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The Effect of Backpack Carriage in Different Weights and Gradients on Ground Reaction Force Parameters of 10-12 Year Old Schoolchildren's Gait in Tehran, Iran

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Original Article

Abstract

Introduction: Schoolchildren have to carry their backpacks every day on routes with different characteristics and slopes. However, the knowledge available on its effects on walking biomechanics is very limited. Therefore, this study aims to evaluate the effects of backpack carriage in different weights and gradients on the kinetics of schoolchildren's gait.

Materials and Methods: 18 primary schoolchildren living in Tehran City, Iran, with age range of 10-12 years completed 7 randomized trials of walking on a treadmill (three tasks on a flat surface, including without a backpack and with backpacks with 10% and 15% of body weight load as the control group, two tasks on a 15% positive gradient, and two tasks on a 15% negative gradient). The values of the vertical ground reaction force parameters including the first force peak, second force peak, mid support force, loading rate, push-off rate, and time-to-peak (TTP) were extracted.

Results: The results of analysis of variance (ANOVA) showed that the effect of gradient on the first and second peaks, loading rate, rate of push-off, and TTP of gait was significant ($P \leq 0.001$), but the effect of backpack weights on the kinetics was not significant.

Conclusion: Carrying backpacks downhill will has more impacts on the children's motor system, so that it seemed to have a different motor control strategy. The modification of backpack carriage methods can be one of the leading strategies to reduce the negative effects of stress on the musculoskeletal system of children.

Keywords: Backpack; Gait; Kinetics; Gradient; Schoolchildren

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Introduction

Carrying a backpack, the average relative weight of which is reported to be about 11% of body weight in elementary male students in Iran (1), causes changes in the body. Increasing the ground reaction force (GRF), braking force, and propulsive force (2-10), as well as increasing the walking speed (cadence), reducing the step length, and increasing the double support time and stance (10-14) increase the likelihood of musculoskeletal abnormalities and pain due to carrying a load on a flat surface. These changes can be a sign of the adoption of compensatory mechanisms to reduce instability or reduce mechanical strain on the musculoskeletal system (12). However, it is common for students to carry heavy backpacks on different surfaces and slopes along the school route. Therefore, it is necessary to conduct studies to identify different aspects of carrying a backpack, especially in functional conditions in students.

The increase in the magnitude of the GRF in proportion to the applied load has been attributed to the load statics, trunk flexion, increase in range of motion (ROM), and hip and knee flexion while carrying the load (3,5,9,10). Numerous studies have examined the effect of gait on slope on postural and

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gait adaptations (15,16), muscle activity (16), joint kinetics and function (17-19), foot kinematics (20), and intra- and inter-limb load-sharing (21). Based on the findings of investigations on the challenges of walking with a load or on a slope (20-26), it can be assumed that carrying a backpack on an uphill is a more difficult and challenging task for schoolchildren. In a study in adults, an increase in internal-external impact, the first and second peaks of GRF and anterior-posterior force, and a decrease in stance time, which indicates an increase in walking speed and can be a compensatory mechanism for reducing body instability, have been reported while walking uphill carrying a backpack compared to unloaded control conditions (22). Additionally, carrying a backpack on a negative or positive slope of 15%, with more torso flexion and, consequently, less torso ROM, has a high negative effect on the torso movement pattern (23). According to studies, information on walking with a load on an inclined surface is scarce, and although the recommended weight range of backpacks for children is 10 to 15% of body weight, available information is limited to heavy mountaineering and military backpacks (22,24,25-27).

The present study is conducted with the aim to investigate and compare the effects of carrying a backpack with a weight of 10 and 15% of body weight on a flat and uphill surface with a slope of 15%, on the kinetics of the step [first and second force peak, minimum force, loading rate, push-off rate, and first time-to-peak (TTP)] among 10 to 12-year-old male students living in Tehran, Iran. It was hypothesized that carrying a backpack on an uphill with weights of 10 and 15% of body weight compared to a flat surface would affect students' walking kinetics.

Materials and Methods

This was a quasi-experimental study with intra-group repeated measures, which was performed as a single-blinded (evaluator) design. The statistical population of the study consisted of all elementary school students aged 10 to 12 years old in Tehran. G*Power software for designing the repeated measures with 5 measurements and power of 0.90, suggested 19 subjects (8,10,11,14). In the present study, the subjects were selected using the convenience sampling method. The study inclusion criteria were age range 10 to 12 years, male gender, individual and parent satisfaction, and dominant right hand and foot. Similarly, the exclusion criteria included having musculoskeletal pain, history of injury during the six months before the measurements, obesity with body mass index (BMI) greater than 30 kg/m^2, chronic diseases, gait and postural abnormalities based on the New York Posture Rating (NYPR) test, medication use, surgical history, severe vision and hearing problems, having a fever in the last 72 hours leading to the measurement, and drinking tea and coffee (caffeine) during the three hours before the measurement (8,11). Before performing the tests, the study was approved with the code of ethics IR.MODARES.REC.1397.045 and Iranian Registry of Clinical Trials (IRCT) registration number IRCT20180614040101N1. In the spring of 2017, the subjects were invited to the Laboratory of Motor Sciences, Central Tehran Branch, Payame Noor University.

