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Effect of Selected Backpack Loads Carried for Selected Durations on Temporal Pattern of Peak Forces of Walking Gait of School-Going Boys

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ABSTRACT

Background: Backpacks are vital for students, offering stability by being close to the body's center of gravity. However, increased weight demands more energy and can lead to negative effects like altered gait, fatigue, and a higher risk of injuries. Understanding the impact of varying backpack loads and walking durations on peak forces during gait is essential for the health and well-being of school-aged children. **Objective:** The primary objective of the study was to observe the effect of varying backpack loads and walking durations on temporal patterns of the first and second peak forces during the gait cycle. **Method:** A total of eighty-five school-going boys, aged 10 to 12 years, were randomly selected as subjects for this study. A repeated-measures experimental approach was employed, utilizing a 5x5 study design. The subjects' gait was analyzed under five different backpack loads: 0% (no additional weight), 8%, 12%, 16%, and 20% of their body weight. And walking gait duration was recorded at five different time intervals (experimental variables) of twenty minutes walking, that is, at zero-minute, at fifth minute, at tenth minute, the fifteenth minute and the twentieth minute of walking gait. The studied variables were, time elapse to get first peak force of the left, time elapse to get the first peak force of the right foot, time elapse to get the second peak force of the left foot, time elapse to get the second peak force of the right foot, average of time elapse to get first peak force of the left and right feet as well as average of time elapse to get second peak force of the left and right feet during the gait cycle. The Zebris FDM-S pressure plate, supported by Win FDM-S software, was used for data collection. Hypotheses were tested at a significance level of 0.05. **Results:** The analysis revealed that the selected variables were significantly influenced by the experimental variables, namely the varying backpack loads and the durations of carrying loads. The results indicate that both increasing backpack weight and longer carrying durations alter the temporal patterns of the first and second peak forces during gait. **Conclusion:** The findings suggest that varying backpack loads and walking durations have a significant impact on the temporal patterns of peak forces during the gait cycle in school-going boys. These results highlight the need for further studies to explore additional gait variables to better understand the full impact of backpack loads on children's gait.

Key words: Backpack Load, First Peak Force, Gait Analysis, Load-carriage, Second Peak Force, Time Elapses

INTRODUCTION

Backpacks are the primary method for students to transport their belongings, as they are positioned close to the body's center of gravity, providing stability (Pascoe et al., 1997; Sheir-Neiss et al., 2003). However, as the backpack's weight increases, so does the energy required to carry it (Castro et al., 2013; Pau et al., 2015). The downside of carrying heavy backpacks is that they can have detrimental effects on the body (Knapik et al., 1996; Knapik et al., 2004). Research has shown that excessive backpack loads can alter gait patterns and increase energy expenditure (Sheir-Neiss et al., 2003), leading to injuries such as shoulder pain, back pain, and redness or swelling (Macias et al., 2008). In extreme cases, they can also increase the risk of musculoskeletal injuries, including kyphosis, lordosis, and shoulder drop (Son, 2013; Song et al., 2014; Castro et al., 2015; Perrone et al., 2018). The weight of the backpack and the duration of walking also contribute to fatigue (Hong & Bartlett, 2008), which prompts individuals to decrease their walking speed and alter their gait cycle (Chow et al., 2005). While previous research has examined the impacts of load carriage on physical health and

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performance, less attention has been given to how varying backpack loads and walking durations specifically affect the temporal variables of peak forces during gait.

Previous studies have explored various aspects of load carriage, including the influence of backpack weight on posture, gait, and overall physical health. However, less attention has been given to the combined effects of backpack load and walking duration on the temporal dynamics of walking gait, particularly regarding the time taken to reach different peak forces during the gait cycle. Peak forces are critical indicators of the stress placed on the body during walking, and understanding how these forces are affected by load and duration is essential for developing guidelines to prevent potential injuries (Paez-Moguer et al., 2019).

The increasing prevalence of heavy backpack use among school-aged children has raised concerns regarding its impact on health, particularly on gait performance and musculoskeletal well-being. Despite previous studies examining the effects of backpack load on posture and gait (Hong & Fong, 2008; Chow et al., 2005), a significant gap remains in understanding how different backpack loads and carrying durations influence the temporal patterns of peak forces during walking. The present study aims to fill this research gap by investigating the effects of varying backpack loads and carrying durations on the temporal patterns of the first and second peak forces in school-aged boys. Specifically, it will observe how these factors are associated with gait performance. This study introduces an experimental design featuring five progressive backpack loads and five carrying durations (5x5), a combination that has not been previously addressed.

