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Effect of Head kinematics on children's Ground Reaction Forces during Backpack Carriage

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ABSTRACT

The purpose of this study was to evaluate the effect of head angles on ground reaction forces (GRFs) while carrying ordinary backpack. **Methods:** Thirty children aged between 8-12 years. The static test, to examine the neck angles through three dimensional motion analysis cameras. The dynamic test, to examine the GRF through force platform. **Results:** No significant difference was found in the craniohorizontal angle and shoulder sagittal posture between carrying backpack and without backpack (P= 0.153 and 0.272). There was significant decrease in the craniovertebral angle in backpack than without backpack (P=0.032). There was significant increase in all GRFs values in backpack than without (P< 0.032). There was a significant positive correlation between the shoulder sagittal posture and propulsion force (P= 0.030) in backpack condition. **Conclusion:** carrying backpack with light weight 7.5% of body weight would be heavy for the child to maintain normal cervical and head posture.

Key words: load carriage; neck angles; ground reaction force; children.

INTRODUCCTION

The carriage of backpacks has been shown to constitute a considerable daily "occupational" load on the spines of school children. It is widely believed that the repeated carriage of heavy school backpacks places additional stress on the rapidly growing spine of school children, making them more prone to postural changes, and ultimately leading to lower back problems[21].

Neck and back pain are among the major problems associated with school bag carriage[13, 16]. Moreover, it was reported that the neck and shoulder were the most affected areas in children, and the younger were more affected than the older[12]. When the backpack weighs more than 10 to 15% of the student's body weight (BW), postural changes, particularly, the forward leaning of the head and trunk is a major problem that may result in spinal deformities[4]. Moreover, Backpack loads are responsible for a significant amount of back pain in children, which in part, may be due to reduced disc height, changes of curvature and greater lumbar asymmetry for common backpack loads in children[26].

Pain attributed to backpack use was reported by 33.5% of the students. Perceived backpack weight, duration of backpack carriage, posture, gender, and school district were significantly associated with reported symptoms[38]. It was stated that the combined effects of heavy loads, position of the load on the body, size and shape of the load, load distribution, time spent carrying, physical characteristics and physical condition of the individual were hypothesized as factors associated with these problems[19].

Relationships were explored between load carriage economy, the kinematics and kinetics of load carriage using both a backpack and a double pack, attention was paid to the trunk movement without giving attention to cervical angles and ground reaction forces (GRFs) during load carriage[23]. While, the effect of military load carriage on GRFs was examined and an increase of the GRF medial-lateral impulse was found during overloaded gait, and it was stated that this characteristic may be linked to a decrease in stability of gait dynamic balance[3].

Shasmin et al., [32] found that the vertical GRF increased in student carrying school bags almost three times when loads increased up to 20% of body weight compared to 10% of body weight. The anterior-posterior GRF were asymmetrical when loads were increased. When carrying school bags of 15% of body weight, all of the students adopted a compensatory trunk inclination. So, it is suggested that the safest load applied should not exceed 15% of body weight[32]. Moreover, it was concluded that the recommended load limit for school children to carry varies from 5% to 20% of their body weight[11]. But it was found that carrying backpacks weighing 15% of body weight appeared to be too heavy to maintain standing posture for school students[33]. In addition, there were significant changes in kinematics, electromyography, and discomfort scores with loads above 10% of BW[10].

Further research is needed to investigate the effect of backpack carriage in static and dynamic conditions on cervical and shoulder posture changes[6]. However, most studies dealt with the metabolic cost of the backpack carriage, but little research is concerned with kinetic and kinematic analysis of school bag carriage[20, 36]. So, the purposes of this study were 1) to evaluate the effect of carrying ordinary backpack on neck angles, and GRFs in children and 2) to correlate neck angles with GRFs in children during carrying backpack.

MATERIALS AND METHODS

Subjects

Thirty children aged between 8-12 years from both sexes were assigned to the study. All subjects were right-handed. Before the schoolbag testing, the subjects and their parents were informed about the purpose, procedures, and applications of the study. A signed parental consent form was obtained. The study was approved by the research ethical committee of the faculty of physical therapy, Cairo University.

All participated children were normal and could walk independently. They could follow the researcher's instructions during static or dynamic tests, and experienced in carrying their schoolbags. Children were excluded if they had any musculoskeletal disorders in upper limbs, lower extremities, or spines, and neurological illness which might impair their performance. The demographic data of the subjects were shown in table 1. They were assigned to a single group. The group passed by two load carriage conditions; static and dynamic loading with 7.5% of BW. The unloaded posture was compared with posture while carrying the ordinary backpack. The static test was used to examine the neck posture through measuring three angles. The dynamic test was used to examine the GRFs (five forces); in the same load carriage situations.

