



Understanding the Effects of Selected Backpack Loads Carried for Certain Durations on Peak Forces of Walking Gait in School-Going Boys

Rabiya Husain^{1ABCDE}, Dessalegn Wase Mola^{2ABCDE} and Dhananjay Shaw^{1ABCDE}

¹University of Delhi

²Ambo University

Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

DOI: 10.17309/jltm.2024.5.3.08

Abstract

Background. Backpacks are commonly used by students to carry their school items. However, increasing backpack loads can lead to negative effects on health and posture, particularly through changes in gait dynamics. Peak forces are a critical variable in understanding gait mechanics, which is significantly impacted by carrying loads. Therefore, it is crucial to investigate the changes in peak forces with varying (increasing) backpack loads and the durations of carrying.

Objectives. The study aimed to examine the effect of various backpack loads, carried for different durations, on the forces at first and second peaks of the left and right foot during a walking gait cycle in school-going boys.

Materials and methods. The subjects ($n = 85$) between the age of 10 to 12 years, were randomly selected from Delhi NCR. The force at first and second peaks was measured using a ZebrisInc pressure platform supported by Win FDM-S software (Germany). Five backpack load conditions were analysed, namely, B1 = backpack load of 0 % of body weight (no additional weight in the backpack); B2 = backpack load of 8% of body weight; B3 = backpack load of 12 % of body weight; B4 = backpack load of 16 % of body weight; and B5 = backpack load of 20 % of body weight, at five following recording time, T1 = recording at zero minute of walking; T2 = recording at fifth minute of walking; T3 = recording at tenth minute of walking; T4 = recording at fifteenth minute of walking; T5 = recording at twentieth minute of walking. Statistical analyses included an assessment of the mean, standard deviation, coefficient of variation, and t-ratio. The significance level for the t-test was 0.05.

Results. The results indicated that increasing backpack loads led to higher peak forces at both the first and second peaks of the gait cycle. The right foot exhibited elevated forces at the first peak, while the left foot showed dominance at the second peak. Furthermore, prolonged load carriage was also found to increase peak forces. A paired sample t-test revealed significant differences between the first and second peaks, with a mean difference of -14.402 N ($p = 0.002$) for the first peak and 4.860 N ($p = 0.001$) for the second peak.

Conclusion. The study concluded that higher backpack loads significantly increased the mean of peak forces in walking gait, which may result in postural imbalances and gait asymmetry. These findings suggest a need for regulating backpack loads to prevent potential musculoskeletal issues in children.

Keywords: backpack, first peak, force, gait cycle, load carriage, second peak, walking gait.

Introduction

Backpacks are the most common means for school students to carry their belongings, as they are positioned close to the body's center of gravity, providing stability during movement (Pascoe et al., 1997; Sheir-Neiss et al., 2003). While carrying a backpack may reduce biomechanical demands due to this optimal positioning, an increase in load significantly raises the energy expenditure required for transport (Castro

et al., 2013; Pau et al., 2015). However, the drawback of using backpacks is that excessive loads can have harmful effects on the body (Knapik et al., 1996; Knapik et al., 2004). Studies have shown that carrying heavy backpacks over extended periods can lead to a range of negative consequences, including altered gait pattern, shoulder pain, fatigue, redness, swelling, back pain, and foot blisters. Moreover, it increases the risk of musculoskeletal injuries such as kyphosis, lordosis, and shoulder drop, among others (Macias et al., 2008; Son, 2013; Song et al., 2014; Castro et al., 2015; Perrone et al., 2018; Sokhi et al., 2022).

In a normal gait cycle, the ground reaction force should equal the individual's body weight (Drerup et al., 2008). However, abnormal gait patterns, such as those induced by carrying heavy loads, can lead to improper distribution of forces and pressure on the feet (Kellis, 2001; Rai & Aggarwal, 2006). Several studies have reported changes in ground reaction force, plantar pressure (Kasović et al., 2018), and gait patterns during load-bearing walking (Ahmad & Barbosa, 2019). It has been observed that students exhibit slower cadence and reduced walking speed when carrying heavy backpacks, with force and pressure time integrals increasing proportionally with the load (Ahmad & Barbosa, 2019). Additionally, when school children carry backpacks exceeding 10 percent –15 percent of their body weight, they experience decreased lung volumes and exhibit compensatory postural and gait changes, such as forward leaning of the upper body and head lowering (Lai & Jones, 2001; Mosaad & Abdel-Aziem, 2015; Vieira & Ribeiro, 2015; Chen et al., 2018). In a gait cycle there are two peaks, namely, first peak and second peak (refer Figure 1).

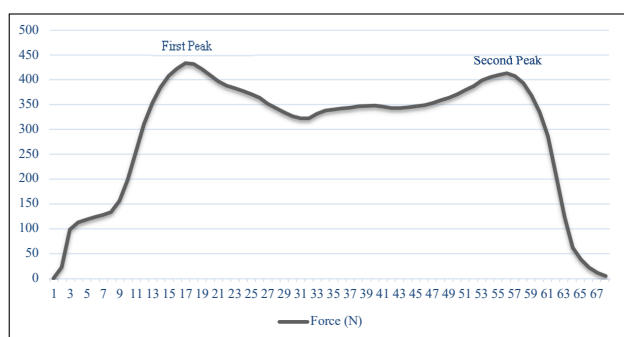


Fig. 1. Phases of first and second peaks in a gait cycle

The first peak occurs during the loading response phase, just after the heel touches the ground. This peak shows the body's ability to absorb impact as the weight shifts to the leading leg. The force at this point is mainly passive, helping the body stabilize under the load, and it can increase with extra weight, like carrying a backpack (Hong & Bartlett, 2008; Richards et al., 2013).