METHODS

Research Design and Participants

The study employed a repeated measures experimental design to assess the impact of varying backpack loads and carrying durations on the temporal pattern of peak forces during the walking gait cycle. A 5x5 within-group structure was used, where each participant experienced five levels of backpack loads and five carrying durations. This allowed for a comprehensive analysis of the effects on the first and second peak forces during the gait cycle. The 5x5 design refers to the five backpack load conditions and five carrying duration protocols tested on a single experimental group (See Table 1).

The study involved 85 school-going boys aged 10 to 12 years from the Delhi National Capital Region (NCR), selected using purposive and random sampling methods. The sample size was calculated using Yamane's (1967) formula, with a 95% confidence level and a 5% margin of error. The research adhered to strict ethical standards, emphasizing voluntary participation; participants were informed of their right to withdraw at any time. Privacy and confidentiality were rigorously maintained, and ethical approval was granted by the Board of Research Studies at the University of Delhi. The inclusion criteria required participants to be boys aged 10 to 12 from Delhi NCR who successfully completed the experimental protocol and passed specific health and physical readiness checks. Conversely, individuals outside this age range, those who failed the health checks, or participants who withdrew during data collection were excluded from the study.

Instruments

The Zebris FDM-S pressure plate (40x30 cm), supported by Win FDM-S software (Zebris GmbH, Germany), was used to measure spatiotemporal gait parameters. Equipped with 11,264 sensors and a sampling rate of 100 Hz, the platform has a sensor area of 149x54.2 cm (Internet page: https://www.zebris.de/fileadmin/Editoren/zebris-PDF-Manuals/Medizin/Software/Alte_ Versionen/Manua l_zebris_ FDM_1.16.x_R1_EN_web.pdf). Participants walked barefoot at a natural pace while avoiding direct targeting of the platform, completing five trials with at least two footprints recorded in each, as recommended by previous studies (Kasović et al., 2020). The system showed high internal consistency (Cronbach's alpha > 0.90) for all study variables, and prior research confirmed its test-retest reliability and validity (Van Alsenoy et al., 2019). A double retest protocol was conducted over two consecutive days to ensure consistency, and a weighing scale was used to measure participants' body weight and adjust the backpack load.

Selection of the Variables

The study focused on examining the impact of varying backpack loads and the duration of carrying these loads on specific gait parameters. The independent variables included different levels of backpack load relative to the subject's body weight. Additionally, the study considered the duration for

Table 1. Backpack load and time duration protocol for data collection

	Duration				
Backpack Load	**D 0 minute**	**D 5 minutes**	**D 10 minutes**	**D 15 minutes**	**D 20 minutes**
BL 0% of BW	S1…S85	S1…S85	S1…S85	S1…S85	S1…S85
BL 8% of BW	S1…S85	S1…S85	S1…S85	S1…S85	S1…S85
BL 12% of BW	S1…S85	S1…S85	S1…S85	S1…S85	S1…S85
BL 16% of BW	S1…S85	S1…S85	S1…S85	S1…S85	S1…S85
BL 20% of BW	S1…S85	S1…S85	S1…S85	S1…S85	S1…S85

S=Subject, S1=Subject First, S85=Subject Eighty-Fifth, BL=Backpack Load, BW=Body Weight, D=Duration which the backpack was carried, with measurements taken at multiple time intervals. The following were the experimental variables of the study:

1. Experimental Variables (Independent Variables)
a. Backpack load
   i. 0% (no) backpack load of the bodyweight of the subject
   ii. 8% backpack load of the bodyweight of the subject
   iii. 12% backpack load of the bodyweight of the subject
   iv. 16% backpack load of the bodyweight of the subject
   v. 20% backpack load of the bodyweight of the subject
b. Duration of carrying the backpack load (recording time)
   i. At zero minute (at the beginning of the walking gait)
   ii. At fifth minute of the walking gait
   iii. At tenth minute of the walking gait
   iv. At fifteenth minute of the walking gait
   v. At twentieth minute of the walking gait

The study observed the effect of progressive backpack loads and carrying durations on the following dependent variables. These measurements aimed to quantify the impact of backpack load and duration on the timing of peak forces during gait, providing insights into the biomechanics of walking under load.

