INTRODUCTION

The postural stability of an amputee is influenced by the severity of his handicap and by his ability to compensate physiologically and biomechanically for absent anatomical parts. The most serious deficits affecting the postural integrity of amputees would appear to be losses of proprioceptive sensations which normally would have emanated from the muscles, joints, fascia, and skin of the missing extremity. Absence of these sensations originating in amputated limbs eliminates feedback information to the nervous system regarding the momentary status of the body's position in space. Stretch reflex reactions, which are necessary adjuncts for the supportive maintenance of posture, are also abolished in the amputated extremity.

Postural stability in amputees also appears to be biomechanically affected by the asymmetrical distribution of body weight incurred by limb losses which then affect muscular forces. These weight discrepancies are not fully compensated for by prosthetic limbs in that these devices are invariably lighter than the weight of the normal extremity. The height of the body's center of gravity is generally higher in lower-extremity amputees than in normal individuals since limb deficiencies tend to raise its location. In spite of seemingly debilitating biomechanical and physiological deficiencies, it appears that amputees are generally able to compensate for their deficits since they are able to maintain postural integrity compatible with their rehabilitation training, their physical condition, and their chronological age. There is currently little information in the literature regarding the physiological and biomechanical aspects of compensatory stance characteristics in amputees evaluated by center of gravity, electromyographic, and photographic procedures. The purpose of this case study was, therefore, to investigate the stance characteristics of an amputee under varying postural and sensory input conditions.
METHODS

The subject was an 11-year-old boy with multiple congenital anomalies. He is a quadrilateral amputee with congenital Lisfranc amputations of both lower extremities, a long above-elbow amputation of the left upper extremity, and a medium below-elbow amputation of the right upper extremity. The subject was currently being fitted for new upper-extremity prostheses since he had outgrown his present devices. For the purpose of this study, the subject could still wear his comfortable old "orthopedic" shoes which had fillers in the forefoot area and Thomas heels.

The assessment procedures consisted of two series of stance tests which were performed with the subject wearing and not wearing his "orthopedic" shoes. The arms were either relaxed at the sides or they were flexed forward from the shoulder to 90 deg. For the first series of tests, the subject wore his shoes and was instructed to assume a normal standing position with the feet comfortably placed on a center of gravity platform. The subject looked straight ahead and the arms were flexed to shoulder height. After the subject stood for a period of 15 seconds to become acclimated to the equipment, electromyograms were recorded and photographs were taken at 2-second intervals for a minute in order to sample variations in anteroposterior and medial-lateral postural patterns. The test was repeated after a rest period of 10 seconds. The subject performed the same procedures with his arms at the side. For the second test series, the subject removed his shoes and repeated the tests in the reverse order.

The scale method and biplane photography were used to locate the vertical projections of the subject's center of gravity in both the anteroposterior and medial-lateral direction. The procedures and calculations used to determine center of gravity locations have been described by Waterland and Shambes (7). The center of gravity apparatus essentially consisted of a triangular pivot platform supported by three dial scales. Instantaneous partial-weight readings on the three scales were photographed by two synchronized motor-driven Nikon 35 mm. cameras. One camera recorded the partial-weight values on the two anteroposterior scales and a profile picture of the subject. The other camera photographed partial-weight readings on the lateral scale and a front view picture of the subject. Since the subject's total weight, the geometry of the platform, and the partial-weight values for all three scales were known, center of gravity locations in the anteroposterior and medial-lateral planes could be calculated by equating torques.

Electromyography was used to determine the timing, magnitude, and general patterns of muscular activity during the stance tests. The soleus and tibialis anterior muscles on both sides were selected for
investigation because of their reciprocal actions of plantar flexion and dorsiflexion at the talocrural joint. To insure accuracy of electrode placement, muscle motor points were found with a Burdick Galvanic stimulator. Five millimeter bipolar silver cup surface electrodes were used. The electrode cups were filled with electrode paste and then were secured to the skin with stretch elastic tape. The proximal electrode was placed over the motor point, the second 2.5 cm. distally in line with the muscle fibers in order to standardize electrode locations over the selected muscles. The subject was grounded by means of a 3.0 by 4.8 cm. indifferent electrode positioned just above the lateral malleolus of the right leg. Muscle action potential activity was recorded on an 8-channel inkwriting electromyograph. Graduated isometric contractions and conventional muscle test responses were recorded in order to confirm electrode placement (2). The electromyograph was calibrated at 200 μv. and 1 in. of deflection was used to calibrate all channels. The paper speed was set at 25 mm. per second in order to obtain a consolidated overview of the action potential patterning. A more complete review of electromyographic rationale and methodology has been previously described by Waterland and Shambes (6). Photographic event marks, designating the time each photograph was taken, were indicated on the electromyographic record. Thus, three criteria of behavioral response (center of gravity, electromyographic, and photographic) evolved synchronously, and patterning evident in one could be checked against the other two.

