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Gait and posture responses to backpack load during level walking in children

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Abstract

Eleven primary school boys aged between 9 and 10 years old completed carrying backpack loads of 0, 10, 15, and 20% of their body weight while level walking using natural cadence. Stride and temporal parameters, trunk lean angles and trunk motion range were analyzed. The results showed that both the backpack load and walking distance exerted no significant influence on stride and temporal parameters. However, when compared with the 0, 10 and 15% load conditions, the 20% load induced a significant increase ($P < 0.05$) in trunk inclination. If trunk inclination is taken as the criteria to determine permissible backpack loads for children, those loads should not exceed 15% body weight. In addition, walking distance should be considered when permissible loads are determined.

Keywords: Trunk posture; Gait; Children; Load carriage

1. Introduction

Concern has often been raised over the heavy school bags carried by children. In Australia, Grimmer et al. [1] reported that the average load carried by children was 5.3 kg or approximately 10% of body weight. Although the mean weight of school bags in Australia was within the recommended standard for loads carried, i.e. 10% body weight, recommended by Sander [2] 50% of students still had overweight bags. Indeed, Grimmer et al. [1] found that there was strong association between the loads carried and reports of spinal symptoms.

In a study in the USA, Pascoe et al. [3] reported that the mean weight of school bags was 17% of the student's mean body weight. They found that the most common symptoms associated with overweight backpacks were muscle soreness, back pain, numbness, and shoulder pain.

The Hong Kong Society for Child Health and Development [4] reported that the mean ratio of school bag weight to body weight was 20.2%. They also found that 45 out of the 812 students examined had spinal deformities, and the mean weight of their school bags was 4.74 kg, which was marginally higher than the 4.61 kg mean of the total sample. The Society believed that there was a causal relationship between the weight of school bags and spinal deformities.

A survey of 1178 students in France conducted by Troussier et al. [5] also suggested that the habitual or prolonged carriage of excessive loads might result in low back pain and muscloskeletal disorder. Johnson and Knapik [6] found that the prolonged carrying of heavy loads in backpacks could lead to symptoms of body soreness, aches, pains, and tiredness.

In recent years, a number of studies have investigated physiological responses to load carriage such as oxygen uptake and energy expenditure and heart rate [7], or movement kinematic responses such as gait pattern and trunk posture [3,8]. Heavy loads were found to induce physiological strain and the alteration of movement kinematics. However, most of the studies that focused on children carrying loads were conducted using treadmills. Little work has been devoted to the prolonged carriage of backpacks in a field setting, which is a more realistic method of simulating load carriage during a

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normal school day. Therefore, the present study examined the possible biomechanical stresses of prolonged load carriage upon children by quantifying the adaptations of stride and temporal parameters, and trunk posture in an appropriate field setting.

2. Methods

2.1. Subjects

Twenty-three primary school boys aged between 9 and 10 years old were recruited as subjects. All children and parents were provided with all the information necessary to allow participation with informed consent. Children included in the study had neither musculoskeletal disorders nor indications of heart disease, as was determined from completion of a health history questionnaire. The experimental procedure was approved by the local Medical Ethics Committee. The study took place in a university gymnasium. The subjects came to the gymnasium for 4 different days to complete the required four sessions. In each session, the subjects were assigned to carry backpack load that was equivalent to one of the following weight: 0, 10, 15, or 20% of their body weight. In each session, the subject was walking around the perimeter of a basketball court (28 m long and 15 m wide) for 23 laps: i.e. a total of 1978 m which was approximately the average distance of backpack carrying of Hong Kong children walking from home to school [4]. The order of sessions was randomized using a Latin square design. Only 11 subjects completed the required four sessions and the data collected from these subjects were used for analysis. The mean age, body weight and body height of these subjects were 9.43(0.51) years, 31.20(5.41) kg, and 134.52(6.00) cm, respectively.