2. Observational Variables (Dependent Variables)
   a. Time elapse to get first peak force of the left foot
   b. Time elapse to get first peak force of the right foot
   c. Time elapse to get second peak force of the left foot
   d. Time elapse to get second peak force of the right foot
   e. Average of time elapse to get first peak force of the left foot and right foot
   f. Average of time elapse to get second peak force of the left foot and right foot

Procedure for Data Collection

The data collection took place at the Biomechanics Laboratory of Indira Gandhi Institute of Physical Education and Sports Sciences, University of Delhi. Informed consent and release from liabilities form was obtained from the guardians of the subjects, prior to the data collection. The bodyweight of the subjects was measured using a weighing scale. For the data collection, subjects were instructed to walk in a single line for twenty minutes with each selected backpack loads, independently. The data regarding the selected variables was collected using a pressure plate (Zebris FDM-S) and processed with the software (Win FDM-S). All the data recorded with the pressure platform was exported to excel for data analysis.

Statistical Analysis

The data recorded from the pressure platform was exported to Excel for analysis. Descriptive statistics, such as mean, standard deviation, and coefficient of variation, were utilized to interpret the results. The findings were then presented using bar chart diagram to provide a clear visual representation of the data.

RESULTS

Figure 1 defines the time elapse to get first peak force (a), that is, time duration from the beginning of the recording until the occurrence of the first peak force, and time elapse to get the second peak force (b), that is, time duration from the beginning of the recording until the occurrence of the second peak force of the subject while stepping on the pressure plate as per the protocol of the study.

The first peak force in the gait cycle occurs during the loading response phase, shortly after heel strike, and reflects the body's impact absorption as weight is transferred onto the leading leg. This peak indicates the passive forces involved in shock absorption (Hong and Bartlett, 2008; Richards et al., 2013; Bigouette, 2016).

The second peak force occurs during the propulsion phase, just before toe-off, representing the active push-off generated by the plantar flexor muscles as the body propels itself forward. This peak indicates the active forces contributing to forward motion (Neptune & Sasaki, 2005; Richards et al., 2013).

Both peaks' forces and their time elapses provide crucial insights into gait mechanics, with the first peak focusing on impact absorption and its time elapse from the beginning of the time recording until the first peak occurrence. The second peak focuses on propulsion efficiency and the time elapse recorded from the beginning of the time recording until the second peak occurrence (Bigouette, 2016). The current study focuses on the effect of varying backpack loads and carrying durations on the temporal pattern of the first peak force and the second peak force. The result of the study is depicted from Table 2 to Table7 and from Figure 2 to Figure 3.

The table above presents the descriptive statistics of the time elapsed to reach the first peak force of the left foot under five different backpack load conditions at five different recording times.

The above table 3 displays the descriptive statistics of the time elapsed to reach the second peak force of the left foot under five different backpack load conditions at five different recording times.

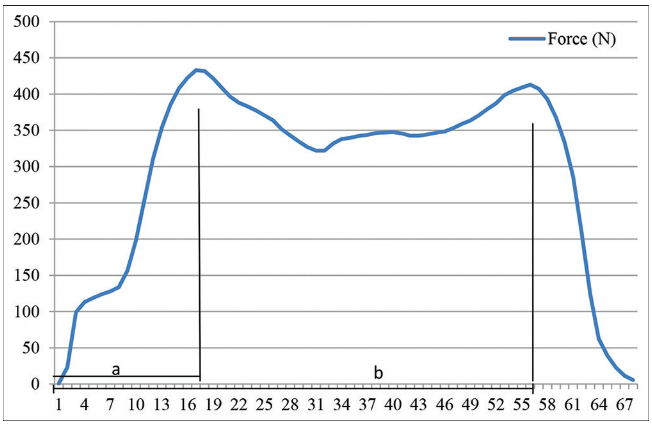

Figure 1. Defining time elapse to get first and second peak forces of right foot and left foot of walking gait
a= represents the time elapsed to get the first peak force;
b= represents the time elapsed to get the second peak force