The second peak happens during the propulsion phase, right before toe-off. This is an active force where the plantar flexor muscles push the body forward (Neptune & Sasaki, 2005). Although the second peak is often smaller than the first, it is essential for moving efficiently and keeping momentum (Neptune & Sasaki, 2005; Richards et al., 2013). Any imbalance between these forces, especially from carrying heavy loads, can affect walking patterns and raise the risk of injury (Perry & Burnfield, 2010; Ahmad & Barbosa, 2019).

There are several determinants of plantar pressure, with peak force being a critical variable (Menz & Morris, 2006). Despite the increasing literature, there is limited research focusing on the specific impact of different backpack loads carried over varying durations on forces at different peak phases of the gait cycle. The current study aims to address this gap by examining the effects of varying (increasing) backpack loads carried over selected durations on force at first peak and second peak during walking in school going boys. The findings will contribute to a better understanding of how

backpack loads influence foot biomechanics and offer insights for reducing the negative effects of heavy backpacks in school children.

Material and Methods

Study Design

The research aimed to observe and analyse the forces at different (first and second) peaks during backpack load carriage at different load percentage of body weight in a gait cycle. The study utilized a repeated measures experimental design, in which all participants were exposed to five different levels of backpack loads, namely, backpack load of 0% (no additional weight in backpack) of the bodyweight, backpack load of 8% of the bodyweight, backpack load of 12% of the bodyweight, backpack load of 16% of the bodyweight, and backpack load of 20% of the bodyweight. Data collection occurred at five specific time intervals during backpack carriage, that is, at the starting of the test (zero minute), and then at the fifth minute, tenth minute, fifteenth minute, and twentieth minute of walking. This 5x5 within-group design allowed for repeated measures across both the varying loads and the different durations.

Subjects

Eighty-five male school-going students from Delhi NCR, aged 10 to 12 years, were randomly selected for this study. Ethical approval was granted by the Board of Research Studies at the University of Delhi (Ref No: DPE/2023/2345). The study adhered to strict ethical guidelines, ensuring voluntary participation, confidentiality, and the right to withdraw at any time. Participants who did not meet the age or health criteria, or who withdrew during the study, were excluded.

Instruments

The portable pressure measurement platform from ZebrisInc; Germany (40x30 cm), supported with Win FDM-S software (Germany) was used for collecting data over five trails for each foot from each subject. A weight machine was also used to measure the bodyweight of the selected subjects and to measure the backpack load.

Selection of the Variables

The study involved the selection of several key variables, categorized into experimental and observational variables. The experimental variables, also known as independent variables, included the backpack load and the duration of carrying the load. The backpack load varied across five levels: 0% of the subject's body weight (representing no additional weight in the backpack), 8%, 12%, 16%, and 20% of the subject's body weight. Additionally, the duration of carrying the backpack load was recorded at five different time points during walking. These time points were at the beginning of the walking gait (zero minute), the fifth minute, the tenth minute, the fifteenth minute, and the twentieth minute of the walking gait.

The observational variables, referred to as dependent variables, included several measures related to the forces exerted on the feet during walking. These included the force at

the first peak of the left foot, the force at the second peak of the left foot, the force at the first peak of the right foot, and the force at the second peak of the right foot. In addition, the study recorded the mean force at the first peak of both the left and right foot, and similarly, the mean force at the second peak for both feet. Moreover, the study calculated the mean of the forces at the first and second peaks for both the left foot and the right foot separately, allowing for a more comprehensive understanding of the impact of backpack load and walking duration on gait dynamics.

Procedure for Data Collection

The subjects were gathered in the biomechanics lab at IGIPSS, University of Delhi. Prior to data collection, informed consent and release of liability forms were obtained from the guardians. The entire data collection procedure was thoroughly explained to the subjects to ensure they understood the process. The subjects were introduced to five backpack load conditions, that are B1 = backpack load of 0% of bodyweight (no additional load in backpack); B2 = backpack load of 8% of bodyweight; B3 = backpack load of 12% of bodyweight; B4 = backpack load of 16% of bodyweight; B5 = backpack load of 20% of bodyweight, which were carried for extended duration of time with the purpose of recording the force distribution at specific periods of time (T1 = recording at zero-minute; T2 = recording at fifth minute; T3 = recording

at tenth minute; T4 = recording at fifteenth minute; T5 = recording at twentieth minute).

Statistical Analysis

For data analysis, the data recorded with the pressure platform software was exported to Excel for further statistical analysis, including mean, standard deviation, coefficient of variation, and t-ratio. A t-test was conducted with the significance level set at 0.05. The results were visually represented using two-dimensional line diagrams for clearer interpretation.

Results

The following Table 1 provides the descriptive statistics for the force at the first peak of the left foot, measured with the selected backpack loads and at the designated recording times.

The following Table 2 presents the descriptive statistics for the force at the second peak of the left foot, measured across various backpack loads and at selected recording times.

The following Table 3 provides the descriptive statistics for the force at the first peak of the right foot, measured with the selected backpack loads and at the designated recording times.

The following Table 4 provides the descriptive statistics for the force at the second peak of the right foot, measured with the selected backpack loads and at the designated recording times.

