# Standing Posture During Functional Tasks: Effect of Foot Placement and Implications for FNS Standing

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**Abstract**

*The long-term goal of this work is to improve the functional capabilities provided by Functional Neuromuscular Stimulation (FNS) standing systems. We are investigating the possibility that proper foot placement can improve standing stability and can simplify the process of adjusting posture in order to prepare to perform a specific task. Our approach is to utilize a combination of computer-based modeling studies and experimental studies with human subjects. In this work, we report results of a study in which we investigated the role of foot placement on movement control strategies used by able-bodied subjects while reaching. Kinematic and kinetic data were collected as subjects moved an object along a counter. Results indicated that posture control strategies used by these subjects during reaching were different for the various foot placements that were studied. These results suggest that in FNS systems, functional reach can be improved through a strategy that matches foot placement with a posture adjustment control system.*

## 1. Introduction

FNS has been used to restore the ability to stand, step, and maneuver in persons with spinal cord injury (SCI) and other neurological disorders that impair lower extremity function [2, 3, 7]. In addition, the ability to stand may enable the FNS system user to perform functions with his/her hands while standing at a counter. Research results have been encouraging, but lower extremity FNS systems have not yet proven to have widespread clinical viability due to the limited degree of functional capability that has been restored. The primary obstacles to achieving this functional capability are that FNS standing requires extensive upper extremity support and that the FNS user often has only a limited ability to adjust posture. Our overall goal is to enhance the clinical viability of lower extremity FNS systems by providing FNS system users with an improved ability to use their hands while standing. Our challenge is to reduce the dependence on the upper extremity to provide balance control and weight support.

Research studies in able-bodied individuals have utilized a variety of experimental paradigms to investigate posture control mechanisms. Most of the posture control studies have been performed with the feet side-by-side at a distance approximately equal to the width of the pelvis [4]. A few studies have investigated effects of altered foot placement on balance control [6]. The implications of these studies are that there exists a variety of testing paradigms and posture control measures that have been widely used, but only a few studies have investigated the effect of foot placement. While routinely performing everyday tasks, people intuitively alter foot placement. In this study, we aim to investigate the effects of foot placement during reaching tasks.

## 2. Methods

Five subjects (age 28.8 ± 7.6 years) volunteered for this study after signing informed consent. Reflective markers were placed on the subjects according to the Cleveland Clinic marker set, with an additional triad placed at the cervicale (superior C7 process). As the subjects performed the functional tasks described below, these markers were tracked using a six camera video analysis system (Motion Analysis Corp.). The sacral marker, the right (dominant hand) elbow marker, the right wrist marker, and the cervicale triad markers were of particular interest for this study. The subjects also stood with each foot on separate force platforms (Kistler, Inc.) during the trials. Centers of pressure for each foot were calculated using the ground reaction measurements from each platform [5].

The subjects first stood quietly for ten second trials using three different foot placements: normal, wide, and tandem. Normal stance was defined by having the feet side by side at a width (ankle joint to ankle joint) approximately equal to the distance between the subject's anterior superior iliac spines. The wide stance also had the feet side by side, but at a width twice that of the normal stance. In contrast, the tandem stance had the feet at normal width, but with the right (dominant leg) shifted anteriorly half the

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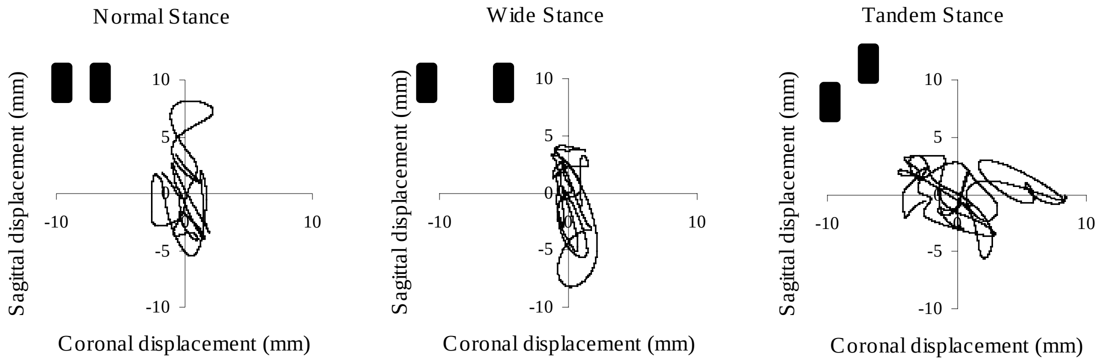


Figure 1: An illustrative example of center of pressure traces for different foot placements during quiet stance. The displacements are aligned primarily in the sagittal plane for normal and wide stances, while displacements are more evenly distributed in the sagittal and coronal planes for the tandem stance. The rounded rectangles in the upper left-hand corner of the graphs give a simple representation of the foot placements.

subject's foot length and the left leg shifted posteriorly half the subject's foot length. Each foot placement was repeated three times in quiet stance, for a total of nine trials per subject. Stance positions were marked on the force platforms to ensure consistent foot placements.

