Motion Analysis and EMG Analysis of the Pelvis and Lower Extremity according to the Width Variation of the Base of Support

The purpose of this study is to identify which width of the base of support (BOS) is safer and more effective in lifting by comparing muscle activations and body sways when lifting objects under the width variation of the BOS. A total of fifteen healthy adults participated in this study. For the width variation of the BOS, the participants changed the width between their feet into three different types (10cm, 32cm, 45cm) and lifted a 10kg four times in each type after going up on a force plate. In order to measure body sways according to the width variation of the BOS, a motion analysis system was used. In addition, in order to measure the muscle activations of lower extremities, including the erector spinae, gluteus maximus, rectus femoris, and tibialis anterior, an electromyogram (EMG) analysis was employed. In addition, the Borg’s scale was drawn by quantifying the subjective discomfort levels felt from each width of the BOS. In conclusion, no statistically significant differences according to the width variation of the BOS were observed (p = .295, .308)(p = .05). However, a statistically significant difference was exhibited between the Borg’s scale, which indicates the discomfort levels from lifting performances, and the width variation of the BOS (p = .000*).

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INTRODUCTION

Movements are very important in human lives. Humans develop their exercise capacity along with taking on new interests or performing routine tasks. In doing so, they make functional movements that enable safe and effective performances in their tasks. In other words, movement patterns most suited to biomechanical systems are produced by factors such as the musculoskeletal systems normal functioning and effective movement, as well as proper controls of muscular strength[1]. Such functional movements are realized when a person makes independent postures from the force of gravity while maintaining physical balance. In other words, in order for human bodies to control postures during their activities, the dual purposes of stability and mobility should be achieved[2]. Feet become a basic support point to maintain a straight-standing position. The space between the feet becomes the base of support (BOS) that helps maintain the posture. At this, a stable posture can be maintained when the gravity line lies within the space between the feet. Shin et al, stated that the stability of posture can be increased by stretching the width between feet, using a cane, or enlarging space through creating another BOS[3]. Holbein and Redfern proposed that the range of safety is defined not only by a person’s feet landed on the ground, but also by the width between his/her lower limbs[4]. In addition, Ilyse and Alexander reported that in their research, when a person makes a movement, a larger width of the BOS resulted in a corresponding decrease in body sways[5]. Furthermore, Aruin et al, said that the width of the BOS affects the movements of L5, S1, and knee joints, and humans feel reduced safety when their widths of the BOS become narrow[6]. Such findings
indicate that when the width of the BOS becomes narrower, the stability of posture lowers. Thus, in order to compensate this, compensational movements are produced. Such study results illustrate that larger widths of the BOS lead to higher stabilities of posture.

Humans act in various industrial sites based on their stability of posture. Meanwhile, a number of musculoskeletal system disorders are occurring due to undesirable postures. One of the tasks that can easily cause musculoskeletal system disorders is lifting or taking down an object. Such movements can be made by squat lifting, which uses low extremities, or stoop lifting, which uses back strength. According to existing studies, in experiments of evaluating pressures applied to disks and ligaments, squat lifting is reported to receive less pressures than stoop lifting, and also squat lifting requires relatively lower energy expenditures and heart rates while receiving less torsion(7, 8).

In addition, Babak et al. proposed squat lifting as a safer technique to reduce stresses exerted to muscle power and ligaments although the same height(T3), weight(180N), and lever had been used for their experiment. Lifting up heavy objects in industrial sites or repetitively occurring trunk flexion and rotation, and extension movements can all become major causes for back pain. In 2008, the number of patients with back pain was reported to have declined to 5,232 from the previous year's 6,333. However, among the above figures, those performing labor-intensive tasks rather rose from 1,390 to 1,471 during the given period. Alongside, this results in increased economic losses every year(9, 10). A lot of studies have been carried out in order to prevent such musculoskeletal system disorders. These include researches on the subjects maximum muscular strengths according to trunk angles and humeral angles(11), as well as researches on the fatigue recovery of trunk muscles. As the results, many effective postures to prevent physical damages have been developed.

In this background, the purpose of this study is to help prevent musculoskeletal system disorders in physical task performers by examining the degrees of muscle activation and body sway, as well as conducting a motion analysis of lower extremities according to different widths of the BOS.

METHODS

Subjects

The subjects of this study consisted of 16 students at N University in Cheonan. The inclusion criteria were that the subjects had to have experienced no musculoskeletal system disorders over the past three months, and be physically healthy. In addition, the subjects agreed on the consent form that is in compliance with the regulations of the Ethics Committee. They were also informed of the experiment's purpose and entire procedure before conducting it. General characteristics of the subjects are shown in Table 1.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Experimental group(n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age(yrs)</td>
<td>21.80±1.282</td>
</tr>
<tr>
<td>Height(cm)</td>
<td>164.07±7.439</td>
</tr>
<tr>
<td>Weight(kg)</td>
<td>56.20±8.550</td>
</tr>
</tbody>
</table>

Mean±SD

Materials and Methods

After being informed of the experiment's purpose, methods, and procedure, the subjects filled in an experiment consent form. In order to observe right-left sways of the pelvis according to the width variation of the BOS, markers for the purpose of motion analysis were attached to the anterior superior iliac spine(ASIS), spinous process of vertebra which is positioned horizontally to the iliac crest spur, great trochanter, apex of fibular head, and lateral malleolus on each side of the subject's body. For the purpose of observing body sways, a triangle was formed by connecting the ASIS and the vertebra horizontally positioned to the iliac crest spur. Then, virtual dots were placed in the half point of the triangle's each line to connect together. For the EMG measurement of the erector spinae, gluteus maximus, rectus femoris, and tibialis anterior, all of which are typically used to lift weights, electrodes were attached to them(13). The areas where markers and electrodes were attached are shown in Figure 1.