Table 1. Descriptive statistics of the force at first peak of left foot with the selected backpack loads at selected recording times

		Force (Newton) at First Peak of Left Foot							
S.N.	Bag Time	B1	B2	B3	B4	B5	Mean	SD	CV
		Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD			
1	T1	361.37 \pm 88.38	398.09 \pm 96.78	410.48 \pm 90.80	430.71 \pm 96.16	434.26 \pm 102.94	406.98	95.01	23.35
2	T2	367.43 \pm 87.25	403.31 \pm 88.60	410.99 \pm 95.46	426.56 \pm 98.72	430.42 \pm 101.00	407.74	94.20	23.10
3	T3	367.21 \pm 87.03	399.09 \pm 91.36	411.79 \pm 91.01	425.84 \pm 99.17	433.54 \pm 94.04	407.49	92.52	22.71
4	T4	367.37 \pm 87.34	399.13 \pm 84.29	415.52 \pm 95.09	429.84 \pm 100.35	433.51 \pm 99.79	409.07	93.37	22.83
5	T5	371.05 \pm 84.84	400.22 \pm 85.80	409.33 \pm 87.35	423.54 \pm 95.95	437.49 \pm 98.56	408.33	90.50	22.16
		366.89 \pm 86.96	399.97 \pm 89.36	411.62 \pm 91.94	427.30 \pm 98.07	433.85 \pm 99.27			
	CV	23.70	22.34	22.34	22.95	22.88			

Note: T1 = Recording at 0 minute; T2 = Recording at fifth minute; T3 = Recording at tenth minute; T4 = Recording at fifteenth minute; T5 = Recording at twentieth minute; B1 = Backpack Load of 0% of Body Weight (No bag); B2 = Backpack Load of 8% of Body Weight; B3 = Backpack Load of 12% of Body Weight; B4 = Backpack Load of 16% of Body Weight; B5 = Backpack Load of 20% of Body Weight

Table 2. Descriptive statistics of the force at second peak of left foot with the selected backpack loads at selected recording times

		Force (Newton) at Second Peak of Left Foot							
S.N.	Bag Time	B1	B2	B3	B4	B5	Mean	SD	CV
		Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD			
1	T1	369.98 \pm 82.12	396.45 \pm 84.18	408.92 \pm 83.60	428.24 \pm 92.58	440.13 \pm 93.21	408.75	87.14	21.32
2	T2	371.65 \pm 81.91	406.12 \pm 85.07	416.77 \pm 82.96	425.12 \pm 100.60	437.81 \pm 96.20	411.49	89.35	21.71
3	T3	372.97 \pm 78.43	406.21 \pm 81.31	416.39 \pm 83.02	426.83 \pm 91.15	441.27 \pm 102.63	412.73	87.31	21.15
4	T4	374.00 \pm 77.66	402.25 \pm 84.46	419.18 \pm 82.60	430.58 \pm 89.86	440.45 \pm 97.45	413.29	86.41	20.91
5	T5	375.02 \pm 79.24	401.71 \pm 88.26	415.89 \pm 84.96	424.05 \pm 83.63	439.14 \pm 95.30	411.16	86.28	20.98
		372.72 \pm 79.87	402.55 \pm 84.66	415.43 \pm 83.43	426.96 \pm 91.56	439.76 \pm 96.96			
	CV	21.43	21.03	20.08	21.45	22.05			

Note: T1 = Recording at 0 minute; T2 = Recording at fifth minute; T3 = Recording at tenth minute; T4 = Recording at fifteenth minute; T5 = Recording at twentieth minute; B1 = Backpack Load of 0% of Body Weight (No bag); B2 = Backpack Load of 8% of Body Weight; B3 = Backpack Load of 12% of Body Weight; B4 = Backpack Load of 16% of Body Weight; B5 = Backpack Load of 20% of Body Weight

Table 3. Descriptive statistics of the force at first peak of right foot with the selected backpack loads at selected recording times

		Force (Newton) at First Peak of Right Foot							
S.N.	Bag Time	B1	B2	B3	B4	B5	Mean	SD	CV
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
1	T1	379.61 ± 85.43	408.71 ± 96.23	424.99 ± 90.47	449.50 ± 91.17	462.67 ± 96.38	425.09	91.94	21.63
2	T2	378.46 ± 88.08	411.77 ± 88.22	421.20 ± 90.11	438.86 ± 99.90	443.76 ± 107.02	418.81	94.66	22.60
3	T3	382.47 ± 83.43	409.20 ± 90.33	422.10 ± 86.99	446.99 ± 106.96	451.46 ± 96.33	422.44	92.81	21.97
4	T4	376.05 ± 91.56	407.93 ± 91.31	423.98 ± 90.17	444.92 ± 101.57	455.56 ± 97.26	421.69	94.37	22.38
5	T5	386.65 ± 83.34	410.46 ± 88.22	422.35 ± 91.94	446.13 ± 106.88	452.46 ± 101.88	423.61	94.45	22.30
		380.65 ± 86.37	409.61 ± 90.86	422.92 ± 89.93	445.28 ± 101.30	453.18 ± 99.77			
	CV	22.69	22.18	21.26	22.75	22.02			

Note: T1 = Recording at 0 minute; T2 = Recording at fifth minute; T3 = Recording at tenth minute; T4 = Recording at fifteenth minute; T5 = Recording at twentieth minute; B1 = Backpack Load of 0% of Body Weight (No bag); B2 = Backpack Load of 8% of Body Weight; B3 = Backpack Load of 12% of Body Weight; B4 = Backpack Load of 16% of Body Weight; B5 = Backpack Load of 20% of Body Weight

Table 4. Descriptive statistics of the force at second peak of right foot with the selected backpack loads at selected recording times

		Force (Newton) at Second Peak of Right Foot							
S.N.	Bag Time	B1	B2	B3	B4	B5	Mean	SD	CV
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
1	T1	363.42 ± 75.93	391.63 ± 83.45	407.72 ± 80.17	421.35 ± 83.55	438.87 ± 89.24	404.60	82.47	20.38
2	T2	365.60 ± 76.29	398.54 ± 84.85	412.64 ± 81.92	418.41 ± 85.14	426.58 ± 105.15	404.35	86.67	21.43
3	T3	366.68 ± 75.30	395.89 ± 85.15	417.38 ± 82.59	421.34 ± 83.76	437.62 ± 91.89	407.78	83.74	20.54
4	T4	366.94 ± 77.44	398.43 ± 83.45	411.49 ± 83.81	425.54 ± 85.44	436.01 ± 96.90	407.68	85.41	20.95
5	T5	373.25 ± 73.45	399.86 ± 82.74	413.96 ± 84.37	422.64 ± 83.95	433.91 ± 95.42	408.72	83.98	20.55
		367.17 ± 75.68	396.87 ± 83.93	412.63 ± 82.57	421.85 ± 84.37	434.60 ± 95.72			
	CV	20.61	21.15	20.01	20.00	22.02			