The subjects then performed reaching tasks over intervals of twenty seconds using the same three foot placements described above. In these trials, the subject was asked to move a one kilogram object to selected positions on a thirty-six inch high table. Initially, the subjects were asked to move the object with their dominant hand to their maximum anterior reach without use of their non-dominant hand or leaning against the table. The anterior reach was measured and 75% of this distance was marked at three different orientations: 45° to the right of the midline, the midline, and 45° to the left of the midline. Subjects were then asked to perform a series of six motions for each reaching trial. The motions included 75% reach to the right, maximum reach to the right, 75% center reach, maximum center reach, 75% reach to the left, and maximum reach to the left. This series of motions was repeated three times for each foot placement for a total of nine trials for each subject.

## 3. Results

Center of pressure data for each foot were combined into an overall center of pressure using a weighted average based on the vertical ground reactions. Figure 1 shows representative plots of the center of pressure for three quiet standing trials. The average absolute maximum sagittal center of pressure displacements were 7.77 ± 1.91 mm for normal stance, 10.26 ± 4.68 mm for wide stance, and 7.73 ± 1.97 mm for tandem stance over all trials (n = 15). Furthermore, the average maximum coronal center pressure displacements were 3.72 ± 1.46 mm for normal stance, 3.68 ± 1.77 mm for wide stance, and 9.52 ± 3.27 mm for tandem stance.

Overall centers of pressure for the reaching trials were determined using the same methods as for the quiet standing trials. The sagittal center of pressure displacements were normalized as a percentage of the subject's stance width (ankle joint medial-lateral offset) plus foot width. Similarly, the coronal center of pressure displacements were normalized as a percentage of the subject's stance depth (ankle joint anterior-posterior offset) plus foot length. Figure 2 summarizes the average maximum center of pressure displacements for the different foot placements and reach directions. The average maximum sagittal center of pressure displacements were 76.2 ± 12.4% for normal stance, 75.0 ± 10.9% for wide stance, and 81.5 ± 5.5% for tandem stance over all trials (n = 15). In addition, average maximum dominant (right) coronal center of pressure displacements were 72.5 ± 8.5% for normal stance, 68.7 ± 12.4% for wide stance, and 94.0 ± 11.7% for tandem stance. Finally, average maximum non-dominant (left) coronal center of pressure displacements were 53.2 ± 9.9% for normal stance, 50.0 ± 5.8% for wide stance, and 34.2 ± 5.9% for tandem stance.

The maximal reach in each direction was determined from the displacements of the right wrist marker. Maximal reach was normalized by the subject's arm length. Figure 3 illustrates the maximum reach for each reach direction using different foot placements. In the 45° dominant direction, average normalized maximum reach was 1.23 ± 0.12 for normal stance, 1.27 ± 0.14 for wide stance, and 1.33 ± 0.18 for tandem stance over all trials (n = 15). In the anterior direction, average maximum reach was 1.24 ± 0.09 for normal stance, 1.24 ± 0.09 for wide stance, and 1.31 ± 0.13 for tandem stance. In the 45° non-dominant direction, average maximum reach was 1.42 ± 0.11 for normal stance, 1.43 ± 0.12 for wide stance, and 1.37 ± 0.12 for tandem stance.

Torso orientations were calculated using the cervicale triad marker positions and Cardan/Euler angle equations with a rotation sequence of flexion-extension, lateral bending, and axial twist [1]. The rotations were referenced to the initial position of the cervicale triad as