Instrumentations:

3-Dimensional motion analysis system with a force plate unit (QUALISYS Company, Sweden) consists of: (a) Pro Reflex infrared cameras with a frame rate of 120 Hz. The cameras were supported on a tripod stand that can be easily adjusted for proper position before capture. (b) Wand-kit, model number 130440 was used for the calibration of the system. The wand kit consists of two parts L-shaped part and T-shaped parts. (c) Personal computer for data processing and analysis with the Q-track software to capture the data from the cameras, Q-view software to view the captured data after being processed, and Q-gait software was used to analyze the exported data format (TSV). (d) Reflective markers: Fifteen silver colored markers were needed to test each child. They were of 9mm diameter. Clothing was rearranged so that shoulders and lower limbs were exposed. With the subject standing, adhesive markers were placed on the dominant side of the body. The markers of the static test were arranged in the following sequences; right eye canthus (over eye angle), right ear tragus, spinous process of C7, lateral side of the right acromion, two reference vertical markers (parallel to the sagittal plane), and two reference horizontal markers (parallel to the frontal plane) to identify both vertical and horizontal planes. The markers of the dynamic test were arranged in the following sequences; the point between the 2nd and 3rd metatarsal heads of the right foot, lateral malleolus of the right foot, posterior of heel of the right foot, lateral joint line of the right knee, over the tibial tuberosity of right knee, on the upper border of the right patella and greater trochanter of the right hip. All markers were placed on all subjects by one individual for placement consistency. These markers were stabilized to the skin by using double face adhesive straps. The position of cameras and their spatial orientation remain unchanged during the study. Any relocation of the cameras required re-calibration. (e) Force platform: An AMTI (Advanced Mechanical Technology Inc., USA) force plate was embedded in the center of walkway which had a length of six meters. Its dimensions were 40x60cm. The sampling rate of the plate was 120Hz. The force plate measures different force components in the three planes. The vertical component presented in the Z direction, the antero-posterior component presented in the X direction, and the medio-lateral component presented in the Y direction. Ordinary backpack was used during conduction of the study with dimensions of 37x25x15cm. This is one of the ordinary backpack styles presented in the domestic market.

Procedures

Calibration of camera system

Three infrared cameras were positioned on the right side of the walkway. The walkway measures 6meter length and 1.5 meter width. In order to cover the entire gait pathway, Camera (1) placed at the beginning of the walkway, camera (2) was perpendicular on the force platform and camera (3) was at the end of the walkway. Before any 3D capture could be performed, the camera system had to be calibrated first. To achieve this, the software used a calibration technique with a wand. This method required two tools: A reference structure for defining the calibration coordinate system and a wand to provide the camera system with markers presented all over the gait pathway. The reference structure was placed over the force platform.

Calibration of the force platform

The force platform must be triggered with the camera system. Then the calibration of the force plate was conducted by applying four markers. One at each corner of the force plate, then a capture was taken by the camera system. This capture allowed identification of the markers at the Q-gait software.

Static test

It was used to measure the normal neck posture angles to compare it with the posture while carrying the bag in standing position. Each child was requested to stand comfortably with bared feet at the center of the walkway, with arms beside his body in normal standing posture. To obtain more reliable and accurate results, the subjects looked directly ahead. Then a capture of 4 second time was taken by the Q-trac software. Then 7.5% of the child body weight was determined.

An assistant was present to help the child to wear the bag in a comfortable way .While the child was resting on a chair near the walkway, the assistant prepared the bag with 7.5% of the child body weight with sandbags, the test order was assigned randomly to prevent any test-order effect. The second capture: the child was asked to stand at the same place of the first capture and then the 2nd capture was taken. During the static test the 4 reference markers were presented; 2 horizontally and other 2 vertically positioned[15,31].

The measured cervical angles were (Fig.1): a) cranio horizontal angle (CHA): the angle formed at the intersection of horizontal line (4) and the line joining the tragus of the ear and external canthus of the eye line (1)[14]. b) craniovertebral angle (CVA): it is the angle formed at the intersection of a horizontal line (4) through the spinous process of C7 and line of the tragus of the ear line (2)[6]. c) Sagittal shoulder posture (SSP): the angle formed by intersection of a horizontal line (5) and the line between posterior aspect of acromion process and C7 line (3)[17].

Fig (1): Representation of lines forming cervical angles.

Dynamic test

There have been some considerations taken before capturing: 1) the subjects were familiarized with the procedures. The contact footfall was monitored visually to insure a normal footfall completely within the area of the force platform. A start point 3 paces from the force plate was found and the subjects walked over the plate at self-selected velocity and continued for further 3 paces past the force platform. The dominant limb only was studied first trained on and which foot to start to take step with, in order to allow right trials[9, 35]. 2) This was repeated until 3 clean (foot landing mid-plate) contacts with the force platform had occurred and the data was recorded. 3) The capture was taken without bag and with the child carrying a bag equals 7.5% of the body weight at the beginning of the walkway.