The belt-driven instrumented HP Cosmos Gaitway treadmill with Kistler forceplates under the conveyor belt (length 1500 mm, width 500 mm, and height 170 mm above the ground), with a sampling frequency of 200 Hz was utilized. At the beginning of each session and before the data recording process began, the equipped treadmill was calibrated. Initially, each participant was informed about the evaluation process and they filled in the consent and personal information forms, then they put on the sports T-shirt and shorts, and shoes (ordinary running shoes in a similar model and in different sizes to fit the participants' feet) prepared in the laboratory. In the next step, the weight, height, and leg length (greater trochanter to external ankle) were measured using a digital scale (with an accuracy of 0.1 kg), a stature meter (with an accuracy of 0.1 cm), and a tape measure, respectively.

In order to get acquainted with the equipped treadmill and choose the walking speed, the participants were asked to walk on the treadmill for 6 minutes. The walking speed for each subject was his usual and self-selected speed. The desired speed of each person was determined and recorded at this stage and maintained in all his experiments to minimize the effect of speed on gait variables (18). Then, according to the hypothesis, in addition to the backpack-free case, they performed four experiments (two backpack weights and two flat and uphill surfaces) randomly. Each experiment lasted for 2 minutes and the data were recorded in the last 20 seconds without informing the subject. All measurements were completed for each participant in one session to reduce the effect of daily changes, but the participants were free to rest between trials. In order for single-blinding (researcher and evaluator), a code was assigned to the data of each task and this code was adapted to the data recording list at the end of the calculations. The common standard backpack with a pelvic belt was set up for all participants and filled with students' daily belongings; So that the lower edge of the backpack was in line with the fifth lumbar vertebra. At the beginning of each task, the subjects' gait was observed and they were asked to walk in the middle of the treadmill and look straight ahead while walking. After each task, the data was checked and in case of missing data and their incomplete recording or errors such as placing both feet on one of the forceplates of the treadmill, the data was re-recorded. The subjects walked on a treadmill at a preferred speed with no backpack, with a backpack with 10 and 15% of body weight, and also on three slopes of zero, +15, and -15%. Previous studies on walking have been performed in different slopes (5,7,16). Slopes in the present study were selected according to previous studies and also, the average of natural slopes of roads. The kinetic data were recorded and stored through the forceplates at a sampling frequency of 200 Hz in all conditions under 20 seconds.

The raw output of the device software was entered into the Excel software version 2013 to perform the required calculations. The data of three walking cycles were randomly selected using Random UX software version 4.2.1 and the average values of each of the desired variables in these three cycles were calculated. First, the GRF data was filtered using a Butterworth low-pass filter (LPF) with a cut-off frequency of 12 Hz. The cut-off frequency was selected based on the previous studies and sampling frequency and also using the residual analysis method. The values of the first peak, the second peak, the loading rate, the push-off rate, and the TTP were obtained by extracting the maximum or minimum digits in the initial, final, and middle intervals of the GRF. All values of the kinetic variables were normalized by the product of the total mass (person mass + bag mass) and the gravitational acceleration (2,4). The TTP was also normalized relative to the percentage of the total stance stage (28). This process was performed for each of the tasks performed by the subject. The Shapiro-Wilk and repeated measures analysis of variance (ANOVA) tests were applied to evaluate the normality of data distribution and to evaluate the difference between conditions, respectively. Bonferroni post hoc test was then used for pair-wise comparison. Finally, the data were analyzed in SPSS software (version 23, IBM Corporation, Armonk, NY, USA). $P < 0.05$ was also considered as the significant level.

Results

18 school boys aged 10 to 12 years with a mean age of 10.95 ± 0.76 years, mean weight of 34.46 ± 11.17 kg, mean height of 142.03 ± 7.83 cm, and mean BMI of 16.77 ± 3.57 kg/m^2 participated in the present study.

The results of Shapiro-Wilk test were indicative of the normal distribution of the data for all variables in different conditions of the tasks performed
($P > 0.050$). The results of the Mauchly test of sphericity showed the presence of a correlation ($P > 0.050$). Based on the results of the repeated measures ANOVA test, there was a significant difference in kinetic variables between the tasks. Table 1 presents the results of the repeated measures ANOVA test as well as the mean of the kinetic variables of the three slopes and three conditions without backpack and backpacks with 10 and 15% of body weight while walking on the treadmill.