RESULTS

The results of this study were based on 240 center of gravity readings, 240 biplane photographs, and eight electromyographic records. The total data collection time was 8 min. Anteroposterior and mediolateral excursions of the center of gravity lines from the axis of rotation at the ankle joint (mean location between the medial and lateral malleoli of both feet) and from the geometric center of the functional base were calculated (Fig. 1). The variances and mean locations of the lines of gravity were then determined. The center of gravity records were also used to determine the average percentage of the anteroposterior base of support used by the subject during stance.

Electromyographic records were visually inspected for spatial-temporal relationships between and within test trials and test series. Five experienced electromyographers evaluated the electromyographic records so that the repeatability of their assessments could be established. Photographs were examined to observe possible differences in postural alignment during the test situations which might have affected the center of gravity and electromyographic data.
The overall center of gravity results suggested that the subject was exceedingly stable and secure when he was not wearing his "orthopedic" shoes, regardless of whether the arms were at the side or flexed to shoulder height (Tables 1–3). The lower variance scores of the anteroposterior and medial-lateral projections of the lines of gravity clearly showed that there was little postural sway occurring during the shoes-off series of tests irrespective of arm position. It was also found that the subject's body weight was evenly distributed over both legs; and again, arm position did not affect the results. However, the most striking finding in the shoes-off test series was that the anteroposterior line of gravity, on the average, fell posterior to the axis of rotation at the talocurral joint as seen in Figure 1. This observation is not in...
keeping with the fact that the line of gravity is located in front of the ankle joint during erect stance in normal subjects (1, 4). The shorter lever arm in front of the ankle joint in comparison to that found in the normal foot may explain this finding.

**Table 1.—Variance of the Center of Gravity Locations**

<table>
<thead>
<tr>
<th></th>
<th>Shoes-off</th>
<th>Shoes-on</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anteroposterior Direction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arms at side</td>
<td>3.38</td>
<td>7.19</td>
</tr>
<tr>
<td>Arms flexed</td>
<td>6.19</td>
<td>8.13</td>
</tr>
<tr>
<td>Average variance</td>
<td>4.79</td>
<td>7.66</td>
</tr>
<tr>
<td><strong>Medial-Lateral Direction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arms at side</td>
<td>1.88</td>
<td>4.57</td>
</tr>
<tr>
<td>Arms flexed</td>
<td>3.34</td>
<td>5.18</td>
</tr>
<tr>
<td>Average variance</td>
<td>2.61</td>
<td>4.78</td>
</tr>
</tbody>
</table>

Note: The smaller the variance, the more stable the subject is during stance.

**Table 2.—Excursions in Centimeters of the Medial-Lateral Center of Gravity Lines from the Geometric Center of the Base of Support**

<table>
<thead>
<tr>
<th></th>
<th>Shoes-off</th>
<th>Shoes-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arms at side</td>
<td>-.090</td>
<td>+.435</td>
</tr>
<tr>
<td>Arms flexed</td>
<td>-.080</td>
<td>-.125</td>
</tr>
<tr>
<td>Average location</td>
<td>-.085</td>
<td>+.155</td>
</tr>
</tbody>
</table>

- Left of the geometric center.
+ Right of the geometric center.

**Table 3.—Excursions in Centimeters of the Anteroposterior Center of Gravity Lines from the Ankle Joint**

<table>
<thead>
<tr>
<th></th>
<th>Shoes-off</th>
<th>Shoes-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arms at side</td>
<td>-.32</td>
<td>+.06</td>
</tr>
<tr>
<td>Arms flexed</td>
<td>-.37</td>
<td>+.38</td>
</tr>
<tr>
<td>Average location</td>
<td>-.35</td>
<td>+.22</td>
</tr>
</tbody>
</table>

- Posterior to the ankle joint.
+ Anterior to the ankle joint.

