Effects of Wearing a Backpack on Trunk-Lower Limb Kinematics at Start of Gait

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Abstract. [Purpose] The purpose of the present study was to analyze the effect of backpack heaviness on trunk-lower limb kinematics at the start of gait. [Subjects] Ten university male students (age=20.3 ± 0.98 years, height=1.69 ± 0.04 m, weight =59.5 ± 5.3 kg) participated in the present study. [Methods] Each subject was asked to stand erect then walk forward in a straight line in four modes: unloaded, and with loads of 10%, 15%, and 20% body weight (BW). A VICON 250 motion analysis system was utilized to study changes in the trunk and lower limb kinematics at the start of gait. [Results] The results show significant trunk backward lean changes between the unloaded mode and loaded modes even with no changes in the center of mass (COM), velocity or displacement. [Conclusion] A 20%BW backpack caused the highest trunk kinematic changes, so backpack weight should be limited to 15%BW. It is also important to be aware of other factors correlated to backpack usage to provide better usage recommendations.

Key words: Backpack, Trunk-lower limbs movement, Centre of mass

INTRODUCTION

Using a backpack is one of the most common ways to carry loads. Students, hikers, and many people in general use them to carry items from place to place1–3). Even though backpacks are very convenient tools, optimum usage without safety and health risk has always been an issue4). Many organizations are interested in knowing the level of safety backpack use and what the satisfactory weight limit is5).

Previous studies correlated the incidences of low back pain and other musculoskeletal injuries with carrying backpacks, especially in adolescents and children2,3,6,7). Skaggs et al. reported a significant association between the backpack weight and the occurrence of back pain in adolescent students8).

Other researchers showed interest in muscular activation and postural changes9–12). RREE Motamans et al. stated that EMG records during backpack carrying show significantly higher and asymmetrical rectus abdominis activity (right 199%, left 154%), but lower and symmetrical erector spinae activity (right 72%, left 77%) while standing13).

Despite evidence linking backpack loads with low back pain and other musculoskeletal problems, few experimental studies have been performed to investigate physiological or mechanical backpack effects on the human body. Also, to the best of our knowledge, no former studies have examined the effects of wearing a backpack during the state transition from standing to walking, even though some researchers have suggested that wearing a
backpack could decrease the pedestrian safety of adults\cite{14}. This is the first research study of backpack load effects on the trunk and lower limbs at the start of gait.

In this study, gait start is identified as the period of transition from the static status of standing to the dynamic status of walking. The purpose of the present study was to analyze the effect of backpack heaviness on trunk-lower limb kinematics at gait start. Load of 10\%, 15\%, and 20\% body weight (BW) for the backpack weight were used to clarify the kinematic changes and compare them with an unloaded gait start. A VICON motion analysis system was utilized to record the kinematics of centre of mass (COM) displacement, COM velocity, and trunk-lower limb joint movements. Biomechanical changes due to wearing a backpack were compared with the unloaded mode, i.e. 0\%BW mode, at gait start. It was hypothesized that wearing different backpack loads would lead to significant changes in trunk-lower limb biomechanics.

**METHODS**

Experimental approval was obtained from the board of Kobe University. In the current study, ten university male students (age=20.3 ± 0.98 y, height=1.69 ± 0.04 m, weight=59.5 ± 5.3 kg, BMI=20.82 ± 1.36) were recruited. The subjects were healthy and did not complain of any medical illnesses. Also, a physical therapist examined them for postural deformities or malalignments. All subjects received an explanation of the study and signed consent forms before participating in the research experiment. Subjects had the right to withdraw from the experiment at any time.

Each subject was asked to stand erect with extended knees and walk forward in a straight line at his natural speed for four meters. To keep the head orientated forward, subjects were asked to focus on a white sign at the sight level five meters ahead. Subjects performed the experimental task in four modes: unloaded (0\%), and with loads of 10\%, 15\%, and 20\% BW. Each subject performed all modes on the same day in random order. The load was a non-framed backpack. The same backpack was used for all subjects in all experimental modes. The backpack was filled with sand bags matching the desired body weight percentage. The sand bags were positioned to match the level of 12\textsuperscript{th} thoracic (T12) and 1\textsuperscript{st} lumbar (L1) vertebrae.

Each subject performed 8 trials, 2 trials per mode. Kinematic data were collected during all trials using a VICON motion analysis system. Collected data were recorded for 2 seconds followed by 15 seconds of initial standing and by 1 minute rest to avoid cumulative fatigue. As already described, gait start was defined as the period of transition from the static status of standing to the dynamic status of walking. In order to measure more specific changes, gait start was divided into 3 consecutive phases: the Static phase, Pre-walking phase, and First-step phase.

a. Static phase: in this phase, the subject stood in a static posture with no dynamic changes. The Static phase ends in a positive change in COM forward velocity and eventual forward displacement. This phase had a duration of approx. 0.4 seconds.

b. The Pre-walk phase started immediately after the end of the Static phase and was identified by positive COM forward velocity. In this phase, the subject prepared himself to take his first step causing dynamic mechanical changes. The Pre-walk phase ended with the right foot toe-off.

c. The First-step phase started at the end of the Pre-walk phase with right toe-off. Dynamic kinematics changes occurred during this phase. The First-step phase ended with right foot heel-strike.