Given the results of the repeated measures ANOVA test, the effect of surface (zero slope, +15% slope, and -15% slope) in backpack carrying conditions (10 and 15% of body weight) on kinetic variables was significant. The results of the Bonferroni post hoc test for pair-wise comparison of different conditions in each variable suggested that the effect of slope was significant in all kinetic variables ($P \leq 0.001$), but the effect of weight did not cause a significant difference. Carrying a backpack on a slope, especially downhill (-15%), led to a significant change in the calculated kinetic variables while walking, but in none of the kinetic variables was there a significant difference between the two weights.

Discussion

The findings of the present study revealed that by carrying a backpack in weights of 10 and 15% of body weight and a slope of 15% uphill, slight changes occur in the walking kinetics of 10 to 12-year-old male schoolchildren; the reduction of the minimum GRF. Weight change from 10 to 15% did not cause a significant change in variables. It seems that the higher load (15% body weight compared to 10%) of the backpack on uphill, acts as a moderator to some extent; So that despite the increase in loading rate at 10% body weight, there was less increase at 15% body weight.

Table 1. Mean kinetic and kinematic variables of participants' gait and Bonferroni test results

Variable	Without a backpack	Flat surface		+15% slope		-15% slope	
		10% body weight	15% body weight	10% body weight	15% body weight	10% body weight	15% body weight
First peak	1.17 ± 0.07	1.14 ± 0.09	1.16 ± 0.10	1.20 ± 0.11	1.19 ± 0.13	1.52 ± 0.08	1.57 ± 0.09
Second peak	1.09 ± 0.04	1.10 ± 0.07	1.10 ± 0.05	1.07 ± 0.09	1.07 ± 0.09	0.66 ± 0.07	0.68 ± 0.08
Loading rate	5.81± 0.84	5.54± 0.55	5.70± 0.72	5.86± 0.84	5.73 ± 1.04	5.09 ± 1.03	5.50 ± 1.04
Push-off rate	9.69 ± 1.05	9.89 ± 0.96	9.73 ± 0.90	9.92 ± 1.20	9.97 ± 1.15	6.10 ± 1.27	5.70 ± 0.93
TTP	20.59 ± 1.79	20.62 ± 1.21	20.48 ± 2.25	20.91 ± 1.47	21.43 ± 2.16	32.71 ± 3.74	32.01 ± 5.38

TTP: Time-to-peak

These results are consistent with the findings of previous studies (18), but there are some discrepancies (22). Of course, previous studies on adults have been carried out with a heavy or unloaded backpack and only on an inclined surface (17,18,22). In their study, McIntosh et al. considered the need to raise or lower the center of mass of the body on the slopes, the amount of work required to move the center of mass, vertical movement of the body during each step, change in the need for friction, and moving the legs forward in the oscillation phase without hitting the ground as the main topics to examine the difference between walking on a flat surface and a sloping surface (16). Therefore, based on these cases, they discussed and concluded about the variables and their changes.

There are few studies on the effects of carrying a backpack on an uphill slope on the kinetic variables of walking in primary school children. In the study by Lay et al., who evaluated walking without load on negative and positive slopes, the first and second peaks did not change significantly, but the minimum GRF showed a significant decrease (18), which was in line with the results of the present study. However, in the study by Lee et al., a significant increase was observed in the first and second peaks of the GRF on a 15-degree uphill slope (22), which is not in agreement with the findings of the present study. In their study, 15 adult men carried a military backpack weighing 25 kg (about 40% of the subjects' body weight) with a gun in their hand on a 15-degree slope (22). But in the present study, school boys carried school backpacks with a maximum weight of 15% of their body weight on a treadmill with their hands free on a 15% incline. Therefore, the discrepancy in the results may be due to these differences. Another important point is that Lee et al. in their study normalized the values of the GRF only with the body weight of each participant (22); While in the present study, these values were normalized with the total weight (participant weight + backpack weight). Therefore, this seems to be the main reason for the significance of the force peak in the present study on the uphill slope.

Another result of the present study is the lack of change of the loading rate on the uphill compared to the flat surface. The loading rate means the slope of application of the GRF. In fact, the first force peak, which of course did not change significantly on the uphill, was applied with a similar slope. This result was also observed in the TTP variable. Although there was no significant difference between the tasks in these variables, it seems that more load (weight 15 compared to 10% of the weight body) of the backpack on the slopes acts to some extent as a moderator and there is less increase in 15% body weight on the uphill compared to 10% despite increasing the loading rate.

In the available studies, the load rate variable on the slopes has not been studied, but in the study of Dahl et al., which evaluated the effect of carrying a backpack on a flat surface with weights of 15 and 25% of body weight, it was found that at 25%, the loading rate decreased relative to the load-free case (29) and the reason was claimed to be the increase in flexion angle of the knee joint at higher weights. In another study which investigated the walking kinetics of amputees while carrying a backpack, without normalization, the loading rate during carrying a load increased, but after normalization with total weight, a significant decrease was observed on the downhill (30).