Data processing: data was processed using the Q-trac software then exported to the Q-gait and Q-tools as TSV files: Q-tools files were used to calculate the posture angles. Q-gait: the motion analysis data file, force data file, and force plate position file to calculate the GRF data.

Statistical analysis

Data was analyzed using the Statistical Package for Social Sciences (SPSS version 16). One-way multiple analysis of variance (MANOVA) was used to investigate the relationship between neck angles and GRFs during carrying backpack by children. The level of significant was set at 0.05 for all statistical tests.

RESULTS

Effect of carrying ordinary backpack on neck angles in children

One-way multiple analysis of variance (MANOVA) revealed that there was no significant increase in the mean value of CHA in backpack conditions when compared with that produced without backpack (P=0.153), There was a significant decrease in the mean value of CVA in backpack condition when compared with that produced without backpack conditions (P=0.032). There was no significant decrease in the mean value of SSA in backpack conditions when compared with that produced without backpack conditions (P=0.272). Descriptive statistics of the neck angles (CHA, CVA, and SSA) in children with and without carrying backpack were presented in table (1).

Table (1): Effect of backpack on neck posture that represented in CHA, CVA and SSP angles (degrees).

Angles (degrees)	Craniohorizontal angle Mean ± SD	Craniovertebral angle Mean ± SD	Shoulder sagittal posture Mean ± SD
Without backpack	24.52 ± 6.54	49.75 ± 2.79	24.43 ± 5.84
With backpack	26.86 ± 4.40	47.52 ± 3.93	22.88 ± 3.59

Effect of carrying ordinary backpack on ground reaction forces

Analysis of variance of vertical force (F1) revealed a significant increase in the mean value of F1 in backpack conditions when compared with that produced without backpack conditions (p=0.001), there was a significant increase in the mean value of vertical force (F2) in backpack condition when compared with that produced without backpack conditions (P=0.006). There was a significant increase in the mean value of vertical force (F3) in backpack conditions when compared with that produced without backpack conditions (P=0.001). Descriptive statistics of the ground reaction forces in children with and without carrying backpack were presented in table (2).

Table (2): Effect of backpack on ground reaction forces.

Forces	Vertical force (F1) Mean ± SD	Vertical force (F2) Mean ± SD	Vertical force (F3) Mean ± SD	For-aft forces (F4) Mean ± SD	For-aft forces (F5) Mean ± SD
Without backpack	378.59 ± 68.66	251.18 ± 49.10	367.18 ± 69.16	59.23 ± 18.09	66.27 ± 12.17
With backpack	419.16 ± 75.46	272.92 ± 62.48	401.24 ± 78.61	67.72 ± 21.63	78.76 ± 16.96

There was a significant increase in the mean value of For-aft forces (F4); anterior (braking) force in backpack conditions when compared with that produced by without backpack conditions (P = 0.004), there was a significant increase in the mean value of For-aft forces (F5); posterior (propulsion) force in backpack conditions when compared with that produced by without backpack (P = 0.001).

The bivariate correlations among each of the cervical angles and GRFs in both conditions were studied through the Pearson Product Moment Correlation Coefficient with a significant level of 0.05. There was a significant positive correlation between the CHA and F2 (r = 0.375, P = 0.005).The bivariate correlations among each of the cervical angles and GRFs in without backpack conditions were studied through the Pearson Product Moment Correlation Coefficient ® with a significant level of 0.05. There was a significant positive correlation between the CHA and F2 (r = 0.415, P = 0.031). The bivariate correlations among each of the cervical angles and GRFs in with backpack condition group were studied through the Pearson Product Moment Correlation Coefficient with a significant level of 0.05. There was a significant positive correlation between the SSA and F5 (r = 0.419, P = 0.030).

DISCUSSION

This study was conducted to assess the neck angles, ground reaction forces and the correlation between these two variables in school children while carrying the ordinary backpack and with no load condition. The results of the study revealed that there was an increase in CHA while carrying the backpack in relation to unloaded condition, but this difference is of no significant value. This increase was consistent with the findings of Mohan et al., [24]. However, Chansirinukor et al., [6] found that CHA decreased with loading which was against the results of this study. This contradiction may be due to differences in measurement techniques, they used two still cameras, and different software for analysis.

The CVA significantly decreased when comparing its value during backpack carrying with its value in unloaded state. That was supported by the findings of Mohan et al., [24] who examined forward head posture in different backpack placements and proved that there was a significant increase in the forward head posture for the backpack carriage in students who carry 10% of their body weight. Moreover, Moore[25] stated that any decrease in this angle would increase forward head posture, which led to increase both neck and shoulder pain.

