Ground Reaction Force During Walking with and Without Counterbalance Load System

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Abstract: The purpose of this study was to determine the ground reaction force (GRF) during walking with and without counterbalance load system. Peak GRF was recorded with force plate while walking with different conditions on the treadmill. Twenty-six students (age was 22.41±1.75 years) attended three test sections in three days apart. Participants after 10 min warm up walked 10 min on the treadmill without any backpack in the first day. On the second day they walked 10 min with normal backpack, and on third day they walked 10 min with counterbalance load backpack. Force peak measured during three conditions of walking. A one way analysis of variance (ANOVA) was conducted for the force peaks variable, to confirm the significant difference between walking with different conditions. If statistical significance was found a between conditions a Tukey post-hoc test was used to examine where the differences exist within the conditions, where applicable. The results of current study showed significant difference in GRF after walking in three condition with p<.05. Within group analysis showed significant difference in GRF after walking with normal backpack and without backpack. In fact the normal backpack load significantly increased GRF when walking on the treadmill. The results also showed that there is no significant difference among GRF between unloaded walking and counterbalance backpack. Findings of current study clearly show the advantage of a counterbalance system for carrying the loads. In addition to these, the reduction of forces is a considerable kinematic and ergonomic benefit of carrying load in such backpacks.

Key word: backpack, injury, ground reaction force.

INTRODUCTION

Students, military personnel, and athletes use various types of backpacks, and while carrying them in various ways they make adjustments to their posture to accommodate the load they are carrying. While the harmful effects of carrying heavy backpack loads have been realized and identified, what is important pertains to the potential long and short term health effects on adolescents who continue carrying backpacks (Goh, et al., 1998). There are various types of backpacks designed for different load capacities but most of them can be worn without discomfort. Also they are designed for various specific purposes, ranging from general load carriage to use by military personnel, hikers and others. Investigations by various researchers have revealed that the size of the external load determines the extent of the forces experienced by the wearer’s joints (Kuster, et al., 1995; Simonsen, et al., 1997).

Analysis human walking has shown that, one leg serves as a support and the other leg moves forward to a new support site, and then, the two legs alternatively reverse their roles. Since walking is a repetitious sequence of body motion, the gait cycle is defined as the time interval between two successive occurrences of one of the repetitive events (Whittle, 2002). Roughly, one gait cycle comprise of two periods: stance phase and swing phase. In one gait cycle, the stance phase lasts about 60 percent of the cycle, and the swing phase is about 40 percent (Murray, et al., 1964). However, the duration of these phases of gate intervals varies and has an inverse relationship with the walking velocity (Andriacchi, et al., 1977). Accordingly, during the swing phase only one foot has contact with ground and this is the period of single support. As opposed to running, in walking, at least one foot is in contact with the ground to transfer body weight from one foot to the other. During running, the double support phase disappears, and between steps there is a flight phase.

Hsiang and Chang (2002), studied the effect of gait speed and load carrying condition on the reliability of ground reaction forces. Fifteen subjects experienced three walking speeds and five loading conditions (no-load, backpack, front-back double pack, front-pack, and two-hand carrying). The results of their study indicated that adding load to various parts of the body and increasing walking speed increased the magnitude of weight acceptance and push-off magnitude. The load also significantly increased weight acceptance rate and push-off rate, regardless of the location of the load. The authors concluded that higher walking speeds and loading conditions that moved the center of gravity from its common position had an adverse effect on the variability and the reliability of the gait pattern. This could be reflected in the higher moments of the distributions of several kinetic variables.
The basic task of walking involves motion in all three directions. Ground reaction force characteristics reflect the acceleration patterns of the center of gravity of a person and describe the mechanics of walking gait (Murray, et al., 1964). Hreljac et al., (2000), Birrell, et al., (2007); Hong and Li., (2005) demonstrated that the primary biomechanical variable that distinguishes injured from non injured walkers and runners is magnitude of the peak force. Other studies also indicated that high forces can be increased the occurrence of injury. However, while there has been comprehensive research done by many researchers on the correlation of load and walking, there has been little done on the comparison of ground reaction forces during walking with different conditions of backpacking load. So this research intends to investigate and compare ground reaction force during walking with and without counterbalance loading system.