There was no change in the push-off rate in the tasks. Previous research has not reported anything on the push-off rate. The push-off rate is defined as the slope of the force exerted by the legs that leads to the advance. This result is in line with other variables such as the second peak. The remarkable thing is that there is no difference between uphill and flat surface walking. In fact, for the displacement of the center of gravity (COG) upward and in the opposite direction of gravity, the normalized rate of the push-off to the total weight did not change. Another reason for the lack of change in this variable and also the second peak variable in the uphill, can be that in the uphill slope, the angle of application of the force is closer to the horizontal position and the anterior-posterior direction and shows the greatest change in the propulsive force (16,18). The results showed that in the uphill, the opposite leg, i.e. the leading leg, also helps the following leg to advance the center of mass by 11 to 31% in the double support phase (19). Since all of these variables are normalized to the combined weight (person and load) and their values do not decrease during carrying the backpack uphill, it is clear that the values of the variables increase in proportion to the applied load. In fact, the lack of change in these variables indicates that the uphill load has not led to an increase in the kinetic values of the step of the primary school children, but has increased in proportion to the applied load. This emphasizes that there are static effects of the load on the child's back that should not be overlooked; because it exerts extra stress on the children's body tissues and can lead to damage.

Another result of the present study was the reduction of the minimum GRF on the 15% uphill compared to the flat surface. This force peak corresponds to the middle phase of stance, at which the COG is at its highest during the entire walking cycle, and at the same time the knees bend, causing a decrease in the GRF and creating valleys in the vertical force diagram. Therefore, if the knee flexion occurs more at this stage, the created valley will be deeper and the minimum vertical force will be smaller. The results showed that participants in the middle of the stance, possibly with more bending of the knee on the uphill than walking on a flat surface, pursued a different strategy to continue walking on the inclined surfaces with a load as steadily as possible and with less stress. In the present study, the immediate effect of carrying load uphill was evaluated. Since male primary schoolchildren in Iran carry a backpack for about 21 minutes a day (1), the potential strain and a variety of pathological conditions is conceivable. In the ankle, knee, and thigh joints, many injuries such as osteoarthritis, anterior knee pain, anterior cruciate ligament (ACL) failure and weakness, and muscle pain and cramps are associated with walking on a slope (17). Various studies have reported the optimal weight of a backpack for students between 10 and 15% of body weight, albeit at a flat surface (25-27). Since in the present study there were small changes in walking kinetics in both 10 and 15% body weight and on inclined surfaces, and students may also walk on sloping school paths, introducing an optimal backpack weight for students faces a challenge.

Limitations

One of the limitations of the present study was the lack of familiarity of the students with walking on a treadmill and its effect on actual walking. However, it was tried to control this limitation to some extent by practicing before the tests and getting acquainted with the treadmill. Another limitation of the present study was the lack of complete similarity between the actual walking conditions on the ground with different slopes and unevenness with the walking conditions on the treadmill with different slopes.

Recommendations

Examining the kinematic and electromyographic variables in students' gait while carrying a backpack on different slopes can provide useful information about the performance of this basic skill in students. It is also recommended to use a backpack with different weights. For future studies, it is suggested that the biomechanical variables of students' gait be examined in conditions more similar to actual walking conditions compared to walking on a treadmill.

Conclusion

The results of the present study showed that slope, especially downhill, has much greater effects on the kinetics of children's gait than the weight of the load. This implies that regardless of the weight of the students' backpacks being 10 or 15% of their body weight (the weight range recommended in the research), this is the slope of the commute that poses a major challenge to the locomotor system to keep travelling safely. In general, the general impression is that walking downhill puts less strain on the body, but the results of the present study were contrary to this general perception. This is in line with the results of physiological studies that have not observed a reduction in energy consumption on the downhill. Changes in the kinetic variables of primary school students' gait as a result of carrying a backpack on a slope, especially on a downhill, confirm that these tasks are challenging relative to a flat surface and show that they have different control strategies. Therefore, considering the travel routes of students while carrying a backpack, which is varied and has different slopes, determining the optimal and safe weight of the backpack is still a challenge. However, modifying the methods of carrying load (backpack) can be one of the leading solutions for researchers.

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Authors' Contribution

Fatemeh Ahmadi-Goodini: Study design and ideation, study support, executive, and scientific services, providing study equipment and samples, data collection, analysis and interpretation of results, manuscript preparation; Mehdi Khaleghi-Tazji: Study design and ideation, study support, executive, and scientific services, manuscript preparation, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Amir Letafakar: study support, executive, and scientific services, analysis and interpretation of the results, manuscript preparation.

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Conflict of Interest

The authors declare no conflict of interest.

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