Note: T1= Recording at 0 minute; T2 = Recording at fifth minute; T3 = Recording at tenth minute; T4 = Recording at fifteenth minute; T5 = Recording at twentieth minute; B1 = Backpack Load of 0% of Body Weight (No bag); B2 = Backpack Load of 8% of Body Weight; B3 = Backpack Load of 12% of Body Weight; B4 = Backpack Load of 16% of Body Weight; B5 = Backpack Load of 20% of Body Weight

Table 5. Comparison between mean of force at first peak of left foot and right foot with the selected backpack loads at selected recording times

Variables	Mean Peak Force (Newton) at Selected Backpack Loads					Total
	B1	B2	B3	B4	B5	
Left Foot	366.89	399.97	411.62	427.30	433.85	2039.00
Right Foot	380.65*	409.61*	422.92*	445.28*	453.18*	2111.64*
Difference b/w Left & Right Foot	-13.76	-9.64	-11.3	-17.98	-19.33	-72.01
Total	747.54	809.58	834.54	872.58	887.03	4151.27
Average	373.77	404.79	417.27	436.29	443.51	2075.63

*Note 't' value found to be significant at 0.05 level

According to Table 5 and Figure 2, the mean of force at first peak of right foot is more as compared to mean of force at first peak of left foot. It is also observed that with the increase in backpack load, the mean of force (in newton) at peak also increases at left and right foot. The t-test analysis revealed significant differences in the mean forces at the first peak between the left and right foot at varying backpack loads, with significance established at the 0.05 level.

According to Table 6 and Figure 3, the mean of force at first peak of left foot is more as compared to mean of force at first peak of right foot. It has also been observed that as backpack load increases, the mean peak force (in newtons) rises correspondingly, both, at left and right foot. The t-test showed significant differences in the mean forces at the

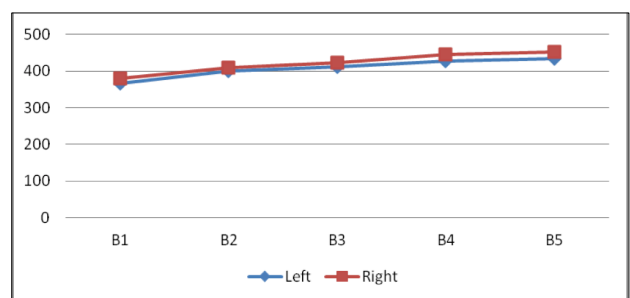


Fig. 2. Comparison between mean of force at first peak of left foot and right foot with the selected backpack loads at selected recording times

Table 6. Comparison between mean of force at second peak of left foot and right foot with the selected backpack loads at selected recording times

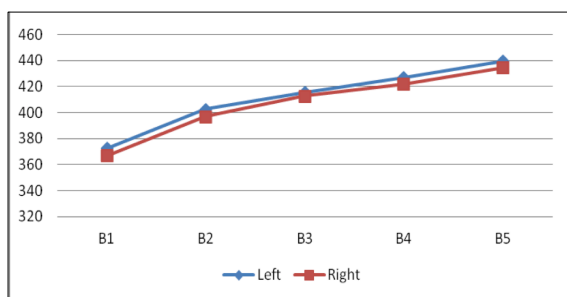
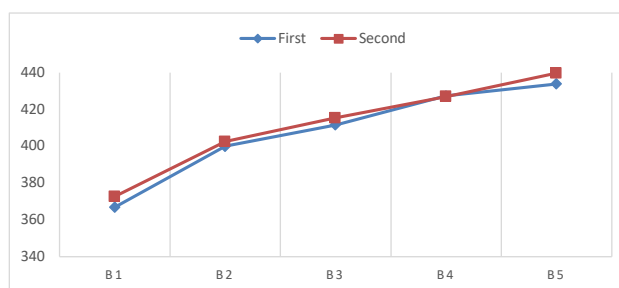
Mean Peak Force (Newton) at Selected Backpack Loads of Left Foot and Right Foot						
Variables	B1	B2	B3	B4	B5	Total
Left Foot	372.72*	402.55*	415.43*	426.96*	439.76*	2057.42*
Right Foot	367.17	396.87	412.63	421.85	434.6	2033.12
Difference b/w Left & Right Foot	5.55	5.68	2.8	5.11	5.16	24.30
Total	739.89	799.42	828.06	848.81	874.36	4090.54
Average	369.945	399.71	414.03	424.405	437.18	2045.27

*Note 't' value found to be significant at 0.05 level

Table 7. Comparison between mean of force (newton) at first and second peak of left foot with the selected backpack loads at selected recording times

Mean Peak Force at Selected Backpack loads of First and Second Peak of Left Foot						
Variables	B1	B2	B3	B4	B5	Total
Force at First Peak	366.89	399.97	411.62	427.3	433.85	2039.63
Force at Second Peak	372.72*	402.55*	415.43*	426.96*	439.76*	2057.42*
Difference b/w Force at First & Second Peak	-5.83	-2.58	-3.81	0.34	-5.91	-17.79
Total	739.61	802.52	827.05	854.26	873.61	4097.05
Average	369.805	401.26	413.525	427.13	436.805	2048.525

