The Biomechanics of Walking in the chung shi Health Shoe

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Executive Summary

Chung shi has developed a new concept for health and wellbeing shoes. The primary innovation in the new footwear is a heel lift of 15° which is proposed to improve posture and balance as well as increase shock absorption. **The purpose of this project was to compare the movement, forces and muscle activity between the new shoes and standard athletic footwear during standing and walking.**

Nine healthy subjects participated in this study. Data were collected at two times: 1) when the subjects first wore the chung shi shoes and 2) after the subjects wore the shoes for 6 hours a day for two weeks. Data were collected during standing and walking and were compared to trials with a standard adidas running shoe. Muscle activity of the leg and movement of the center of pressure (sway) were quantified while subjects stood quietly for 30 seconds. Muscle activity and ground reaction forces were measured during walking, as well as ankle and knee joint movement and loading.

During standing, the movement of the center of pressure is increased approximately 60% when wearing the chung shi shoe compared to a control shoe. As a result increases of muscle activity in the shank of over 100% are required to help balance the body.

During walking, the ankle is approximately 14° more dorsiflexed during landing due to the 15° heel lift in the chung shi shoes. The knee compensates slightly by flexing approximately 2° more. As a result of the changes in the walking movement, the ground reaction forces are applied more quickly, although the peak magnitudes do not change. Muscle activity of the quadriceps, hamstring and calf muscles do not change when walking in the chung shi shoes while the activity of the tibialis anterior on the front of the leg decreases by about 10%. The resultant joint moments at the ankle and knee joints decrease from 21-60% with the largest reductions occurring during landing.

To summarize the main aspects of the chung shi shoe:

- During standing, the stability of the chung shi shoes is lower than normal shoes. This results in increased swaying movement and increased muscle activity of the calf muscles to balance the body. For standing, the chung shi shoe acts as a muscle training device.
- During walking, the chung shi shoes change the movement, increasing ankle and knee flexion. The result is a more upright stance.
- The chung shi shoes change muscle activity minimally during walking. The activity of the muscle on the front of the shank (tibialis anterior) is decreased slightly and the activity of the quadriceps (vastus medialis) is increased slightly.
- The chung shi shoes reduce joint loading at the ankle and knee joint during the landing and weight acceptance phase of walking.
- The influence of the chung shi shoe is immediate and does not change after wearing the shoes for two weeks.
Introduction

Stability is an important factor in athletic performance, preventing falls and injury, and increasing mobility in aged individuals. Stability may be promoted through two methods, external equipment and the strengthening of small muscles across a joint. External equipment may include shoes, braces and other devices that increase contact area with the ground and restrict joint movement in order to align body segments with the ground reaction force at the foot. Small muscles with lines of action close to the joint centre promote stability by reducing joint movement and aligning body segments, effectively providing outcomes similar to external devices such as braces. Strengthening muscles, however, has the advantage of increasing muscular strength, while external devices may actually cause atrophy in stabilizing muscles.

Stability training, for small muscles, has been previously incorporated into athletic training programs. This type of stability training is generally performed on an unstable surface, allowing the participant to develop muscular strength and motor-coordination. Such uses of stability training have been shown to reduce injury, and promote rehabilitation and while the mechanisms behind this are not entirely clear, it is known that stability training may improve ankle and knee joint proprioception.

Recently, a new type of unstable shoe has been developed by chung shi Health Shoes. This shoe incorporates a rounded sole with a 15 degree heel lift, which is proposed to improve posture and balance through stability training. Currently, however, the effects of the use of this shoe on human gait patterns are unknown. The purpose of this project was to compare the movement, forces and muscle activity between the new shoes and standard athletic footwear during standing and walking.
Subjects

Nine (8 male and 1 female) healthy subjects, who were free of lower extremity injury, volunteered for this study. Subject characteristics are shown in the table below. All subjects gave informed consent prior to data collection, according to the regulations of the Calgary Health Research Ethics Board.