Table 2. Descriptive statistics of the time elapse to get first peak force of left foot at the selected bag weights with selected recording time

		Time elapse to get first peak force (millisecond) of left foot							
S.N.	**Bag Time**	**B1**	**B2**	**B3**	**B4**	**B5**	**Mean**	**S.D.**	**CV**
		Mean and SD	**Mean and SD**	**Mean and SD**	**Mean and SD**	**Mean and SD**			
1	T1	150.94±30.65	155.18±54.13	155.06±28.89	150.00±32.11	153.88±29.44	153.01	35.05	22.90
2	T2	147.29±26.52	148.12±33.40	153.88±26.64	144.12±27.18	162.71±38.93	151.22	30.53	20.19
3	T3	147.65±27.59	156.35±45.30	154.24±28.05	147.76±24.17	159.76±61.16	153.15	37.25	24.32
4	T4	153.41±37.75	149.29±31.61	148.82±26.30	147.06±32.62	151.76±25.87	150.07	30.83	20.54
5	T5	144.24±26.20	147.53±28.15	156.24±32.95	147.88±21.22	151.76±29.16	149.53	27.54	18.42
		148.71±29.74	151.29±38.52	153.65±28.57	147.36±27.46	155.98±36.91			
	CV	20.00	25.46	18.59	18.63	23.67			

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; B1=0% Backpack load of bodyweight (No bag); B2=8% Backpack load of bodyweight; B3=12% Backpack load of bodyweight; B4=16% Backpack load of bodyweight; B5=20% Backpack load of bodyweight

Table 3. Descriptive statistics of the time elapse to get second peak force of left foot at the selected bag weights with selected recording time

		Time elapse to get second peak force (millisecond) of left foot							
S.N.	**Bag Time**	**B1**	**B2**	**B3**	**B4**	**B5**	**Mean**	**S.D.**	**CV**
		Mean and SD	**Mean and SD**	**Mean and SD**	**Mean and SD**	**Mean and SD**			
1	T1	494.00±55.34	497.18±71.02	505.29±61.35	483.76±64.73	485.88±56.62	493.22	61.81	12.53
2	T2	484.82±51.26	484.24±59.89	491.18±51.81	475.65±63.76	503.18±61.03	487.81	57.55	11.80
3	T3	471.41±54.40	496.59±68.06	500.35±55.62	484.71±55.52	496.12±67.63	489.84	60.25	12.30
4	T4	485.18±61.27	497.65±69.64	492.71±62.59	482.00±58.18	491.65±58.65	489.84	62.07	12.67
5	T5	474.59±49.63	496.47±58.45	504.12±64.37	484.71±55.84	496.71±61.01	491.32	57.86	11.78
		482.00±54.38	494.42±65.41	498.73±59.15	482.16±59.61	494.71±60.99			
	CV	11.28	13.23	11.86	12.36	12.33			

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; B1=0% Backpack Load of Bodyweight (No bag); B2=8% Backpack Load of Bodyweight; B3=12% Backpack Load of Bodyweight; B4=16% Backpack Load of Bodyweight; B5=20% Backpack Load of Bodyweight

Table 4. Descriptive statistics of the time elapse to get first peak force of right foot at the selected bag weights with selected recording time

		Time elapse to get first peak force (millisecond) of right foot							
S.N.	**Bag Time**	**B1**	**B2**	**B3**	**B4**	**B5**	**Mean**	**S.D.**	**CV**
		Mean and SD	**Mean. and SD**	**Mean and SD**	**Mean and SD**	**Mean and SD**			
1	T1	147.53±20.17	148.94±35.32	154.59±49.08	146.59±25.43	147.41±24.11	149.01	30.82	20.68
2	T2	144.35±19.55	144.47±28.31	147.53±24.68	146.24±28.99	152.47±27.60	147.01	25.82	17.57
3	T3	144.59±21.58	150.71±25.90	151.06±25.17	143.76±21.60	151.88±40.28	148.40	26.91	18.13
4	T4	143.06±26.05	156.00±41.44	151.41±25.87	145.76±24.61	150.24±23.40	149.29	28.27	18.94
5	T5	140.12±17.89	150.71±24.73	157.88±40.65	143.65±19.20	150.47±27.38	148.56	25.97	17.48
		143.93±21.05	150.16±31.14	152.49±33.09	145.20±23.97	150.49±28.55			
	CV	14.62	20.74	21.70	16.51	18.97			

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; B1=0% Backpack load of bodyweight (No bag); B2=8% Backpack load of bodyweight; B3=12% Backpack load of bodyweight; B4=16% Backpack load of bodyweight; B5=20% Backpack load of bodyweight

Table 4 above presents the descriptive statistics of time elapse to get first peak force of right foot with five different backpack load conditions at five different recording times.