In order to minimize measurement errors, feet locations were standardized. In other words, the subjects were instructed to stand based on the parallel lines that connect the heels of their feet and the tips of their second toes(14). The distances between their feet were set to be 10cm, 32cm, and 45cm(2) respectively. In order to exclude any biased influences
from the order of participation, the subjects performed their tasks in the random order selected by themselves. In reference to the studies suggesting that the squat technique is safer as a sitting mode, the due technique was selected for the experiment as well. The squat technique used in this experiment is shown in Figure 2.

According to the study of the Korea Occupational Safety & Health Agency where 10kg is proposed as an appropriate weight when assuming lifting four times for one minute(5), the subjects were instructed to go up on a force plate and lift the respective weight four times for each width. The boxes used for the experiment were generally used 26×33×26cm in size(4). After the experiment, the subjects were guided to rate on the Borg's Scale that quantifies subjective discomfort levels according to each width of the BOS(Table 2)(11, 16, 17).

Table 2 Modified Borg’s CR–10 rating scale

<table>
<thead>
<tr>
<th>Scale</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Extremely strong–almost maximal</td>
</tr>
<tr>
<td>9</td>
<td>Very strong</td>
</tr>
<tr>
<td>8</td>
<td>Strong</td>
</tr>
<tr>
<td>7</td>
<td>Moderate</td>
</tr>
<tr>
<td>6</td>
<td>Weak</td>
</tr>
<tr>
<td>5</td>
<td>Very weak</td>
</tr>
<tr>
<td>3</td>
<td>Extremely weak (just noticeable)</td>
</tr>
<tr>
<td>2</td>
<td>Nothing at all</td>
</tr>
</tbody>
</table>

**Measurement Instrument**

Measurement instruments used in this study are listed in Table 3. A three dimensional motion analysis system(BTS) is shown in Figure 3, and a pocket EMG in Figure 4.

**Fig. 1.** Electrode attachment locations for motion analysis markers and muscle activation measurement

**Fig. 2.** Squat Lifting

**Fig. 3.** Three dimensional motion analysis system(BTS engineering, Italy)
EMG signal collected by surface electrode is amplified 10 times through amplifier to subjects noise and interference, moved to subjects through cable, then converted to digital data using A/D converter in 16 bit. Data collected from patient unit is received by access pointer connected with LAN cable and computer through WIFI immediately after the completion of collection, and the indication of automation of raw data in Myolab (software, BTS co, Italy) software used in pocket EMG was processed. The sampling rate of EMG signal was set to 1,000Hz, and band pass filter of 20–500Hz and notch filter of 120Hz were used. The collected signal was calculated in RMS(root mean square) after going through full-wave rectification.

Data Analysis

The data derived from the experiment was statistically processed using the WINDOW based SPSS version 12.0 program. The characteristics of all resulted values were verified of their normal distribution by a Kolmogorov–Smirnov test. In addition, an one way ANOVA test was conducted to evaluate the muscle activations and angle changes of hip and knee joints according to the width variation of the BOS, as well as the differences in body sways according to the left–right movement routes of the virtual dots. In addition, a Scheffe post–hoc analysis was employed to observe statistically significant differences. The statistical significance level was .05.

RESULTS

The Comparison of Muscle Activations according to the Width Variation of the BOS

In order to measure muscle activations according to the width variation of the BOS, RMS values of the tibialis anterior, rectus femoris, erector spineae, and gluteus maximus were used. Consequently, statistically significant differences in muscle activation of the respective muscles were not detected(p>.05) (Table 3).

Table 3. The comparison of muscle activations according to the width of the BOS

<table>
<thead>
<tr>
<th></th>
<th>10cm</th>
<th>32cm</th>
<th>45cm</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis anterior</td>
<td>0.0809 ± 0.0232</td>
<td>0.0697 ± 0.0211</td>
<td>0.0697 ± 0.0211</td>
<td>0.320</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>0.0706 ± 0.0225</td>
<td>0.0766 ± 0.0279</td>
<td>0.0766 ± 0.0279</td>
<td>0.755</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>0.0368 ± 0.0156</td>
<td>0.0367 ± 0.0165</td>
<td>0.0367 ± 0.0165</td>
<td>0.168</td>
</tr>
<tr>
<td>Erector spineae</td>
<td>0.0654 ± 0.0282</td>
<td>0.0642 ± 0.0293</td>
<td>0.0642 ± 0.0293</td>
<td>0.803</td>
</tr>
</tbody>
</table>