2.2. Experimental procedure

Standard clothing in the form of T-shirts, shorts and shoes was required. After consent was obtained, the anthropometry data—including body height and body weight—was recorded. At the beginning of each session, each subject was required to sit on the chair at the starting point of the walkway for 3 min, then stand with the backpack for 1 min. Afterward, the subjects were required to walk at their natural cadence around the perimeter of the basketball court. The most popular school bag—a two straps backpack—was employed in this study.

A total of three gait cycles were filmed in two dimension (2-D) for four different distances of total walking, with the first distance being one lap from the starting point of walking and the other distances having seven laps increment, i.e. 86 (1st distance), 688 (2nd distance), 1290 (3rd distance) and 1892 m (4th distance) from the starting point. The mean of the kinematics parameters of the three cycles was then calculated and used to represent the gait cycle at this distance.

2.3. Measurement

The present study was to examine the changes of gait pattern and trunk posture due to carrying two-strap backpack while level walking. The previous study [3] indicated that the load of two-strap backpack did not induce lateral spinal deviation and spinal rotation. Therefore, only the movements in the sagittal plane were considered. For this purpose, a 2-D video technique was employed to record the locomotion of subjects as they crossed the filming zone. A video camera (GY-X2BE, JVC, Japan) with a 50 Hz filming rate and a 1/250 s shuttle speed was placed 12 m to the sagittal plane of the subjects to record the locomotion. The filming field of 4 m provided at least one gait cycle for analysis. A 2 m reference bar was placed on the subject movement position before and after the experiment for calibration purposes. The recorded video was digitized and analyzed by a motion analysis system (Bewegungs Analyse System, Germany) to provide movement kinematics. A biomechanical model with 21 points and 15 segments was used in the digitization process. An experienced biomechanics laboratory technician performed the video image digitization throughout the study so that the reliability of data collection could be assured.

One gait cycle was deemed to contain the foot strike, opposite toe-off, opposite foot strike, toe-off, foot clearance, and the second strike. The stride length was measured as the distance between two consecutive heel strikes by the same foot, while the step length was the distance between two consecutive heel strikes [9,10]. Cadence was the number of steps per unit of time. Foot movement was divided into a stance phase and swing phase. The stance phase was measured as the period of time when the foot was in contact with the ground, while the swing phase was the period of time when the foot was not in contact with the ground. Double leg support duration was measured as the period of time when both feet were in contact with the ground, while single leg support duration was the period of time when only one foot was in contact with the ground [11]. Walking velocity was the average horizontal speed of the subject's center of gravity along the plane of progression.

The mean and standard deviation (S.D.) of the stride parameters, including stride length, cadence, velocity, the normalized single leg support duration (% cycle time), double leg support duration (% cycle time), stance phase (% cycle time), and swing phase (% cycle time) among the subjects were calculated by the motion analysis system. Furthermore, to compare gait characteristics across subjects, stride length, and walking velocity were normalized according to body dimensions [12]. A correction for differences in body height was made before the comparison of mean values of stride length and walking velocity [13].

The trunk leaning angle referred to the angle formed by the line connecting the shoulders and hips and the horizontal passing through the hips. Values greater than 0° represented a forward lean, while values less than 0° represented a backward lean of trunk position. The trunk range of motion referred to the range of angular motion that was observed in one complete stride.

2.4. Statistics

Two-way MANOVA (weight by distance) with repeated measures on the second independent variables were performed on the parameters of trunk posture and gait pattern. Gait pattern comprised walking velocity, stride length, cadence, stance phase, swing phase, single leg support duration and double leg support duration. Trunk posture consisted of the trunk inclination angle and range of motion. Provided the MANOVA was significant, a univariate two-way ANOVA was performed on each dependent variable to determine those which possessed significant variance. If the univariate two-way ANOVA showed significance for the main effect for distance and weight-by-distance interaction, then trend analysis was performed as a multiple comparison [14]. For the significant main effect of weight, a Tukey post hoc test was used to identify the specific mean differences between weights [14]. Statistical significance was accepted at the 0.05 level of confidence.