Methods:

Subjects:

Twenty six (26) healthy male university students participated in this investigation. The mean age was 22.41±1.75 years, height 178 ±4.83 cm, weight 75±6.56 kg, and BMI 23.71±1.44 kg/m². Subjects completed a health history questionnaire and signed a consent form. They were verbally informed about the experimental procedure and applied methods. Subjects were briefed on the use of backpack on a treadmill with different conditions of walking before participating in any testing. They were instructed to wear the same shoes for each trial, and to wear the shoes in which they would normally walk. Simple random sampling as explained above was used in this study.

Instrumentations:

Motion analysis was used for analysis of kinematic data, and light-emitting diodes were positioned on the right side of each subject on the four anatomical landmarks. Normal backpack was used in this investigation with approx 1.5 kg (AARN, USA). New backpack with its pockets at the front with approx weight 1.75 kg (counterbalance loading backpack, AARN USA) (Figure 2), and by force platform were mounted to the treadmill as shown in Figure 1 (Gottschall and Kram, 2005).

Fig. 1: Force measuring treadmill.

Experimental Procedure and Data Collection:

Ground reaction force is measured by a force platform mounted on treadmill. It is constructed with three sets of aluminum wedges to tilt the force treadmill (Gottschall and Kram, 2005). The base of each wedge is bolted to the mounting plate. Then, the force transducer box is bolted at each corner of the force platform to the corresponding wedge. Lastly, the treadmill is bolted to the force platform (see Figure 1).

Before to collected walking data, would be rapped the treadmill to determine that the unloaded natural frequencies of the force treadmill in the normal and parallel directions would be adequate. Participants walked 1.5 m/s on the force treadmill mounted on the level. Each participant completed experimental sessions on three different days. The order of the sessions would be randomized for each subject. During each session, the subjects completed a warm-up run for 5 min on a level Quinton 18–60 treadmill and 5 min static stretching. They walked on the force treadmill on the level, for 10 minute. Data were collected during the last 10 seconds of each trial.
Fig. 2: Normal (a), and Counterbalance (b) loading backpack.

With no subject on the treadmill the motor operated at a belt speed of 1.5 m/s and force data were collected. It filtered the GRF data using a zero phase-shift, fourth-order recursive, Butterworth low-pass filter with a cutoff frequency of 70 Hz, followed by a notch filter, with a band stop range of 40–50 Hz. Next, filtered GRF data were adjusted. Lastly, foot strike would be determined by a positive change in the normal GRF which is greater than 1000 N/s, occurring while the force is below a threshold of 100 N. Foot strike pattern, rear-foot versus midfoot will be determined by the analysis of the normal GRF data and visual observation.

Data Analysis:
A one way analysis of variance (ANOVA) in SPSS was conducted for the force peaks variable, to confirm the significant difference between walking with different conditions. A significance level of p<.05 was considered statistically significant for this analysis. As statistical significance was found between conditions, a post-hoc Tukey test was used to examine existing differences within the conditions.

Results:
The descriptive results of force peaks, demonstrated in Table 1 the Mean of peak of force data after different conditions are illustrated in Figure 3. In addition, results of ANOVA are illustrated in Table 2. Significant level force peaks during walking without backpack, normal and counterbalance backpack demonstrated in Table 3.

| Table 1: Mean (± SD) for force peaks after walking with different conditions. |
|-----------------|------|------------|-----------|
| Source          | N    | Mean       | Std. Deviation |
| force peaks (BW)|      |            |             |
| Without Backpack| 26   | 1.149      | .009       |
| Normal Backpack | 26   | 1.224      | .030       |
| Counterbalance Backpack | 26   | 1.159      | .012       |
| Total           | 78   | 1.177      | .038       |

Based on ANOVA Table between group analysis F(2,75) =112.684 showed significant difference in force peaks after walking in three condition with p<.05 (Table 2).

| Table 2: One-way ANOVA analyses on force peaks during walking. |
|-----------------------------|-------|---------|-----------|-----------|
| Source                      | Sum of Squares | df   | Mean Square | F        | Sig.   |
| force peaks (BW)            | Between Groups | .085 | 2        | .043 | 112.684 | .000   |
|                            | Within Groups   | .028 | 75       | .000 |         |        |
|                            | Total            | .114 | 77       |       |         |        |

