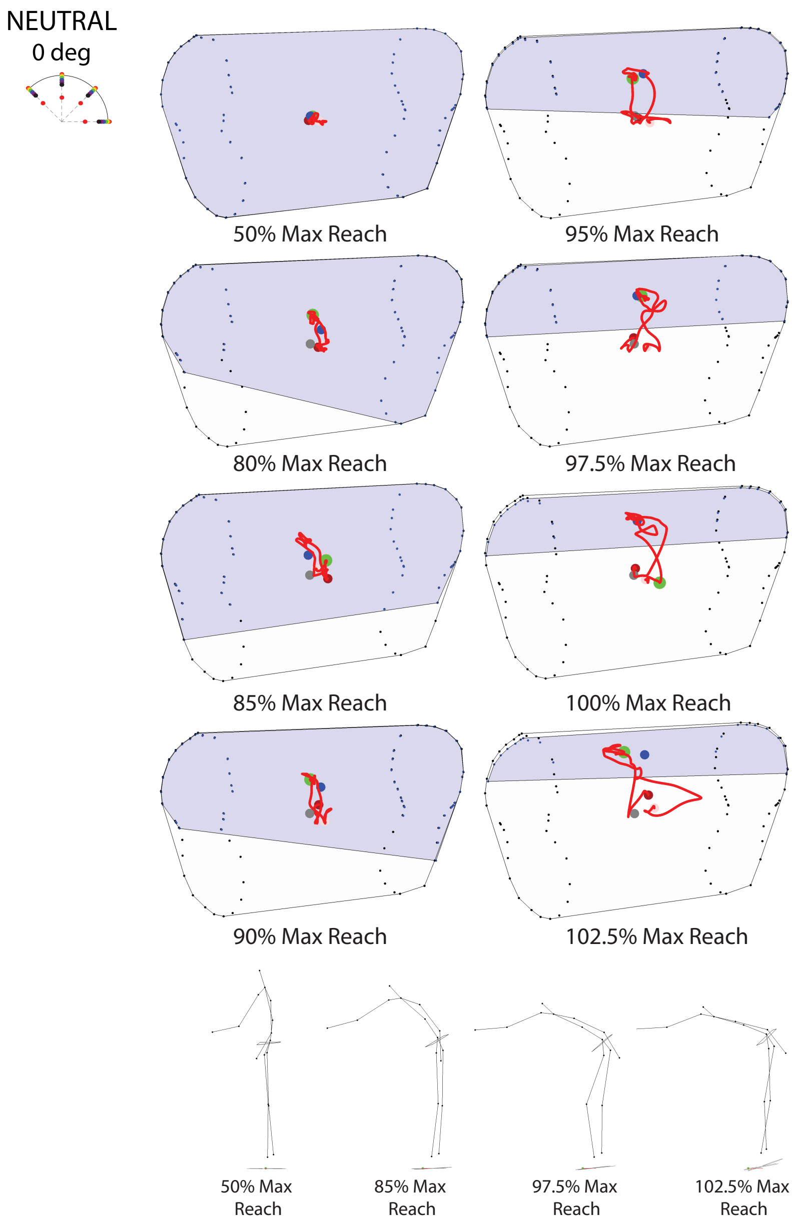


Figure 6. Center of pressure locations for reaches with side-by-side stance, 0-deg azimuth (forward) reaches at medium height. Stick figure illustrates (forward) reaches in the sagittal plane. CoP trajectory (red line) throughout the reach task was expressed in terms of both the reach task (opaque shaded region) and nominal neutral (light gray shared region) base of support. Center of each base of support are illustrated: 1) neutral stance (gray); 2) reach task (blue). The trial start and end are denoted by the light red and dark red centroids respectively. CoP excursion is parameterized at the point of the maximal horizontal distance by a green centroid.

Figure 7 shows the range of posture and CoP excursion for tandem narrow stance, all target azimuth test conditions for the medium (63% of stature) target height, and two horizontal reaches (80% and 100% maximum) for a representative participant.