3. Results

3.1. Gait pattern

The two-way MANOVA analysis revealed a significant overall distance effect (Wilks' Lambda $= 0.308$, $P < 0.05$). This significant result allowed for further univariate analysis to determine which dependent variables were significant. The subsequent univariate ANOVA demonstrated a significant distance effect in walking velocity ($F = 3.148$, $P < 0.05$) and stride length ($F = 3.693$, $P < 0.05$). Trend analysis showed linear trends of walking velocity across the distances ($F = 5.929$, $P < 0.05$). Among all loads conditions, the normalized walking velocity increased from 1.40 U/s at the 1st distance to 1.47 U/s at the 4th distance. A trend analysis for stride length showed that a quadratic trend was significant ($F = 9864$, $P < 0.005$). The normalized stride length increased from 92.15 U/s at the 1st distance to 93.35 U/s at the 4th distance. Table 1 demonstrates the normalized walking velocity. Due to the missing of data, the available sample size for 15 and 20% load conditions was 9 and 10, respectively. Table 2 shows the summary of trend analysis.

The main effects of weight on both stride (walking velocity, cadence and stride length) and temporal (stance phase, swing phase, double leg support duration, single leg support duration) parameters, and weight-by-distance interaction and their univaritate ANOVA were not statistically significant. All these gait parameters displayed during load carriage were similar to that of unloaded walking, and each load displayed the same pattern of reactions to the distance.

3.2. Trunk posture

The two-way MANOVA with repeated measure performed on the trunk inclination angle resulted in significant main effects for weight and distance (Wilks' Lambda $= 0.611$, $P < 0.005$; Wilks' Lambda $= 0.676$, $P < 0.05$, respectively). Significant main effects and interaction were not found in trunk range of motion.

Table 3 shows the trunk inclination angle across distance and weight, respectively. The mean trunk inclination angle increased with the weight carried. The Tukey post-hoc assessment indicated that there was a significant increase in trunk inclination angle for the 20% load as compared with those of 0, 10, and 15% of body weight. Moreover, there was also a significant main effect for distance in the trunk inclination angle ($P < 0.05$) (Table 4), indicating that the trunk inclination angle increased as the walking distance increased.

4. Discussion

4.1. Gait pattern

In this study, the effects of prolonged load carriage on stride and temporal parameters were investigated in a field situation. As load carriage is an abnormal condition in human walking [15], one of the hypotheses tested was that the gait pattern would be affected during load carriage. However, the findings did not support this hypothesis: the walking pattern, including stride and temporal parameters, was not affected by the carriage of loads up to 20% of body weight. The means of the normal gait parameters obtained in this study are very close to those values reported by Waters [16], who derived data from the overground walking of 6–12 years old children.

4.1.1. Stride parameters

While walking velocity is an influential parameter in gait pattern, there has been little investigation regarding its adaptation when a backpack is carried. In the present study, the walking velocity did not change substantially

Table 1
Mean and S.D. of normalized walking velocity (U/s) ($N = 11$)

Weight	Distance				Mean
	I	II	III	IV	
0%	1.37(0.09)	1.43(0.18)	1.51(0.17)	1.51(0.23)	1.45(0.14)
10%	1.40(0.13)	1.43(0.12)	1.48(0.16)	1.52(0.14)	1.46(0.11)
15%[a]	1.39(0.14)	1.48(0.19)	1.45(0.18)	1.41(0.16)	1.43(0.14)
20%[b]	1.45(0.19)	1.45(0.16)	1.44(0.20)	1.42(0.18)	1.44(0.14)
Mean	1.40(0.14)	1.45(0.16)	1.47(0.17)	1.47(0.18)	

Values enclosed in parentheses represent S.D.
[a] Due to the missing of data, $N = 9$.
[b] Due to the missing of data, $N = 10$.