*Note 't' value found to be significant at 0.05 level

**Fig. 3.** Comparison between mean of force at second peak of left foot and right foot with the selected backpack loads at selected recording times**Fig. 4.** Comparison between mean of force at first and second peak of left foot with the selected backpack loads at selected recording times**Table 8.** Comparison between mean of force (newton) at first and second peak of right foot with the selected backpack loads at selected recording times

Mean Peak Force at Selected Backpack loads of First and Second Peak of Right Foot						
Variables	B1	B2	B3	B4	B5	Total
Force at First Peak	380.65*	409.61*	422.92*	445.28*	453.18*	2111.64*
Force at Second Peak	367.17	396.87	412.63	421.85	434.6	2033.12
Difference b/w First & Force at Second Peak	13.48	12.74	10.29	23.43	18.58	78.52
Total	747.82	806.48	835.55	867.13	887.78	4144.76
Average	373.91	403.24	417.775	433.565	443.89	2072.38

*Note 't' value found to be significant at 0.05 level

second peak between the left and right foot across different backpack loads, with statistical significance at the 0.05 level.

As shown in Table 7 and Figure 4, the mean of force at the second peak is higher compared to the first peak of the left foot. Additionally, the mean of force at both the first and second peaks increase as the backpack load on the left foot increases. The differences between the first and second peak forces of the left foot were found to be statistically significant at the 0.05 level, as indicated by the t-test results.

As indicated in Table 8 and Figure 5, the mean of force at the first peak of the right foot is higher compared to the second peak. Additionally, both the first and second peak forces increase as the backpack load on the right foot increases. The t-test results demonstrated significant differences between the first and second peak forces of the right foot, with significance at the 0.05 level.

According to Table 9, the mean of force at the first peak of the right foot is greater than the mean of force at the sec-

Table 9. Comparison between mean of force (newton) at first and second peak of right foot and left foot as a whole*

Mean of Force (Newton) at First and Second Peak of Right Foot and Left Foot as a Whole*				
Peak Force/Foot	Right Foot	Left Foot	Total (Newton)	Sig.
Force at First Peak (Newton)	2111.64	2039.63	4151.27	0.002
Force at Second Peak (Newton)	2033.12	2057.42	4090.54	0.001
Total (Newton)	4144.76	4097.05	8241.81	

*Whole = All backpack loads and recording times, collectively

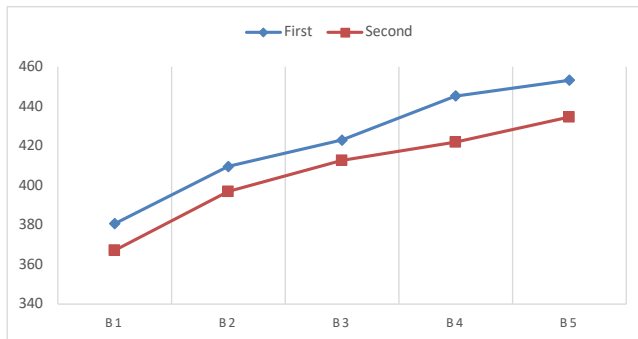


Fig. 5. Comparison between mean of force at first and second peak of right foot with the selected backpack loads at selected recording times

ond peak of the left foot across the selected backpack loads and recording times.

Table 10. Result of paired sample t-test at first and second peak of right foot and left foot as a whole*

Force (Newton) at First and Second Peak of Right Foot and Left Foot as a Whole*				
Peak Force	MD	SED	t-value	p-value (Sig. 2-tailed)
Force at First Peak	-14.402	1.868	-7.709	0.002
Force at Second Peak	4.860	0.526	9.230	0.001

*Whole = All backpack loads and recording times, collectively.

Table 10 presents the results of a paired sample t-test comparing the forces (in Newtons) at the first and second peaks of the right and left feet, treated collectively across all backpack loads and recording times. The t-test evaluates whether there is a statistically significant difference in the peak forces between these two time points. For the first peak force, the mean difference is -14.402 Newtons, with a standard error of difference (SED) of 1.868. The t-value is -7.709, and the p-value is 0.002, which is statistically significant at the 0.05 level. For the second peak force, the mean difference is 4.860 Newtons, with an SED of 0.526. The t-value is 9.230, and the p-value is 0.001, which also shows statistical significance. Overall, these results demonstrate significant changes in force between the feet at both peaks, emphasizing how backpack load and timing affect foot force dynamics.

Discussion

The aim of the present study was to investigate the influence of different backpack loads carried by the students on forces at different peaks of left and right foot during walking gait. The results of this study indicate that an increase in

backpack load significantly affects the peak forces during the gait cycle. As observed, the mean of force at both the first and second peaks of the left and right feet increased with heavier backpack loads. The t-test confirmed that these increases in peak forces across different backpack loads were statistically significant at the 0.05 level, highlighting the biomechanical impact of heavier loads on walking gait. This finding is consistent with the literature, which reports that carrying backpacks exceeding 10% of body weight increases ground reaction forces, thereby placing additional strain on the musculoskeletal system (Ahmad & Barbosa 2019; Pau et al. 2015).

Interestingly, the study revealed an asymmetry between the mean of forces on the right and left feet, with the right foot dominating at the first peak and the left foot dominating at the second peak. The observed differences in mean of forces between the left and right foot were also found to be statistically significant, as confirmed by the t-test at the 0.05 level, suggesting that carrying a backpack may induce gait asymmetry, potentially leading to altered posture and gait mechanics. Such asymmetry may contribute to the development of musculoskeletal disorders in children, as imbalances in force distribution can lead to compensatory mechanisms, increasing the risk of injury (Mackenzie et al. 2003; Rai & Agarwal 2013).