*Characteristics of the subjects used in this investigation. Average time per day refers to the amount of time each subject wore the chung shi shoe during the two week training period.*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age  [yrs]</th>
<th>Height [m]</th>
<th>Mass [kg]</th>
<th>Avg Time/Day [hrs]</th>
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<tr>
<td>1</td>
<td>34</td>
<td>171</td>
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<td>6</td>
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<td>5.4</td>
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<td>7</td>
<td>23</td>
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<td>71.6</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>22</td>
<td>186</td>
<td>75</td>
<td>6.3</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>170</td>
<td>63</td>
<td>9.3</td>
</tr>
<tr>
<td>Average</td>
<td>27.8</td>
<td>174.3</td>
<td>70.8</td>
<td>6.7</td>
</tr>
<tr>
<td>Std Dev</td>
<td>7.5</td>
<td>8.4</td>
<td>8.6</td>
<td>1.4</td>
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</table>

Footwear

Each subject was provided with a chung shi walking shoe for testing purposes. The chung shi shoes have a rounded sole with 15° heel lift which is designed to improve posture and balance during walking. The control shoes used during testing were adidas Supernova running shoes. Two testing sessions were performed. The first session was when the subjects first received the chung shi shoes. For the second session, the subjects returned to the lab after wearing the shoes for a period of 2 weeks for a minimum of 6 hours per day.

*Photographs of the chung shi shoes and the adidas Supernova shoes used for comparison.*
Standing trials were collected over a period of 30 seconds of quiet-standing. Ground reaction forces were collected using a force plate embedded in the lab floor, sampling at 2400Hz. The ground reaction forces were used to determine the movement of the center of pressure which is an indication of stability. Electromyography (EMG) data from the right leg were collected to determine muscle activity for the quadriceps (vastus medialis), hamstrings (biceps femoris), calf (medial gastrocnemius) and tibialis anterior muscles. EMG data were sampled using bipolar silver-chloride electrodes and leads equipped with pre-amplifiers collecting at 2400Hz. EMG data were bandpass filtered between 5Hz and 500Hz.

In order to compare EMG data across testing sessions, three maximal voluntary contractions were performed for each of the muscles, during each testing session. An assistant provided resistance for the subject while they contracted their muscle maximally for ten seconds. The first two seconds of each EMG trace were used to determine the magnitude of each maximum voluntary contraction, and the average was calculated for the three trials. Values for the standing trials were then converted into percentages of the maximum voluntary contraction for each session.

Photograph of the subject during the standing trial with the EMG electrodes on the muscles. The subject is standing on a force platform used to measure ground reaction forces and movement of the center of pressure. The schematic shows the muscles that were measured.
Center of Pressure
The center of pressure excursions were significantly greater while standing in the chung shi shoe compared to the control shoe. Center of pressure movement in the front to back direction (anterior-posterior) increased by 14.5mm and movement in the side to side direction (medial-lateral) increased by 7.2 mm when subjects wore the chung shi shoe. These are increases of approximately 60% with the chung shi shoe in comparison to the control shoe. The increased center of pressure excursions still remained after the two week training period with the chung shi shoes.

Representative schematic showing the movement of the center of pressure for one subject.

Muscle Activity
During quiet standing with the chung shi shoe, the muscles of the lower extremity were more active than standing with the control shoe. The differences were greatest and were significant for the muscles of the shank but increases in the thigh were seen as well.
Representative schematic showing the increased muscle activity (EMG) while standing in the chung shi shoes. The bold values indicate significant differences.

Walking speed was monitored during walking trials, which were only accepted when the speed was 5km/h ± 0.5km/h. Ten walking trials were collected in each condition. When beginning a new shoe condition, subjects were allowed a period of ~10min during which time they could walk around to acclimate to the shoe condition.

Movement (kinematic) data were collected using eight high-speed digital video cameras sampling at 240Hz. Ground reaction forces (kinetic data) were collected using a force embedded in the lab floor, sampling at 2400Hz. Kinematic data were low-pass filtered with a cut-off of 10Hz and force data were low-pass filtered with a cut-off of 50Hz. Kintrak software was used to calculate joint angles, joint moments and ground reaction forces.