Table 4. The comparison of the angle changes of hip and knee joints according to the width of the BOS

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip joint angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between groups</td>
<td>225,425</td>
<td>2</td>
<td>112,713</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within groups</td>
<td>7911,786</td>
<td>87</td>
<td>90,940</td>
<td>1.239</td>
<td>.295</td>
</tr>
<tr>
<td>Total</td>
<td>8137,211</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee joint angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between groups</td>
<td>233,001</td>
<td>2</td>
<td>116,501</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within groups</td>
<td>10352.472</td>
<td>87</td>
<td>118,994</td>
<td>.979</td>
<td>.380</td>
</tr>
<tr>
<td>Total</td>
<td>10585.473</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Comparison of the Angle Changes of Hip and Knee Joints according the Width Variation of the BOS

Hip joints were defined as the angles connecting the ASIS, great trochanter, and the apex of fibular head on each side of the subject’s body. Knee joints were defined as the angles connecting the great trochanter, apex of fibular head, and lateral malleolus on each side. According to the comparison, no statistically significant differences were exhibited in the angle changes between hip joints and knee joints by the width variation of the BOS(p > .05)(Table 4).

Movements of the Pelvis according to the Width Variation of the BOS

The right–left sways of the virtual dots didn’t exhibit statistically significant differences according to the width variation of the BOS(p > .05)(Table 5).

Table 5. Movements of the pelvis according to the width of the BOS (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>10cm</th>
<th>32cm</th>
<th>45cm</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movements of the pelvis</td>
<td>309,708 ± 20,181</td>
<td>302,336 ± 18,072</td>
<td>318,9615 ± 112,280</td>
<td>.628</td>
</tr>
</tbody>
</table>

Subjective Discomfort Levels according to the Width Variation of the BOS

In terms of subjective discomfort levels according to the widths of the BOS, the subjects felt the highest discomfort in 10cm and the highest comfort in 32cm, there was significant difference(p < .05)(Table 6). While 45cm, the largest width given in the experiment, was revealed to be the second most uncomfortable width, no statistically significant differences were detected between 32cm and 45cm(p > .05).

Table 6. Subjective discomfort levels according to the width of the BOS (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>10cm</th>
<th>32cm</th>
<th>45cm</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective discomfort levels</td>
<td>6,8667 ± 1.925</td>
<td>4,4333 ± 2.157</td>
<td>4,6667 ± 2.123</td>
<td>.000*</td>
</tr>
</tbody>
</table>

*: p < .05

DISCUSSION

The purpose of this study was to examine which width of the BOS is safer and more effective in the movement of lifting by comparing muscle activations and body sways according to different widths of the BOS when lifting objects. In order to minimize individual differences in movement strategies, somewhat controlled movements, in terms of the time allowance of one minute and the distances between the feet, were required to the subjects. In addition, given that a number of researches have focused their experiments on symmetric exercises(12, 19, 20), this study applied symmetric exercises as well.

According to this study, no statistically significant differences were observed when comparing the muscle activations of trunk muscles and lower extremity muscles according to the width variation of the BOS. Such results differ from those of the study by Yoon et al(2), which suggest that the widths of the BOS result in statistically significant differences in the muscle activation of lower extremities while doing upper extremity exercises. Again, such results are in conflict with Kollmitzer’s findings(21) that a larger width of the BOS resulted in a corresponding decline in muscle activation.

In addition, when virtual dots(by connecting the ASIS on each side and the vertebra) were defined and body sways were measured according to different widths of the BOS, the second largest width, 32cm, showed the least sways, but with no statistical significance.

In measuring the subjective discomfort levels for lifting, 32cm, the second largest width in the experiment, was revealed to be most comfortable. The participants noted that the narrowest BOS felt most uncomfortable. In fact, this is in accordance with the results of some existing researches where a larger width of the BOS resulted in a corresponding rise in the stability of posture, and thus, a decline in muscles usage(6).
In addition, the results that the subjects felt more comfortable with 32cm than 45cm, the largest width given, may support Holbien’s study findings that functionally stable widths of the BOS lie within a statistically narrower range than generally assumed large widths of the BOS.

Limitations of this study include the facts that the experiment site differed from actual industrial sites, as well as the subjects couldn’t make the most natural and functional movements since they were requested for somewhat controlled movements.

In order to prevent musculoskeletal system disorders in industrial sites, further research results may be needed on the subject of taking down, or pushing or pulling objects according to the width variation of the BOS.

**CONCLUSION**

This study, using a three dimensional motion analysis system and EMG, carried out experiments to evaluate the angle changes of hip and knee joints, variations of muscle activation, and degrees of body sways using virtual dots according to the width variation of the BOS. In conclusion, no statistically significant differences according to the width variation were observed(p>.05). However, a statistically significant difference was exhibited between the Borg’s scale, which indicates performance discomfort levels, and the width of the BOS(p<.05).

**REFERENCES**