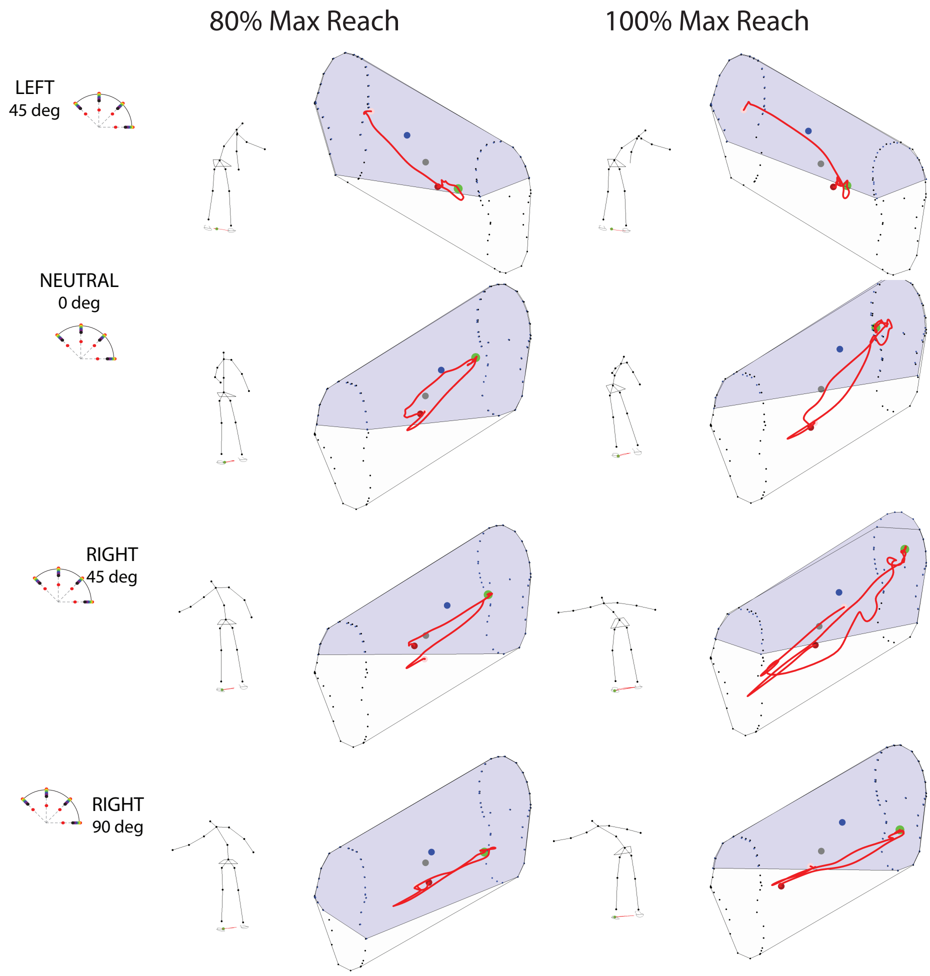


Figure 7. Data from one female participant with tandem narrow stance, showing targets at all four azimuths and medium height. Stick figure illustrates (horizontal) reaches in the frontal plane. CoP trajectory (red line) throughout the reach task was expressed in terms of both the reach task (opaque shaded region) and nominal neutral (light gray shared region) base of support. Center of each base of support are illustrated: 1) neutral stance (gray); 2) reach task (blue). The trial start and end are denoted by the light red and dark red centroids respectively. CoP excursion is parameterized at the point of the maximal horizontal distance by a green centroid.

Discussion

Participants performed a series of right-handed horizontal reaches to targets throughout a large reach capability volume. The effects of target location and foot placement were on CoP locations were quantified. Preliminary analyses have demonstrated that CoP excursion was significantly related to stance, reach direction (azimuth), target vertical and horizontal location. CoP excursion was greater for more maximal reaches, likely because the forward shift in the whole-body center-of-mass and subsequent extension of the effective base of support. The effect of participant anthropometry and age on posture, foot placement and effective base of support and subsequent functional stability limit will be considered in future analysis.

A few parameterizations of the CoP excursion with respect to the base of support associated with preferred foot placement were investigated. CoP excursion was expressed in terms of the base of support associated with both neutral stance (i.e. initial shoe perimeter) and reach task, which capture the change in base of support that results from foot flexion, for a given target location. Further analysis will use a standing reach and return phase paradigm to examine the CoP trajectory displacement and smoothness in terms of the anticipatory postural adjustment, dynamic balance during movement execution, and postural stabilization at the end of the movement.

The overall goal of this research is to develop a quantitative model of center of pressure (CoP) excursion Empirical models of balance maintenance as a function of task demand and worker characteristics will by predictive of posture selection. These models that can be integrated into DHMs to improve prediction of standing kinematic reach tasks typically observed in industrial tasks and ergonomic assessments.

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