EMG data were sampled using bipolar silver-chloride electrodes and leads equipped with pre-amplifiers (Biovision) collecting at 2400Hz. EMG data were bandpass filtered between 5Hz and 500Hz. For walking, the EMG data were broken up into steps from 200ms prior to heelstrike to toe-off. The root-mean square (RMS) of the signal was then calculated for each step, and then steps were averaged for each trial.
**Movement**
The ankle joint was significantly more dorsiflexed in the chung shi shoe throughout the stance phase. During the landing phase the ankle joint was approximately 14° more dorsiflexed, which is related to the 15° slope in the heel of the chung shi shoe. Subjects flexed their knee slightly more during the landing phase with the chung shi shoe, approximately 2° to help accommodate the changes in ankle dorsiflexion. The ankle joint was also more everted (approximately 2-3°) and abducted (approximately 2°) when subjects walked with the chung shi shoes.

*Average movement of the ankle and knee during walking with the chung shi shoe compared to the control shoe.*

**Ankle dorsiflexion/plantarflexion angle**

![Graph showing ankle dorsiflexion/plantarflexion angle](image-url)
Ankle abduction/adduction angle

Schematic showing average foot and leg position at touchdown, mid-stance and toeoff during walking.
Forces
The magnitudes of the ground reaction forces generally did not change when subjects wore the chung shi shoe. However, the rate of force application was increased with the chung shi shoe suggesting that the loading occurred more quickly.

Average ground reaction forces during walking with the Chung shi shoe compared to the control shoe.

Vertical Ground Reaction Force

Anterior/Posterior Ground Reaction Force
Medial/Lateral Ground Reaction Force

Joint Loading
The chung shi shoes reduce joint loading (resultant joint moments) in the ankle and knee joint. The reductions occur in the sagittal and transverse planes and are more pronounced during landing and weight acceptance.

Schematic showing the resultant joint moments at the knee joint.
Reduction in knee joint loading when walking with the chung shi shoe compared to the control shoe.

<table>
<thead>
<tr>
<th></th>
<th>Landing</th>
<th>Push-off</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ankle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sagittal plane</td>
<td>-27%</td>
<td>No difference</td>
</tr>
<tr>
<td>Frontal plane</td>
<td>No difference</td>
<td>No difference</td>
</tr>
<tr>
<td>Transverse plane</td>
<td>-60%</td>
<td>No difference</td>
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<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sagittal plane</td>
<td>No difference</td>
<td>-24%</td>
</tr>
<tr>
<td>Frontal plane</td>
<td>No difference</td>
<td>No difference</td>
</tr>
<tr>
<td>Transverse plane</td>
<td>-21%</td>
<td>No difference</td>
</tr>
</tbody>
</table>

**Muscle Activity**

There were only small changes in muscle activity when walking with the chung shi shoes. The vastus medialis and tibialis anterior muscles showed significant differences in muscle activity with an increase of 13% and a decrease of 7% respectively.

*Representative schematic showing the changes in muscle activity (EMG) while walking in the chung shi shoes. The bold values indicate significant differences.*
Changes After 2 Weeks of Wearing

Only minor changes occurred after subjects wore the chung shi shoes for two weeks. The ankle and knee joint movement and the ground reaction forces did not change as the subjects became accustomed to the shoes. Similarly, muscle activity patterns did not change during the two-week wear period. Only one change in joint moments occurred. Initially, ankle abduction moments during push-off were lower with the chung shi shoes, however, these increased to similar levels of the control shoe after two weeks. Overall it appears that subject mechanics when walking with chung shi shoes do not change over a two week accustomization period.

Summary

- During standing, the stability of the chung shi shoes is lower than normal shoes. This results in increased swaying movement and increased muscle activity of the calf muscles to balance the body. For standing, the chung shi shoe acts as a muscle training device.
- During walking, the chung shi shoes change the movement, increasing ankle and knee flexion. The result is a more upright stance.
- The chung shi shoes change muscle activity only minimally during walking. The activity of the muscle on the front of the shank (tibialis anterior) is decreased slightly. The muscle activity of the quadriceps muscles (vastus medialis) is increased slightly.
- The chung shi shoes reduce joint loading at the ankle and knee joint during the landing and weight acceptance phase of walking.
- The influence of the chung shi shoe is immediate and does not change after wearing the shoes for two weeks.