Furthermore, the incremental increase in mean of force at peaks, across the different recording times suggests that the effects of backpack loads may compound over time, emphasizing the need for caution when children carry heavy backpacks for extended periods. The t-test results further validated that these cumulative effects of backpack loads over time were statistically significant. Reinforcing the need for regulated backpack weight to prevent long-term biomechanical strain. This finding aligns with research suggesting that prolonged load carriage leads to greater biomechanical stress and fatigue (Castro et al. 2013). In high-intensity sports, exercises like Nordic hamstring curls are essential for strengthening the hamstrings and developing eccentric strength, which helps reduce injury risk. The hamstrings play a key role in controlling heel strike and the swing phase during walking and running. This is particularly relevant in our study on the effects of backpack loads on peak forces during walking gait, as strong hamstrings are crucial for managing altered gait dynamics and preventing muscle strain (Islam et al., 2024).

There was an overall increment in the mean of force at first peak when the subjects walked with different backpack loads. It was reported by Barbosa et al. (2019) that there was increase in first peak magnitude of class fifth grade students during walking with different backpack loads. Contradictory to the study by Behmaram et al. (2022) who stated an increase in second peak ground reaction force with increase in backpack loads as one has to overcome greater force for moving forward when backpack load increases. Contra-

diction between Barbosa et al. (2019) and Behmaram et al. (2022) requires further investigation.

In light of these findings, it is critical to establish guidelines for safe backpack loads for schoolchildren. It was reported that carrying a backpack weighing 10% of body weight is too heavy for students aged between ten and fifteen years and affects their normal cervical and shoulder posture alignment (Chansirinukor et al., 2001). Similarly, Husain et al. (2024) found that heavier backpack loads and longer walking durations significantly affected the timing of peak forces in the gait cycle of schoolboys, underscoring the need for further research on the effects of backpacks on children's gait. A commonly recommended limit of 10-15% of body weight may still be too heavy, especially for younger students, as even the lightest load in the present study (8% backpack load of bodyweight) resulted in a measurable increase in peak forces.

This study was limited to male students aged 10 to 12 years, and future research should include female participants to explore gender-based differences in gait biomechanics. The controlled experimental environment may not fully replicate natural walking conditions over longer distances. However, the study's strengths include its systematic examination of multiple backpack loads on walking gait using a precision pressure platform, providing reliable data on peak forces. The findings emphasize the need to regulate backpack loads to protect children's musculoskeletal health, and future research should investigate long-term effects and explore interventions like ergonomic backpack designs and educational programs.

Conclusions

The study concludes that the increasing backpack loads lead to higher mean of forces at both the first and second peaks of the gait cycle, particularly in the right foot at the first peak and the left foot at the second peak. The asymmetry observed between the two feet suggests that prolonged backpack use with heavy loads can contribute to posture and gait imbalances, which may increase the risk of musculoskeletal problems. Additionally, future research should investigate the long-term effects of backpack carriage on musculoskeletal health and explore potential interventions, such as ergonomic backpack designs and educational programs for students and parents.

Acknowledgment

The authors express their gratitude to all participants who contributed to the study.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- Pascoe, D. D., Pascoe, D. E., Wang, Y. T., Shim, D.-M., & Kim, C. K. (1997). Influence of carrying book bags on gait cycle and posture of youths. *Ergonomics*, *40*(6), 631-640. <https://doi.org/10.1080/001401397187928>
- Sheir-Neiss, G. I., Kruse, R. W., Rahman, T., Jacobson, L. P., & Pelli, J. A. (2003). The association of backpack use and

- back pain in adolescents. *Spine*, *28*(9), 922-930. <https://doi.org/10.1097/01.BRS.0000058725.18067.F7>
- Castro, M., Abreu, S., Sousa, H., Machado, L., Santos, R., & Vilas-Boas, J. P. (2013). Ground reaction forces and plantar pressure distribution during occasional loaded gait. *Applied Ergonomics*, *44*(3), 503-509. <https://doi.org/10.1016/j.apergo.2012.10.016>
- Pau, M., Mandaresu, S., Leban, B., & Nussbaum, M. A. (2015). Short-term effects of backpack carriage on plantar pressure and gait in schoolchildren. *Journal of Electromyography and Kinesiology*, *25*(2), 406-412. <https://doi.org/10.1016/j.jelekin.2014.11.006>
- Knapik, J., Harman, E., & Reynolds, K. (1996). Load carriage using packs: A review of physiological, biomechanical and medical aspects. *Applied Ergonomics*, *27*(3), 207-216. [https://doi.org/10.1016/0003-6870\(96\)00013-0](https://doi.org/10.1016/0003-6870(96)00013-0)
- Knapik, J. J., Reynolds, K. L., & Harman, E. (2004). Soldier Load Carriage: Historical, Physiological, Biomechanical, and Medical Aspects. *Military Medicine*, *169*(1), 45-56. <https://doi.org/10.7205/milmed.169.1.45>
- Macias, B. R., Murthy, G., Chambers, H., & Hargens, A. R. (2008). Asymmetric Loads and Pain Associated with Backpack Carrying by Children. *Journal of Pediatric Orthopaedics*, *28*(5), 512-517. <https://doi.org/10.1097/bpo.0b013e31817d8143>
- Son, H. (2013). The Effect of Backpack Load on Muscle Activities of the Trunk and Lower Extremities and Plantar Foot Pressure in Flatfoot. *Journal of Physical Therapy Science*, *25*(11), 1383-1386. <https://doi.org/10.1589/jpts.25.1383>
- Song, Q., Yu, B., Zhang, C., Sun, W., & Mao, D. (2014). Effects of Backpack Weight on Posture, Gait Patterns and Ground Reaction Forces of Male Children with Obesity during Stair Descent. *Research in Sports Medicine*, *22*(2), 172-184. <https://doi.org/10.1080/15438627.2014.881823>
- Castro, M. P., Figueiredo, M. C., Abreu, S., Sousa, H., Machado, L., Santos, R., & Vilas-Boas, J. P. (2015). The influence of gait cadence on the ground reaction forces and plantar pressures during load carriage of young adults. *Applied Ergonomics*, *49*, 41-46. <https://doi.org/10.1016/j.apergo.2015.01.004>
- Perrone, M., Orr, R., Hing, W., Milne, N., & Pope, R. (2018). The Impact of Backpack Loads on School Children: A Critical Narrative Review. *International Journal of Environmental Research and Public Health*, *15*(11), 2529. <https://doi.org/10.3390/ijerph15112529>
- Sokhi, S.S., Shaw, D., Andrabi, S.M.H., & Singh, D. (2022). Back Pack Load Carried for Extended Time Durations Correlated with Mean Ground Reaction Force on the Plantar Aspect of the Foot of School Going Children's Gait (A Descriptive Approach). *International Journal of All Research Education and Scientific Methods (IJARESM)*, *10*(4), 1410-1415.
- Drerup, B., Szczepaniak, A., & Wetz, H. H. (2008). Plantar pressure reduction in step-to gait: A biomechanical investigation and clinical feasibility study. *Clinical Biomechanics*, *23*(8), 1073-1079. <https://doi.org/10.1016/j.clinbiomech.2008.04>
- Kellis, E. (2001). Plantar pressure distribution during barefoot standing, walking and landing in preschool boys. *Gait & Posture*, *14*(2), 92-97. [https://doi.org/10.1016/s0966-6362\(01\)00129-1](https://doi.org/10.1016/s0966-6362(01)00129-1)