Table 5 provides the descriptive statistics of the time elapsed to reach the second peak force of the right foot under five different backpack load conditions at five different recording times.

Table 5. Descriptive statistics of the time elapse to get second peak force of right foot at the selected bag weights with selected recording time

		Time elapse to get second peak force (newton) of right foot							
S.N.	**Bag Time**	**B1**	**B2**	**B3**	**B4**	**B5**	**Mean**	**S.D.**	**CV**
		Mean and SD	**Mean. and SD**	**Mean and SD**	**Mean and SD**	**Mean and SD**			
1	T1	494.47±51.26	498.59±63.90	509.29±71.01	481.88±50.93	489.65±49.17	494.78	57.25	11.57
2	T2	486.35±46.36	483.29±55.75	491.06±48.23	470.94±68.10	494.82±52.14	485.29	54.12	11.15
3	T3	482.82±43.52	502.47±55.48	495.65±50.41	477.88±43.10	492.71±55.71	490.31	49.64	10.13
4	T4	479.65±55.39	502.47±65.10	498.24±58.31	481.06±58.23	494.82±51.33	491.25	57.67	11.74
5	T5	476.82±41.55	499.29±50.77	503.41±54.89	488.24±56.76	491.18±47.29	491.79	50.26	10.22
		484.02±47.62	497.22±58.20	499.53±56.57	480.00±55.42	492.64±51.13			
	CV	9.84	11.71	11.33	11.55	10.38			

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; B1=0% Backpack load of bodyweight (No bag); B2=8% Backpack load of bodyweight; B3=12% Backpack load of bodyweight; B4=16% Backpack load of bodyweight; B5=20% Backpack load of bodyweight

Table 6. Average of time elapse to get first peak force of left foot and right foot at the selected bag weights with selected recording time

S.N.	Back pack load/ Time	B1	B2	B3	B4	B5
1	T1	149.24	152.06	154.83	148.30	150.65
2	T2	145.82	146.30	150.71	145.18	157.59
3	T3	146.12	153.53	152.65	145.76	155.82
4	T4	148.24	152.65	150.12	146.41	151.00
5	T5	142.18	149.12	157.06	145.77	151.12

Derived from Table 2 and Table 4

The pressure distribution system, of pressure plate, documents the time elapse to get two peak forces, that is, time elapse to get first peak force and time elapse to get second peak forces in each step. Naturally left foot has two peak forces, the first peak force and second peak force. Similarly, the right foot also has first peak force and second peak force. And both the peak forces have time elapses, the time elapse to get first peak force is recorded from the beginning of the walking gait till the occurrence of the first peak force. And the time elapse to get the second peak force is recorded from the beginning of the walking gait till the occurrence of the second peak force. Same has been documented in Table 2 and Table 3 for the left foot, and for the right foot, it is documented in the Table 4 and Table 5.

Table 6 displays the average time elapsed to reach the first peak force for both the left and right feet, calculated from the data in Table 2 and Table 4.

Table 6 and Figure 2 illustrates the average time elapse to reach the first peak force for both the left and right foot across varying backpack loads and time intervals. In the pre-test period (T1), a linear increase is observed up to B3 (12% backpack load), followed by a sudden decrease at B4 (16% load) and a subsequent increase from B4 to B5 (20% load). This pattern is similarly reflected in the 5th minute (T2), where the average time elapse rises to B3, drops at B4, and then increases again at B5. At the 10th minute (T3), the data show linear progression up to B2, a slight decrease from B2 to B3, a significant drop from B3 to B4, and an increase from B4 to B5. The trend continues in the 15th minute (T4), where the average time elapse increases to B2, decreases until B4, and rises from B4 to B5. Finally, at the 20th minute (T5), the figure indicates a linear increase up to B3, a decrease at B4, and an increase at B5. Overall, this Figure 2 and Table 6 effectively captures the dynamic relationship between backpack load, time intervals, and the timing of peak forces during the gait cycle.