Table 2
Summary of trend analysis for stride parameters

	Distance effect[a]		Weight-by-distance interaction[b]	
	F	*P*	*F*	*P*
Velocity				
Linear	5.929	0.020	2.953	0.045
Quadratic	2.287	0.139	0.709	0.553
Cubic	0.005	0.943	0.266	0.849
Stride length				
Linear	1.346	0.253	1.454	0.243
Quadratic	9.864	0.003	0.787	0.509
Cubic	2.228	0.144	0.905	0.448
Cadence				
Linear	3.322	0.076	1.072	0.373
Quadratic	0.057	0.812	0.841	0.480
Cubic	0.793	0.379	0.380	0.768

[a] df = 1.
[b] df = 3.

even when subjects were carrying a load of up to 20% of their body weight. Most of the load carriage studies using backpacks have not yielded significant changes in stride length and cadence [15,17,18,8]. Only Pascoe et al. [3] found that there were significant decreases in stride length and increases in cadence with respect to normal walking when children walked overground with a backpack. However, it is difficult to compare this result with that of the present study because the walking distance and velocity were not reported by Pascoe et al. [3].

Table 4
Summary of trend analysis for trunk inclination angle and its range of motion

	Phase effect[a]		Weight-by-phase interaction[b]	
	F	*P*	*F*	*P*
Trunk inclination angle				
Linear	9.865	0.003	0.658	0.583
Quadratic	5.102	0.030	0.181	0.908
Cubic	0.33	0.858	1.432	0.248
Range of motion				
Linear	3.535	0.068	0.057	0.982
Quadratic	2.179	0.148	0.883	0.459
Cubic	0.248	0.621	0.095	0.963

[a] df = 1.
[b] df = 3.

The finding of the present study was in contrast to the speculation of Kinoshtia [19], who proposed that if walking speed was self-determined by the subjects with heavy loads, then they would prefer to walk at a slower speed using a shorter stride length. Nottrodt and Manley [20] provided evidence for Kinosthia's speculation. Nottrodt and Manley [20] found that when subjects carried loads of up to a self-determined maximum limit, the preferred walking speed relative to unloaded walking decreased, stride length decreased,

Table 3
Means and S.D. of trunk inclination angle (°) ($N = 11$)

Weight	Distance				Mean
	I	II	III	IV	
0%	3.41(4.24)	4.38(5.02)	6.28(5.27)	5.44(4.85)	4.88(4.13)
10%[a]	4.84(3.74)	5.98(2.63)	7.90(3.90)	7.87(3.34)	6.65(2.30)
15%[a]	5.98(2.98)	9.02(5.76)	7.55(6.74)	7.52(5.14)	7.52(4.81)
20%	10.64(4.47)	12.17(7.91)	12.89(5.14)	11.95(3.60)	11.91(3.65)
Mean	6.25(4.70)	7.91(5.45)	8.70(5.77)	8.22(4.80)	

Values enclosed in parentheses represent S.D.
[a] Due to the missing of data, $N = 10$.

and cadence increased. Since maximum acceptable loads were employed in that study, the results of present study can be explained by assuming that the backpacks were not heavy enough to induce changes in walking velocity, stride length, or cadence.

It has been suggested that the aim of adjusting walking velocity under conditions of load carriage is to minimize energy expenditure. It has been pointed out that many biological systems associated with muscle activity are controlled under the criterion of minimum effort [11]. The preferred walking speed is close to the most economical speed [21]. Thus, as the weight of load increases, the preferred velocity is expected to decrease to compensate for the additional energy expenditure required for load carrying. However, Hong et al. [7] found that carrying a load of up to 20% of body weight did not induce a much higher workload in children than unloaded walking. Therefore, it was not surprising to find that walking velocity did not decrease substantially in this study. It was also not surprising that walking velocity increased when distance increased.

4.1.2. Temporal parameters

Significant changes in the temporal parameters were not found in this study. The results of the present study were consistent with those of Charteris [17], who determined the temporal parameters of gait pattern under incremental loads from 0 to 60% of body weight with self-determined constant walking velocity on a walkway. He found that the temporal parameters were not sensitive to the changes in the loads carried.