Greater anteroposterior and lateral instability, as indicated by larger variance scores, was observed when the subject was wearing his "orthopedic" shoes (Table 1). Moreover, lateral displacements of the lines of gravity (Table 2) were calculated to fall slightly to the right of the geometric center of the base of support when the arms were in their normal position and to the left of center when the arms were flexed 90 deg. The mean anteroposterior positions of the lines of gravity were located slightly anterior to the ankle joint regardless of arm place-
ment (Table 3). This result may have been due to the longer anterior lever arm given by the subject's shoes. An illustration of how the center of gravity projections clustered around the axis of rotation at the ankle is shown in Figure 2.

Figure 2.—Biplane photographs and "foot-print" records during a shoes-on trial. The photographs show the mean projection of the lines of gravity when the subject is wearing shoes. The drawing indicates the distribution of the line of gravity locations around the axis of rotation at the ankle joint (+) during one of the shoes-on trials.

The center of gravity data also revealed that the subject, in toto, used 39.0 percent of the anteroposterior base of support available to him during all the experimental conditions. This seems to be a very small area indeed when one considers that 61.0 percent of the total base of support area is still accessible for postural sway movement before body balance and equilibrium is completely lost.
Shambes and Waterland: Stance of a Quadrilateral Amputee

Covert Patterning

The eight electromyograms were easily separated into shoes-on and shoes-off categories by the five readers even though all identification labels had been covered on the records. Increases in muscle action potential amplitudes consistently occurred when the subject wore his "orthopedic" shoes (Fig. 3). (The slight asymmetry of foot placement observed in the stance tracings is not considered gross enough to affect muscle patterning.) The shoes-on test results also showed that the right soleus muscle and the left tibialis anterior muscle were active throughout the entire test procedures. However, it was observed that when the subject stood with his shoes off, most of the action potential activity was observed in both the right and left tibialis anterior muscles (Fig. 3). The soleus muscles were relatively quiescent except for intermittent bursts of activity which seemed to mirror gross anterior displacements of the lines of gravity. Thus, bilateral muscular activity in the tibialis anterior muscles was seen when the subject was not wearing "orthopedic" shoes whereas contralateral reciprocal patterning in the tibialis anterior and the soleus muscles with general increments in muscular activity were consistently found when the shoes were worn. These findings may be due to a longer anatomical or bony lever arm in back of the axis of rotation at the ankle joint as a result of the Lisfranc amputation. This structural condition may thus cause more posterior displacements of the body's center of gravity therefore eliciting more muscular activity in the tibialis anterior muscles bilaterally when the subject was not wearing shoes.

Further visual inspection of the electromyograms by the readers unanimously revealed that no gross spatial-temporal differences were detected in muscle activity within a test series (arms down/arms up) as illustrated in Figure 3. These findings supported the anteroposterior center of gravity location observations that no apparent discrepancies were noted with regard to arm position during each series of tests. Lateral displacements of the center of gravity lines were not reflected in the electromyographic results since the muscles principally concerned with inversion and eversion of the foot were not sampled.

Overt Patterning

Profile view pictures of the subject disclosed a relaxed abdomen, a kypholordosis which was accompanied by a forward head, and an anterior tilt and forward displacement of the pelvis. This "slouched" postural configuration was discernible regardless of the test condition. No evidence of a scoliosis or lateral trunk displacements were observed in the front view photographs and recent X-rays of the subject's back confirmed these findings. The subject's general "relaxed" posture may therefore be due to reflex adjustments occurring as a result of a smaller
Figure 3.—Electromyographic records of muscle patterning. The top records show the muscle activity occurring during trials when the subject was not wearing shoes. The lower records illustrate the spatial-temporal characteristics of muscle patterning occurring during a shoes-on trial. The insets of the subject's image on each of the electromyographic records were drawn directly from the film negatives, and they denote whether or not shoes are being worn and the arm position during that particular trial.
Shambes and Waterland: Stance of a Quadrilateral Amputee

than average area of standing support. It was also noted that the center of gravity lines fell posterior to the axis of rotation at the knee joint during all test conditions and the quadriceps muscles were bilaterally in a state of constant contraction in order to keep the knees extended, as illustrated in Figures 1 and 2. There was no evidence from the photographs of alternate contractions occurring between the hamstring and quadriceps muscles since the quadriceps muscles seemed to be contracting throughout the entire experiment.

DISCUSSION

Assessment of the center of gravity, electromyographic, and photographic data revealed that when the subject stood with his shoes off, the center of gravity projections were located posterior to the ankle joint midway between both legs. The variance measurements were small, suggesting that the subject was stable, and the electromyographic records showed that the subject very frequently contracted the tibialis anterior muscles bilaterally. The stability of the subject’s posture was linked with posterior displacements of the center of gravity positions which necessitated bilateral activity in the tibialis anterior muscles.