A VICON 250 motion analysis system (Oxford Metrics Group, Oxford, UK) was utilized to study the changes in the trunk and lower limb kinematics during the gait start period\cite{15-17}. The studied kinematic measurements were COM displacement, COM velocity, trunk and lower limb joint movements (trunk forward-backward bending, trunk side bending, trunk rotation, hip flexion-extension, hip abduction-adduction, knee flexion-extension, and ankle dorsi-plantar flexion). The VICON 250 has 2 Kistler force platforms and five cameras which can locate reflective markers in three-dimensional co-ordinate space. VICON cameras have 300,000 pixel resolution and sample frames at 60 Hz. VICON reflective skin markers are 25 millimeters in diameter and are placed on external body sites. In this study, the reflective markers were placed on each subject’s sacrum, bilateral acromion processes, elbow lateral epicondyle, radius styloid process, one third the distance from the anterior superior iliac spine and the femur greater trochanter, knee joint lateral
aspect, calcaneus and forefoot. To calculate the COM position, COM displacement and trunk-lower limb joint movements, the equations and procedures described by Winter DA were utilized \(^{18}\). Diff Gait and Wave Eyes software programs were used to analyze VICON 250’s collected raw data.

COM displacement, COM velocity, and trunk-lower limb joint movements (trunk forward-backward bending, trunk side bending, trunk rotation, hip flexion-extension, hip abduction-adduction, knee flexion-extension, and ankle dorsiplantar flexion) mean and standard deviation were calculated for all modes (unloaded, 10%, 15%, and 20% BW modes). Repeated ANOVA was used to analyze trunk-lower limb kinematics changes in all modes. To identify the main significant effect, the IC Tukey Kramer test was utilized to derive the specific mean differences. Results were considered significant at \(p<0.05\).

**RESULTS**

Fig. 1, Table 1 and Table 2 elaborate the results. In Table 2 positive values are used for trunk forward bending, trunk right side bending, and trunk right rotation, and conversely negative values are used for trunk backward bending, trunk left side bending, and trunk left rotation.

Subjects had very similar body characteristics. All subjects started walking from the right side, and there was no significant difference in walking velocity or step length among subjects (Table 1).

No significant changes were found in COM displacement or velocity between the different modes (Fig. 1, Table 1). COM continued to have similar displacement and velocity even when the load changed to 10%, 15%, and 20% BW.

The VICON motion analysis system showed significant trunk backward bending changes.

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**Table 1.** Subjects Average COM Velocity and Step length

<table>
<thead>
<tr>
<th></th>
<th>COM Velocity (m/s)</th>
<th>Step length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unloaded</td>
<td>10%BW</td>
</tr>
<tr>
<td>Subjects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.68</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>±0.08</td>
<td>±0.09</td>
</tr>
</tbody>
</table>

**Table 2.** Average Trunk angles during the Static, Pre-walk, and First-step phases

<table>
<thead>
<tr>
<th></th>
<th>Static phase average angles (°)</th>
<th>Pre-walk phase average angles (°)</th>
<th>First-step phase average angles (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%BW</td>
<td>10%BW</td>
<td>15%BW</td>
</tr>
<tr>
<td>Trunk Forward-backward bending</td>
<td>4.71</td>
<td>0.089*</td>
<td>1.702*</td>
</tr>
<tr>
<td></td>
<td>±0.143</td>
<td>±0.119</td>
<td>±0.186</td>
</tr>
<tr>
<td>Trunk Side bending</td>
<td>-0.37</td>
<td>-0.441</td>
<td>-0.076</td>
</tr>
<tr>
<td></td>
<td>±0.104</td>
<td>±0.076</td>
<td>±0.099</td>
</tr>
<tr>
<td>Trunk Rotation</td>
<td>-0.639</td>
<td>-0.774</td>
<td>-1.826</td>
</tr>
<tr>
<td></td>
<td>±0.119</td>
<td>±0.155</td>
<td>±0.137</td>
</tr>
</tbody>
</table>

* \(p<0.05\)
between the unloaded mode (0%BW) and the loaded modes (10%, 15%, 20%BW) in the Static phase (p<0.012), Pre-walking phase (p=0.012) and First-step phase (p<0.034) (Table 2). In the Static phase the average trunk forward-backward bending angles were 0%BW=4.71°, 10%BW=0.089°, 15%BW=1.70°, 20%BW=0.80°, while in the Pre-walk phase they were 0%BW=3.14°, 10%BW=−0.98°, 15%BW=−0.036°, 20%BW=−1.26°. All average trunk bending angles were backward during the first-step phase: 0%BW=−0.60°, 10%BW=−3.57°, 15%BW=−3.71°, 20%BW=−4.58°. It was also noticed that significant changes were found only between the loaded modes and the unloaded mode, but no significant changes were found among the loaded modes of 10%BW, 15%BW, and 20%BW. Also there were no significant changes in the trunk side bending or rotation between the loaded modes and the unloaded mode in all the phases (Table 2).