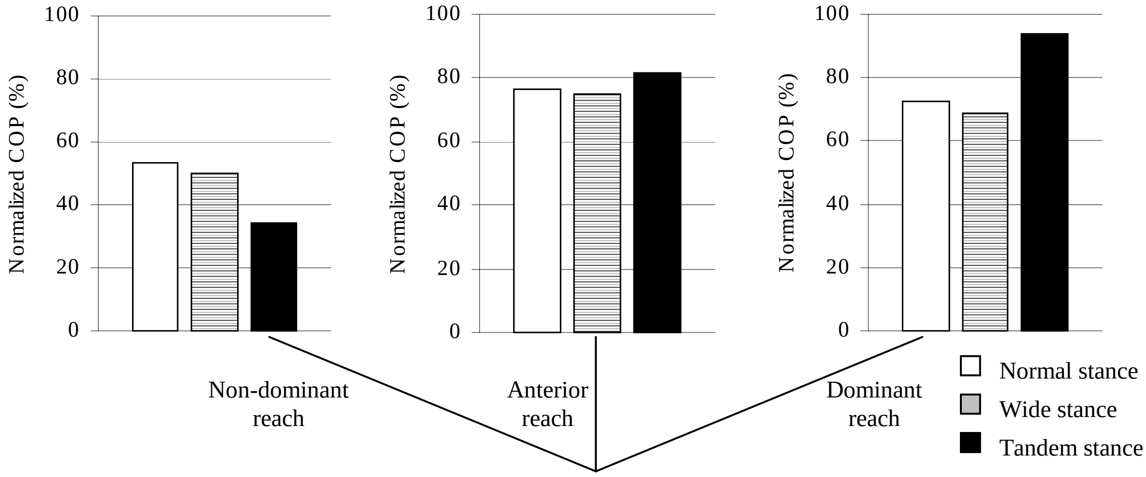


Figure 2: Average maximum center of pressure displacements for different foot placements in specified reach directions. A greater percentage of the center of pressure range was utilized in tandem stance for the anterior reach and the dominant reach. The lines connecting the graphs give an indication of the reach directions from the subject's point of view.

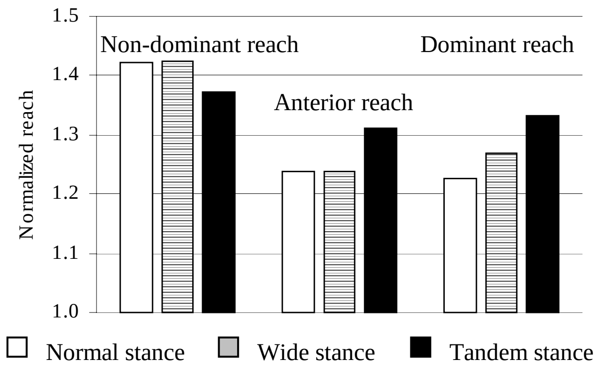


Figure 3: Average maximum reach for different foot positions in specified reach directions. The maximum reach values were greatest in the non-dominant direction and lowest in the anterior direction.

the subject was in quiet stance prior to the initiation of the reaching motions. Figure 4 displays the maximum torso rotations achieved during the reaching tasks when using different foot placements. Average maximum torso flexion angles were 35.8 ± 14.1° for normal stance, 35.7 ± 13.4° for wide stance, and 41.5 ± 18.5° for tandem stance over all trials (n = 15). In addition, average maximum lateral bending angles were 58.5 ± 10.3° for normal stance, 54.1 ± 6.9° for wide stance, and 61.3 ± 7.2° for tandem stance. Finally, average maximum axial twist angles were 40.2 ± 12.0° for normal stance, 41.5 ± 11.6° for wide stance, and 47.6 ± 11.8° for tandem stance.

## 4. Discussion

Although our ultimate goal is to improve the functional capabilities of persons with SCI, we feel that valuable insight can be gained by first studying able-bodied individuals. In analyzing the coordination strategies of the able-bodied while considering what movements might be possible with FES, we hope to find postural adjustments that appear particularly promising for application to SCI subjects. In this study, we focus on different foot placements and their effect on standing postures. Initially analyzing quiet standing is of interest since a stable base posture is a necessity before the execution of other functional tasks will be possible. When examining the center of pressure data for quiet standing, it appears that the wide stance increases postural sway in the sagittal plane and the tandem stance increases postural sway in the coronal plane. Subjects with sagittal instability may be better suited using the normal or tandem stance during quiet standing, and subjects with coronal instability may be better suited using the normal or wide stance.

Normalized center of pressure results for the reaching tasks are an indication of a subject's ability to shift their weight from foot to foot to maintain balance. When reaching forward, the tandem stance allows for a greater shift of weight in the sagittal plane since the base of support is relatively closer in alignment with the direction of motion. The increased ability to shift weight using the tandem stance is even more dramatic when reaching to the dominant side because the base of support is nearly directly aligned with the direction of motion. The opposite is true in the non-dominant direction, where the ability to shift weight was decreased with the tandem stance as the reach direction was approximately perpendicular to the base of support. However, the tandem stance lends itself to a three-point base of support if non-dominant hand forces are still necessary for the SCI subject to maintain balance. For the different reach strategies tested, the normal and wide stances resulted in similar weight shifting by the subjects. It should be noted that the centers of pressure were normalized to the base of support to account for differences in subject anthropometry and to give a measure of relative stability rather than magnitude of displacement.