Although significant changes could not be observed in the present study, the temporal parameters seemed to change slightly according to the load carried. However, there was no further change when the weight of the load was increased. This result is similar to that of Pierrynowski, Norman and Winter et al. [22], who described gait patterns in terms of mechanical energy.

However, the results of the present study were inconsistent with most load carriage studies that used backpacks. Hong and Brueggemann [8] found that walking on a treadmill with a load of 20% of body weight induced a significant increase in double leg support duration with a decrease in swing duration. Likewise, Ghori and Luckwill [15] found that there was a significant decrease in swing duration when walking on a treadmill at a constant velocity with a load of 20, 30, 40 and 50% of body weight. Changes in the temporal parameters can be attributed to the employment of constant walking velocity in these studies. According to Winter [10], the temporal parameters actually depend on walking velocity.

To conclude, gait pattern was not altered by load conditions in this study. It is possible that significant changes in gait pattern during load carriage are confined to situations where the weight is heavy enough or the walking velocity is constant.

4.2. Trunk posture

The results showed that the 20% body weight load induced significant forward lean of trunk. The forward inclination of trunk would increase as the walking distance increased. The findings indicated that the children counterbalanced the load on their back by shifting their trunk forward, and this is in agreement with the findings from studies on adults [19,23] and children [3,8].

This trunk inclination can be explained by the motor control theory. One of the main functions of motor control is to orient the body with respect to the external world, which involves maintaining posture to minimize the disturbance of balance, thus stabilizing the whole-body center of gravity.

When loaded with a backpack, the individual will try to shift the center of gravity of the body–backpack system back to that of an unloaded condition. This can be achieved by forward inclination [24], and such adjustment helps the body to minimize the energy expenditure and increase the efficiency of walking with weight.

Carrying a backpack induces deviations from natural postures, and increased the stress at the low back [25]. The prolonged postural strain caused by the trunk, which is greatly displaced from its normal position, may lead to postural discomfort and muscular pain in the shoulders, or lower back injury [25]. Goh et al. [18] found that the maintenance of stability and effective forward progression resulted in increased peak lumbosacral forces when subjects carried a load in a backpack.

In a survey of 1178 students conducted by Troussier et al. [5], the risk factors of back pain in school children were investigated. The habitual or prolonged carriage of excessive loads was found to result in lower back pain, muscular–skeletal disorders, and related compensation costs. Therefore, based on the results of the present study, load carriage of 20% of body weight would not be acceptable because it exerts significant forward inclination.

Hong and Brueggemann [8] studied the load carriage of children during treadmill walking and found that when the load increased from 10 to 15% body weight, significant trunk forward lean was observed, showing different findings from the present study. Treadmill walking, however, has been demonstrated to result in significant reduction in locomotion variability and significant improvements in local dynamic stability when compared with level walking as adopted in the present study [26]. The change in experimental condition may be the reason for the different outcomes.

4.3. Limitations

The 2-D video analysis was used in this study to detect the major biomechanics strain induced by load carriage on the gait pattern and trunk posture. This analysis may miss important 3-D variations that occur in human gait mechanics due to load. Future studies should be based on 3-D analysis so that the lateral deviation and rotation of trunk could be observed.

The study environment of a level ground presented in this study does not intend to represent the environment where children walking up and down stairs, walking to and from school up and down inclinations, and on uneven ground. These critical situations should be included in the future studies.

5. Conclusion

In this study, no significant effect of load on gait pattern was found, and significant changes in trunk posture were observed only when the loads were increased from 15 to 20% of body weight. The effects of adaptation of trunk posture under the experiment condition on musculaoskeletal strain of the low back muscles need to be studied. It has been suggested that discomfort, pain, and musculoskeletal disorders can be reduced through the prevention of postural deviations. Caution should be raised when children carry backpack loads that exceed 15% body weight for their daily schooling.

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