There were no significant changes in hip, knee, or ankle angular changes among the modes. Lower limb movements were similar during all phases even with change of load.

DISCUSSION

As described in the results, changes in backpack load did not cause significant effects on subjects’ walking velocity and step length. These results were expected as similar results were found by previous researchers19–22). Hong Y and Cheng C (2003), considered load carrying as an abnormal condition of human walking, and hypothesized that it would affect gait pattern. However, their results didn’t support their hypothesis20). In the present study, the subjects could adapt to the changes in backpack load because the subjects were given the choice to walk at their own natural walking pace and style.

Figure 1 shows almost the same COM path was taken during all modes. It was expected that changes in backpack load would lead to different COM position and displacement. Goh J-H et al. (1998) reported that a backpack load of 30% BW displaced COM mildly upward and backward compared to the unloaded condition. They also reported that this particular COM displacement is compensated by trunk postural changes19). This lack of change in COM displacement proves subject awareness of the extra load added to their bodies. Therefore, each subject would like to resist the change by adopting new strategies at gait start, leading to stabilized temporal parameters and COM displacement.

During all load modes (10%, 15%, and 20%BW) and gait start phases (Static, Pre-walking, and First step), the trunk showed a trend of small but significant and constant angular backward bending.

In the Static phase, the backward inclination angular changes were 4.71°, 0.089°, 1.70°, and 0.80° during 0%, 10%, 15%, and 20% BW respectively. Singh T and Koh M (2008) reported similar results as they found that wearing a 10%BW backpack led to trunk backward lean23). However, in contrast to the results of the present study, they emphasized that 15% and 20%BW backpacks cause trunk forward lean. They also considered that wearing a backpack with upper trunk orientation (above T8-9 level) would result in greater forward lean. Their result agrees with the current study in which the backpack was positioned at the level of T12-L1, leading to more backward lean. In another study, it was reported that 10%, 15%, and 20%BW backpack loads led to significant increases in trunk backward inclination and bilateral EMG activities of the rectus abdominis24).

Another point is that the average backward bending between the unloaded mode (0%BW) and all load modes were significant, but not among the loaded modes (10%,15%, 20%BW). The small angular differences among the loaded modes indicate that the subjects used the same adaptation mechanism for different loads even though it was reported that abdominal muscle activity increases with increase of backpack heaviness24).

As subjects proceeded to the Pre-walking and First-step phases, the backward angular lean of the Static phase was adopted almost without change. The average trunk forward-backward movements in the Pre-walk and First-step phases respectively were 3.14°/−0.60° for 0%BW, −0.98°/−3.57° for 10%BW, −0.036°/−3.71° for 15%BW, and −1.26°/−4.58° for 20%BW. Goh J-H et al. suggested subjects would adopt compensatory trunk flexion while carrying backpack loads19). However, their data collection occurred during walking, not standing or the gait start periods, and subjects were wearing heavier backpacks (30%BW) with higher backpack orientation. These differences in research conditions and environment may contribute to the differences in the results. Singh T et al. emphasized that trunk adaptation posture will differ during
dynamic conditions compared with the static condition when wearing backpack\textsuperscript{25}).

Excluding backward inclination angular changes, both trunk side bending and rotation were unaffected by the backpack load (Table 2). Similar results were reported by other researchers\textsuperscript{3,11,24,25}). The weight of the backpack was centered in the mid region of the trunk in order not to load one side more than the other side. Therefore, changes in the trunk side bending or rotation were not expected even with the heaviest load of the 20% BW backpack.

As there were no changes in the walking speed and step length between the loaded and unloaded modes, we predicted that there would be no significant differences in the lower limb joint movement data as well. Most research about backpack effect on human biomechanics have studied the trunk biomechanics and only few have investigated lower limb biomechanics\textsuperscript{26–28}). Considering the location of the backpack load, the direct effect of the backpack manifests itself on the trunk biomechanics and the indirect effect might affect the lower limb biomechanics. There is also a lack of reported lower limb injuries and disorders correlated with backpack usage\textsuperscript{6–20}).

In the present study, no significant effect of the backpack load was noticed on gait velocity, step length or COM displacement, but significant changes were found in the trunk sagittal plane backward-forward bending movement in all the gait start phases. A 20%BW backpack caused the highest trunk kinematic changes, so backpack weight should be limited to 15%BW. It is also important to be aware of other factors correlated to backpack usage such as gender, fatigue level, and daily walking distance to provide better usage recommendations.

\textbf{REFERENCES}