When the subject stood with his shoes on, however, the line of gravity tended to fall slightly anterior to the ankle joint and the variance measurements were larger indicating less postural stability. These results were coupled with the observation that the right soleus and left tibialis anterior muscles contracted synchronously in contralateral cross-diagonal fashion. The overall magnitude of muscle activity also increased during the shoes-on trials suggesting that more muscular effort had to be exerted in order to maintain an erect postural position. Therefore, it appears that anterior displacements of the center of gravity position and reciprocal contralateral muscle patterning with concomitant increases in action potential activity were associated with less stable postures.

The muscle patterning, center of gravity, and photographic results are not in keeping with the postural characteristics found in normal individuals. Experimental evidence has shown that the center of gravity line in normal adult females wearing low-heeled shoes and not wearing shoes falls about 5 cm. anterior to the axis of rotation at the ankle joint (9). It has also been found in normal man that the soleus muscles are tonically active in order to keep the body’s center of gravity from falling too far forward (1).

The shoes-off situations apparently provided optimum conditions for postural stability since there were smaller variances in the line of gravity locations and also because there was less muscle activity observed in the electromyographic records. Thus, direct contact with the supporting surface may account for the increased stability observed in the
shoes-off test series. The sensory receptors in the stump area may have exhibited lower thresholds to incoming stimuli allowing the subject to utilize available compensatory reflex mechanisms to better advantage when he was not wearing his “orthopedic” shoes. When the subject was wearing his well-worn shoes, however, the stumps were loosely in contact with the shoes and this condition may have been instrumental in evoking more non-discrete types of stimulation to the stump sensory receptors. Therefore, the increased muscular effort noted when the subject was wearing shoes may have been due to the neuromuscular system over-reacting to diffuse incoming sensory stimuli in an effort to keep the center of gravity over the base of support.

Lower and higher level reflex reactions in remaining body segments would also appear to be partially responsible for the overall postural adjustments observed during the varying stance conditions. Lower level postural reactions are evoked by receptors found in the subject’s remaining intact muscles, joints, tendons, ligaments, fascia, and skin. These peripheral receptors are known to elicit observable motor responses and they also relay feedback information to all levels of the central nervous system where information is then consciously or unconsciously processed to further modify and adjust postural activity. Higher level equilibrium and postural reactions emanating from supraspinal structures were also probably instrumental in the physiological regulation and control of the subject’s postural attitudes during the different test conditions.

Biomechanical evidence of the remarkable compensatory ability of the amputee during stance was demonstrated when the subject only used 39.0 percent of the total anteroposterior base support available to him. Hellebrandt (5) found that normal man uses 66.0 percent of his base area during stance, whereas lower-extremity amputees wearing prosthetic limbs utilize about 36.6 percent of their total base area. Since there is no known information in the literature regarding the percentage of the supporting base that normal children or quadrilateral amputees use during stance, one cannot directly compare the results of this study with those of Hellebrandt who used normal adults and lower-extremity amputees wearing prosthetic limbs in her experiments. However, it does appear that the base of support area utilized by amputees is indeed less than that used by normal individuals. It may be that the smaller base of support used by amputees during biped stance allows for greater margins of security, particularly since the upright position has been structurally threatened.

The most significant finding of this study was, therefore, that the accessory area of “static” stability provided by the well-worn shoes was not used effectively or efficiently during stance. Therefore, artificial extensions of the stumps had no physiological or biomechanical value.
This may explain why the subject preferred to walk, run, and jump on his stumps rather than to wear shoes while in his home surroundings.

**SUMMARY AND CONCLUSIONS**

The purpose of this study was to investigate the stance characteristics of a congenital quadrilateral amputee under differing postural and sensory input conditions. The results included center of gravity data, electromyographic records, and biplane photographs. Within the limitations of this study, the following conclusions seem justified:

1. The subject was always more stable when he was not wearing his well-worn "orthopedic" shoes, regardless of arm position.
2. The subject's weight was more evenly distributed over both stumps when shoes were not worn.
3. In the shoes-off series of tests, bilateral symmetrical muscular activity was noted in the legs, whereas contralateral reciprocal muscle activity with concomitant increases in action potential amplitudes was evidenced in the shoes-on test series.
4. The subject, on the average, used 39.0 percent of his total anteroposterior base of support during stance activities regardless of test position thus maintaining a substantial margin of safety.
5. A "slouched" postural configuration was observed in the subject throughout the entire experiment.

**ACKNOWLEDGMENT**

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**REFERENCES**