Table 7 displays the average time elapsed to reach the second peak force for both the left and right feet, calculated from the data in Table 3 and Table 5.

Table 7 and Figure 3 illustrate the average time elapse to reach the second peak force for the left and right feet across different recording times. At T1, the average time shows a linear progression from B1 to B3, followed by a decrease at B4 and an increase at B5. At T2 (fifth minute), fluctuations occur at B4 and B5, marked by a sudden decrease and subsequent increase. At T3 (tenth minute), there is a progression up to B2, followed by a regression to B4 and then an increase at B5. At T4 (fifteenth minute), the average time elapse increases from B1 to B2, decreases to B4, and then rises again at B5. Finally, at T5 (twentieth minute), a linear progression is observed up to B3, with a similar trend continuing from B4 to B5.

As the backpack load increases, there is a corresponding rise in the average of time elapse of force values (to get first peak force and second peak force) for both the right and left feet but there was some fluctuation noted at B4 in average of time elapse to get first peak force at T1, T2, T3, T4 and T5. A similar phenomenon was noted in the average of time elapse of the right and left feet to get the second peak force. Here, T1, is the pre-test or at the zero-minute recording. T2, is the recording of the experimentation at the fifth minute, T3, is the tenth minute recording, T4, is the fifteenth minute recording of the experimentation, and T5, and is the twentieth minute recording of the experimentation. Each of these observations was recorded independently at the specific times during the experiment.

Table 7. Average of time elapse to get second peak force of left foot and right foot at the selected bag weights with selected recording time

S.N.	Backpack load/Time	B1	B2	B3	B4	B5
1	T1	494.24	497.89	507.29	482.82	487.77
2	T2	485.59	483.77	491.12	473.30	499.00
3	T3	477.12	499.53	498.00	481.30	494.42
4	T4	482.42	500.06	495.48	481.53	493.24
5	T5	475.71	497.88	503.77	486.48	493.95

Derived from Table 3 and Table 5

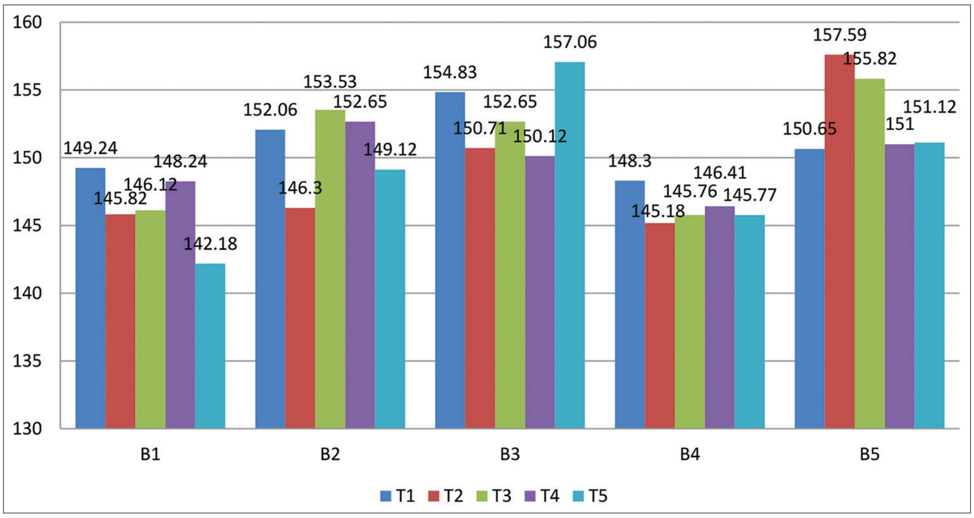

Figure 2. Average of time elapse to get first peak force of left foot and right foot at the selected bag weights with selected recording time