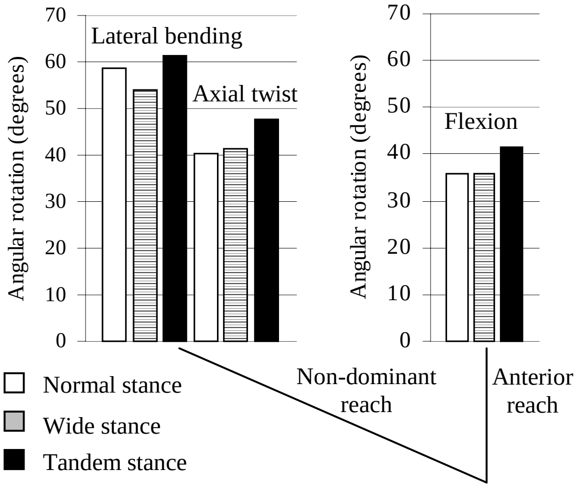


Figure 4: Average maximum torso rotations for different foot placements. The lines below the graphs indicate the reach direction from the subject's point of view. Maximum flexion angles occurred during anterior reach and both the maximum lateral bending and maximum axial twist occurred during non-dominant reach. Maximum torso rotations were greatest during tandem stance.

Maximum reach as a function of foot placement defines the outer range of ability in each of the movement directions. In agreement with the center of pressure results, maximum reach in the anterior direction and the dominant direction was greater when utilizing the tandem stance. Also in agreement was the fact that maximum reach was compromised in the non-dominant direction as compared to the normal and wide stances. The normal and wide stances resulted in similar maximum reaches, with a slight increase in the dominant direction with the wide stance which is due to increased stability in the coronal plane. At first glance, the greatest maximum reaches occurring in the non-dominant direction may seem surprising. However, this is a function of the types of motion required to complete each motion: anterior reach (torso flexion only), dominant reach (flexion and lateral bending), and non-dominant reach (flexion, lateral bending, and axial twist).

Maximum torso rotations as a function of foot placement provide the type and extent of torso orientation that is required to complete the reach trials. The greatest amount of torso flexion occurred during anterior reach, while the most lateral bending and axial twist occurred during non-dominant reach. The greatest rotations in each of these maximal cases resulted during tandem stance. Maximum rotations were similar for the normal and wide stances, with less lateral bending required during non-dominant reach for the wide stance as more lower extremity postural adjustments were possible with the wider coronal base of support. As these results are applied to SCI subjects, torso rotations should be minimized since stiffening of back muscles such as the erector spinae may be utilized to stabilize standing posture. Such considerations indicate that non-dominant reach may be difficult with the tandem stance and more easily achieved with the normal or wide stances.

In further study, EMG data that was collected during the experimental trials may yield information about differences in the muscles activated as a function of foot placement. Calculation of joint forces and moments may also indicate the use of alternative coordination control such as hip vs. ankle strategies. In addition, reaching trials where the able-bodied subjects are allowed to support themselves with their non-dominant hand are of interest since SCI subjects may require hand support to maintain balance. Finally, the testing of SCI subjects using FES during standing and functional tasks will be the ultimate evaluation concerning the benefits of posture adjustments.

## 5. Conclusions

In studying quiet standing and reaching tasks for able-bodied subjects, the results indicate a number of recommendations that may be of benefit to SCI subjects. During quiet standing, subjects may be able to reduce sagittal instability by adjusting their posture to a tandem stance, while coronal instability may be slightly reduced with a wider stance. For reaching in anterior and dominant directions, subjects would likely benefit from using a tandem stance due to improved alignment of the base of support along the line of motion. In contrast, reaching in the non-dominant direction appears to be better achieved by maintaining a normal stance, moving to a wider stance, or possibly by a postural adjustment to a non-dominant tandem stance (in the case that the non-dominant hand is not needed for support). In future work, we will incorporate foot placement and posture control into our system in order to evaluate the effects on functional capabilities while standing with FNS.

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Acknowledgments**:** The work on this project was partly funded by a grant from the NIH Neural Prosthesis Program, NIH-NINDS-N01-NS-6-2351, and by the University of Kentucky.