- Rai, D.V., Aggarwal, L.M. (2006). The Study of Planter Pressure Distribution in Normal and Pathological Foot. *Pol J Med Phys Eng*, 12(1), 25-34.
- Kasović, M., Zvonar, M., Gomaz, L., Bolčević, F., & Anton, V. (2018). The influence of a school bag carriage on the pattern changes in plantar pressure during walking among schoolchildren in the first grade. *Kinesiology*, 50(2), 188-193.
- Ahmad, H. N., & Barbosa, T. M. (2019). The effects of backpack carriage on gait kinematics and kinetics of schoolchildren. *Scientific Reports*, 9(1), 3364. <https://doi.org/10.1038/s41598-019-40076-w>
- Lai, J. P., & Jones, A. Y. (2001). The effect of shoulder-girdle loading by a school bag on lung volumes in Chinese primary school children. *Early Human Development*, 62(1), 79-86. [https://doi.org/10.1016/s0378-3782\(01\)00121-9](https://doi.org/10.1016/s0378-3782(01)00121-9)
- Mosaad, D. M., & Abdel-Aziem, A. A. (2015). Backpack carriage effect on head posture and ground reaction forces in school children. *Work*, 52(1), 203-209. <https://doi.org/10.3233/wor-152043>
- Vieira, A. C., & Ribeiro, F. (2015). Impact of backpack type on respiratory muscle strength and lung function in children. *Ergonomics*, 58(6), 1005-1011. <https://doi.org/10.1080/00140139.2014.997803>
- Chen, Y.-L., & Mu, Y.-C. (2018). Effects of backpack load and position on body strains in male schoolchildren while walking. *PLOS ONE*, 13(3), e0193648. <https://doi.org/10.1371/journal.pone.0193648>
- Hong, Y., & Bartlett, R. (2008). *Handbook of Biomechanics and Human Movement Science*. Routledge.
- Richards, J., Chohan, A., & Erande, R. (2013). *Biomechanics*. Tidy's Physiotherapy, 331-368. <https://doi.org/10.1016/b978-0-7020-4344-4.00015-8>
- Neptune, R. R., & Sasaki, K. (2005). Ankle plantar flexor force production is an important determinant of the preferred walk-to-run transition speed. *Journal of Experimental Biology*, 208(5), 799-808. <https://doi.org/10.1242/jeb.01435>
- Perry, J., & Burnfield, J. M. (2024). *Kinetics of Gait: Ground Reaction Forces, Vectors, Moments, Power, and Pressure*. In *Gait Analysis* (pp. 457-469). CRC Press.
- Menz, H.B., & Morris, M.E. (2006). Clinical determinants of plantar forces and pressures during walking in older people. *Gait & Posture*, 24(2), 229-236. <https://doi.org/10.1016/j.gaitpost.2005.09.002>
- Mackenzie, W. G., Sampath, J. S., Kruse, R. W., & Sheir-Neiss, G. J. (2003). Backpacks in Children. *Clinical Orthopaedics and Related Research*, 409 78-84. <https://doi.org/10.1097/01.blo.0000058884.03274.d9>
- Rai, A., & Agarawal S. (2013). Back Problems Due to Heavy Backpacks in School Children. *IOSR Journal of Humanities and Social Science (IOSR-JHSS)*, 10(10), 1-5.
- Islam, M. S., Rahman, M. H., Mola, D. W., Adane, A. K., & Pramanik, T. N. (2024). Nordic hamstring curls are aremedy for hamstring muscle injury: A narrative review. *International Journal of Human Movement and Sports Sciences*, 12(4), 692-698. <https://doi.org/10.13189/saj.2024.120411>
- Barbosa, J.P., Marques, M.C., Neiva, H.P., Esteves, D., Alonso-Martinez, A.M., Izquierdo, M., Ramirez-Campillo, R., Alvarez, C., & Marinho, D.A. (2019). Effects of Backpacks on Ground Reaction Forces in Children of Different Ages When Walking, Running, and Jumping. *International Journal of Environmental Research and Public Health*, 16(24), 5154. <https://doi.org/10.3390/ijerph16245154>
- Behmaram, S., Jalalvand, A., Hoseini, Y., & Jahani, M.R. (2022). The effect of backpack carriage in different weights on ground reaction force components, loading rate and free moment of Schoolchildren's gait. *International Journal of Industrial Ergonomics*, 90(6), 1-4. <https://doi.org/10.1016/j.ergon.2022.103324>
- Chansirinukor, W., Wilson, D., Grimmer, K., & Dansie, B. (2001). Effects of backpacks on students: measurement of cervical and shoulder posture. *Aust J Physiother.*, 47(2), 110-6. [https://doi.org/10.1016/s0004-9514\(14\)60302-0](https://doi.org/10.1016/s0004-9514(14)60302-0)
- Husain, R., Mola, D. W., & Shaw, D. (2004). Effect of selected backpack loads carried for selected durations on temporal pattern of peak forces of walking gait of school-going boys. *Int J Kinesiol Sports Sci.*, 12(4), 48-56. <https://doi.org/10.7575/aiac.ijkss.v12n.4p.48>