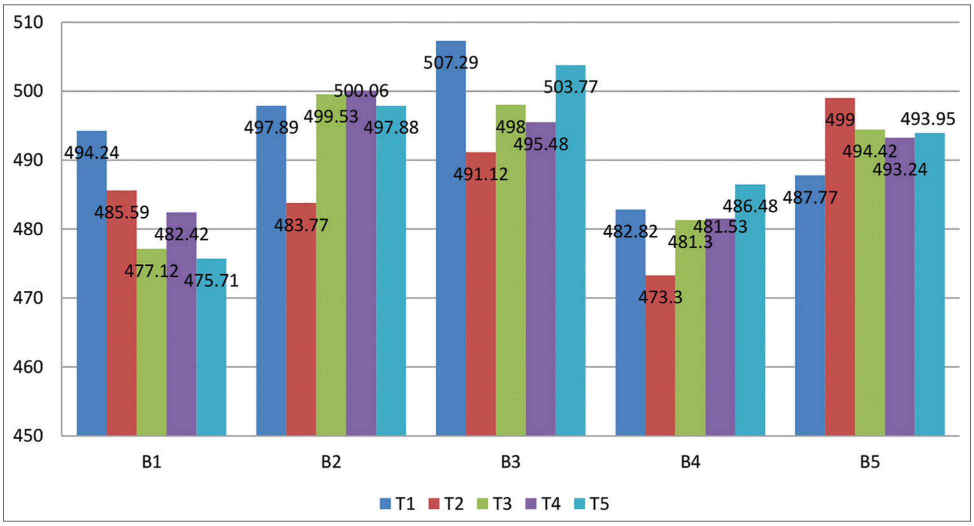

Figure 3. Average of time elapse to get second peak force of left foot and right foot at the selected bag weights with selected recording time

DISCUSSION

The study analyzed the effect of varying backpack loads and the duration of carrying these loads on the temporal patterns of peak forces during the walking gait of school-going boys using a defined protocol. The research focuses on understanding how different backpack weights ranging from 0% (no additional backpack) to backpack load of 20% of the bodyweight and walking durations from T1(zero-minute) till T5 (twentieth minute of the recording) of walking gait affect the average of time elapse to get the first and second peak forces of the left and right feet during a gait cycle. The research found that the progressive backpack loads and carrying durations of walking gait having effect on dependent variables, namely, time elapse to get first peak force of the left foot; time elapse to get first peak force of the right foot; time elapse to get second peak force of the left foot; time elapse to get second peak force of the right foot; average of time elapse to get first peak force of the left foot and right foot; average of time elapse to get second peak force of the left foot and right foot. The graphs provide a visual representation of the average of time elapse to get the first and second peak forces and trends related to backpack loads across different time intervals of the walking gait.

There is sudden decrease in the average of time elapse to get the first peak force with increasing backpack load can be attributed to several interrelated factors. The body's increased sensitivity to additional weight likely prompts quicker adjustments to maintain stability and balance, thereby altering the timing of peak forces. The added load modifies gait mechanics, impacting how forces are generated and distributed during movement. Additionally, as backpack weight increases, fatigue accelerates, leading to changes in force application and duration of the walking gait (Lenton et al., 2018). It is also found that the necessity for rapid balance and stability adjustments in response to heavier loads further influences the timing of peak forces. Strong hamstrings are critical in controlling heel strike and swing phase during walking and running, especially in altered gait studies like ours on backpack loads, helping prevent muscle strain (Islam et al., 2024). These findings are consistent with similar research, which has shown that increased external loads can disrupt normal gait patterns and force distribution (Harman et al., 2000; Seay, 2015; Ahmad & Barbosa, 2019).

It has been observed in the findings (from Figure 2 to Figure 3) that a linear progression of time elapse to get first peak force of the left foot, time elapse to get first peak force of the right foot, time elapse to get second peak force of the left foot, time elapse to get second peak force of the right foot, average of time elapse to get first peak force of the left foot and right foot as well as average of time elapse to get second peak force of the left foot and right foot, with little fluctuations which could be answered with other related gait variables which are not considered at present in the conducted study. It is considered that attributing factors for the above could be the fatigue (duration of walk) and load, as well as the interactions of the same.