Within group analysis showed significant difference in force peaks after walking with Normal backpack (1.224 ± .03) and walking without backpack (1.149 ± .009), and also there is significant difference in force peaks between walking with normal backpack and counterbalance backpack (1.159 ± .012). Within group analysis indicated that there is no significant difference between unloaded walking and walking with counterbalance backpack with p<.195 (Tables 3, Figure 3).
Table 3: Significant level force peaks during walking without backpack, normal and counterbalance backpack.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>(I) Condition</th>
<th>(J) Condition</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>force peaks (BW)</td>
<td>without Backpack</td>
<td>Normal Backpack</td>
<td>-.074 *</td>
<td>.005</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Normal Backpack</td>
<td>Counterbalance Backpack</td>
<td>.009</td>
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<td></td>
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<td>without Backpack</td>
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<tr>
<td></td>
<td>Counterbalance Backpack</td>
<td>Counterbalance Backpack</td>
<td>.065 *</td>
<td>.005</td>
<td>.000</td>
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<tr>
<td></td>
<td>Counterbalance Backpack</td>
<td>Normal Backpack</td>
<td>-.009</td>
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</tr>
<tr>
<td></td>
<td>Normal Backpack</td>
<td>-.065 *</td>
<td>.005</td>
<td>.000</td>
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</table>

*. The mean difference is significant at the .05 level

Figure 3 also indicated that the greatest force was for normal backpack condition (M= 1.149), less for walking with counterbalance backpack condition (M= 1.159) and least for unloaded walking condition (M= 1.224).

![Fig. 3: Mean and SD of force peaks after different conditions.](image)

**Discussion:**

As we hypothesized, peak of GRF was much larger in the backpack users vs. unloaded subjects and was substantially reduced by walking without any backpack. Our GRF results are similar to Messier, et al., (1996) results. According to results the greatest force was for loading response phases of walking for all three conditions. The lowest force was for initial contact phases of walking for all conditions. There are significant differences between GRF during walking for three conditions in initial contact and terminal stance phases. The results of current study also indicated that there is significant difference between GRF at loading response and mid stance phases for normal backpack condition and another conditions. In the loading and mid stance phases were not find significant difference on GRF for counterbalance backpack condition and unloaded walking. The results of force peaks indicated that there is much difference between a normal backpack and counterbalance backpack in the loading response phase. Also were fined there is not much difference between counterbalance backpack and unloaded walking. Whilst the counterbalance produced smaller forces than normal backpack in the loading phase, closer to that of walking without backpack condition. Based on the results for peak of GRF, 6.52 percent increase was seen for normal backpack as a compare with unloaded walking. Increase for counterbalance backpack from without backpack was 0.87 percent. This increase was not statistically significant.

The force peak data suggest that the probability for musculoskeletal injury increases during walking with normal backpack and decreases during walking with counterbalance backpack and unloaded walking (Hreljac, et al., 2000). demonstrated that the primary biomechanical variable that distinguishes injured from never injured runners is magnitude of the impact peak force. The results of this study were in agreement with previous studies by (Birrell, et al., 2007; Hong and Li, 2005). Other studies also indicated that high impact forces can be increased the occurrence of injury (Birrell, et al., 2007; Gottschall and Kram, 2005; Hreljac, et al., 2000). Increasing the forces during carriage a load can be moderated by increasing the knee flexion angle while walking with backpack, but such changes are metabolically costly (Derrick, et al., 1998). Another option can be purported to reduce impact forces is athletic footwear. Increasing carried load has a significant overall effect on the total of GRF and peak of GRF measured. An increase in load (adding a backpack with 20% of body weight) has been demonstrated to increase GRF consistently within the literature (Birrell, et al., 2007; Harman, 2000; Lloyd and Cooke, 2000).
Conclusion:

According to finding in this study, carrying the load with counterbalance backpack allows a more upward position, by shifting the center of gravity of the load forward. This posture modification resulted in a better comfort expressed by the majority of the researches. The better comfort could be explained by less force to the knee and ankle to compensate the load located in the back of the backpack user. Counterbalance backpack allows load to distributed between front and back of the trunk is more appropriate for carrying relatively loads than a carrying a load with normal backpack. Findings obviously show the advantage of a counterbalance backpack for carrying the loads. In addition the reduction of GRF is a considerable kinematic and ergonomic benefit of carrying load in such backpacks.

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REFERENCES