Розуміння впливу окремих навантажень рюкзака з певною тривалістю носіння на показники максимальних зусиль під час пішої ходьби у хлопчиків шкільного віку

Рабія Хуссейн^{1ABCDE}, Дессалегн Васе Мола^{2ABCDE}, Дананджой Шоу^{1ABCDE}

¹Університет Делі

²Університет Амбо

Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 9 с., 10 табл., 5 рис., 33 джерела.

Історія питання. Рюкзаки зазвичай використовуються учнями для перенесення шкільного приладдя. Однак збільшення обсягів навантаження рюкзака може призвести до негативного впливу на стан здоров'я та поставу, зокрема, через зміну динаміки ходи. Показник максимальних зусиль є критично важливою змінною в контексті розуміння механіки ходи, на яку суттєво впливають навантаження під час носіння. Тому вкрай важливо дослідити зміни показників максимальних зусиль при різних (зростаючих) навантаженнях рюкзака і тривалості його носіння.

Мета дослідження. Метою дослідження було вивчити вплив різних обсягів навантажень рюкзака під час носіння протягом різної тривалості на показники зусиль, що виникають на першому та другому пікових значеннях тиску лівої та правої стоп під час циклу пішої ходьби у хлопчиків шкільного віку.

Матеріали та методи. Суб'єктами дослідження були особи ($n = 85$) віком від 10 до 12 років з Національного столичного регіону Делі, яких було відібрано за методом рандомізації. Показники зусиль на першому та другому піках вимірювали за допомогою платформи для визначення тиску ZebrisInc, що підтримується програмним забезпеченням Win FDM-S (Німеччина). Проаналізовано п'ять умов навантаження рюкзака, а саме: B1 = навантаження рюкзака 0 % від маси тіла (без додаткової ваги в рюкзаку); B2 = навантаження рюкзака 8 % від маси тіла; B3 = навантаження рюкзака 12 % від маси тіла; B4 = навантаження рюкзака 16 % від маси тіла; і B5 = навантаження рюкзака 20% від маси тіла, на п'яти наступних записах часу: T1 = запис на нульовій хвилині ходьби; T2 = запис на п'ятій хвилині ходьби; T3 = запис на десятій хвилині ходьби; T4 = запис на п'ятнадцятій хвилині ходьби; T5 = запис на двадцятій хвилині ходьби. Статистичний аналіз включав оцінку середнього значення, стандартного відхилення, коефіцієнта варіації та t-співвідношення. Рівень значущості t-критерію становив 0,05.

Результати. Результати дослідження показали, що збільшення обсягів навантаження рюкзака призводить до зростання показників максимальних зусиль як на першому, так і на другому піках циклу ходи. Під час першого піку права стопа розвивала підвищені показники сили, тоді як на другому піку домінувала ліва стопа. Крім того, встановлено, що тривале носіння навантаження також призводить до збільшення максимальних зусиль. T-критерій на основі парної вибірки виявив значні відмінності між першим і другим піками, із середньою різницею — 14,402 Н ($p = 0,002$) для першого піку і 4,860 Н ($p = 0,001$) для другого піку.

Висновок. За результатами дослідження було визначено, що збільшення навантаження рюкзака значно підвищує середнє значення максимальних зусиль під час пішої ходьби, що може призвести до порушення постави та асиметрії ходи. Отримані дані свідчать про необхідність регулювання навантаження рюкзака з метою запобігання виникненню потенційних проблем з опорно-руховим апаратом у дітей.

Ключові слова: рюкзак, перший пік, сила, цикл ходи, перенесення навантаження, другий пік, піша ходьба.

Information about the authors:

Husain, Rabiya: rabiyaahn70@gmail.com; <https://orcid.org/0000-0003-1434-1191>; Department of Physical Education and Sports Sciences, University of Delhi, Delhi, India.

Mola, Dessalegn Wase: dessalegn.wasie@gmail.com; <https://orcid.org/0000-0001-9688-0775>; Department of Sports Science, Ambo University, Ambo, Ethiopia.

Shaw, Dhananjoy: dhananjoyshaw1960@gmail.com; <https://orcid.org/0000-0002-4275-6389>; Indira Gandhi Institute of Physical Education and Sports Sciences, University of Delhi, Delhi, India.

Cite this article as: Husain, R., Mola, D. W., & Shaw, D. (2024). Understanding the Effects of Selected Backpack Loads Carried for Certain Durations on Peak Forces of Walking Gait in School-Going Boys. *Journal of Learning Theory and Methodology*, 5(3), 144-152. <https://doi.org/10.17309/jltm.2024.5.3.08>

Received: 19.11.2024. Accepted: 27.12.2024. Published: 30.12.2024

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