Other studies on load carriage have also reported similar findings in other variables, where increase in load lead to longer contact times and peak forces during walking. For instance, studies on military personnel carrying heavy loads often show a gradual increase in peak ground reaction forces and altered gait patterns as fatigue sets in (Knapik et al., 2004). The fluctuation in peak force timing at certain load thresholds, like at B4 in the present study, is consistent with findings that suggest a critical load percentage (often between 15% to 20% of the bodyweight) where the body begins to show significant compensatory behaviour due to the added strain. Studies by Hong et al. (2008) and Chow et al. (2005) emphasized how increased load leads to alterations in gait patterns, primarily due to fatigue, which slows down walking speed and modifies temporal variables similar to the timing of peak forces as fatigue is defined as a temporary reduction in physical activity ability and force exertion capability (Balko et al., 2022; Enoka & Duchateau, 2008). The observed changes in the timing of peak forces are consistent with the body's adaptive mechanisms to manage the additional load, as documented in studies by Knapik et al. (2004) and Pau et al. (2015). These adaptations may include alterations in stride length, gait cycle duration, and peak force timing to maintain balance and reduce the risk of injury. Keeping in view the compensatory approach of the body (coordination) with the right and left foot and vice versa, the selected variables were averaged between right and left, hence produced two average variables, namely, average of time elapse to get first peak force of the left and right feet; and average of time elapse to get second peak force of the left and right feet (refer Table 6 and Table 7, and from Figure 2 to Figure 3).

At B5 (backpack load of 20% of the bodyweight) the walking gait slows as the subject adapts to the load and the average of time elapse to get the second peak force of left foot and right foot increases. Also due to the onset of fatigue the time elapse increases or variations in the subject's gait due to the progressive load, which is a common occurrence in biomechanical studies of load carrying. The study revealed that both the average of time elapse to get the first and second peak forces of the left and right feet were significantly influenced by the experimental variables, namely the backpack loads and the duration of load carriage.

The conducted study deserves further study. However, the studies in regard to the six variables, namely, time elapse to get first peak force of the left foot, time elapse to get first peak force of the right foot, time elapse to get second peak force of the left foot, time elapse to get second peak force of the right foot, average of time elapse to get first peak force of the left foot and right foot, and average of time elapse to get second peak force of the left foot and right foot have been hardly addressed in the past studies. Hence, its relationship with other related variables is considered to be the research gap for future research.

Strengths and Limitations

The study was limited to a sample of eighty-five school-going boys aged between 10 to 12 years, all from the Delhi NCR region. It specifically focused on examining the time elapse to reach peak forces. Additionally, the study was limited by its consideration of walking durations only up to 20 minutes. However, the study used a robust experimental design, ensuring that the effects observed were directly related to the varying backpack loads and walking durations. The use of advanced technology, like the Zebris FDM-S pressure plate, provided accurate data on the temporal patterns of peak forces. The study addresses an important issue related to the impact of backpack loads on school-going boys' gait, which is a relevant concern since students carry backpacks nearly every day.

Future Implications

Additional studies could explore other gait variables and include different age groups and longer walking durations. The findings could further contribute to the development of guidelines for safe backpack use in students to prevent potential injuries.

CONCLUSION

The study concluded that an increase in backpack load significantly impacts the average time required to reach both the first and second peak forces during the walking gait for both the right and left feet. Additionally, longer durations of carrying the load were found to influence the temporal variables of peak forces. Notably, heavier loads were associated with a delay in reaching the second peak force, indicating a delayed propulsion phase during gait. These temporal changes in peak forces suggest potential concerns about the long-term effects of backpack use, highlighting the need for further research in this area to better understand the implications on children's biomechanics and overall health.

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Author Contributions

RH contributed to the conception, design, data collection, and data analysis. She also prepared the tables and figures, drafted the manuscript, and revised and finalized it for publication. DWM contributed to the conception, design, and data analysis. He also prepared the tables and figures, drafted the manuscript, and revised and finalized it for publication. DS contributed to the conception, design, planning, and supervision of the research. He set the goals, provided substantive supervision, and finalized the manuscript for publication.

Ethics Approval and Consent to Participate

This study was approved by the University of Delhi's Board of Research Studies (Ref No: DPE/2023/2345). Participants were assured of voluntary participation and their right to withdraw at any time. They were also informed of their rights throughout the study, in accordance with the Declaration of Helsinki.

DATA AVAILABILITY STATEMENT

The authors can provide data upon reasonable request.

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