In addition, the results of this study were consistent with the findings of Cheung et al., [7] who concluded that CVA gradually decreased with incremental increase of backpack loadings and the amount of decreases became significant from 10% of body weight in adolescents with and without neck pain. Another study on the effect of carrying backpacks on trunk posture was reported by Rahman et al., [28] who stated that carrying weight load of 15% and 20% of body weight, during level walking induced a significant increase in trunk forward lean for children aged 6 years. No significant difference in trunk forward lean was observed between 0% and 10% of body weight load condition by Bauer et al., [1].

Singh and Koh[34] showed higher forward trunk lean for dynamic conditions compared to static conditions indicating differences in strategies employed to maintain balance for static and dynamic conditions.

Sagittal shoulder posture was less in carrying backpack conditions than the unloaded conditions but this decrease was of no significant value. Raine and Twomey[29] mentioned that the smaller SSP angle indicated relatively forward shoulder in relation to C7 and so represented a more rounded position of the posture, which is in agreement with the results of this study. Chansirinukor et al., [6] indicated that a smaller sagittal shoulder angle may also represent a more rounded shoulder if the forward head posture is increased.

In contrast, Shivananda et al., [33] found that carrying backpacks weighing 15% of body weight produced a significant increase in the CHA and SSP angles which is against the findings of the current study, and CVA significantly decreased that is in agreement with the result of our study. This difference can be explained by using heavier backpack than that used in the present study. Ramprasad et al.,[30] and Kistner et al.,[18] evaluated the changes in various postural angles with different backpack weights in preadolescent children and found that the CVA changed significantly after 15% of body weight of backpack load. The head on neck, head and neck on trunk angles changed significantly after 10% of body weight of backpack load. The trunk and lower limb angle also changed significantly after 5% of body weight of backpack load. Moreover, Brackley et al., [5] found significant changes in children's trunk forward lean, and CVA when the backpack was loaded to 15% body weight.

Ground reaction forces were measured in the dynamic test, while the children walk along the walkway at their normal speed of walking. The measured GRFs in this study were F1 represents the first peak of the vertical (Z) force, F2 represents the trough of the vertical force, F3 the 2^{nd} peak of the vertical

(Z) force, F4 represents the anterior braking force, and lastly F5 posterior propulsive force. All the studied GRFs increased significantly in relation to no load test, that is in agreement with results of Chow et al.,[8] and Razali et al.,[31] who proved that the GRF increases with an increasing backpack loads. Increasing backpack load also caused significant increase in all the recorded GRF parameters.

Kinetic changes with different load carriage were studied from different views. Changes in kinetics from unloaded walking and with load carriage using both a traditional and a new rucksack design were examined. There was a significant increase in the braking (F4) and propulsive forces (F5) but these changes were not proportional to system weight. The vertical forces (F1, F2, and F3) increased significantly in proportion to increase in load[22]. However, it was concluded that shifting the center of mass posteriorly by carrying load solely in a backpack significantly reduced the force produced at toe off, whilst also decreasing stance time at the heavier loads. Conversely, distributing load evenly on the trunk significantly decreased the maximum braking force by 10%[3].

Moreover, Chow et al., [8] mentioned that the changes in the vertical GRFs are more likely to be simply due to the increased load, rather than changes in gait pattern. In the present study the vertical GRF (F1) represented 90% of body weight without backpack and increased when the child carried 7.5% of body weight to reach to 120% with the backpack. When the child was carrying the backpack there was an increase in the total vertical GRF, not only due to the increased load but also due to changes in gait pattern. When carrying the backpack it leads to forward leaning of the head and trunk which leads to movement of the center of gravity of the body anteriorly and so increase acceleration which leads to higher force.

There was deficiency in the studies examined the correlation of the cervical angles and GRFs in load carriage. The results of this study revealed that there was a significant positive correlation between the CHA and F2 during unloaded condition, the increase in this angle means more upper cervical extension. In late mid stance, the valley (F2) is created by the rise of the center of gravity as the body rolls forward over the stationary foot, called the propulsion peak[(27)]. This valley is accentuated by the momentum of the swinging, contralateral limb, which tends to unload the force plate. According to the results of the present study, this means that during unloading, the upper cervical region tends to be more flexed in relation to loaded condition and so the center of gravity tends to be more anteriorly, the more rise of the center of gravity and an increase in the propulsion peak. This correlation supporting that the increase in the F1 was not only due to the backpack weight but also due to the walking pattern and the increase in the acceleration.

Moreover, it was proved that the increased loading is due to the position of the center of gravity of the head relative to the supporting joints. With the head in a flexed position, muscle activity must be used to counteract the tendency of the head to fall forward. This muscle activity also produces compression in the cervical joints. In one model, forward flexion beyond 30 degrees produced joint reaction forces equal twice the weight of the skull[35].

There was a significant positive correlation between the SSP and F5 while carrying backpack, F5 indicates posterior propulsive force. The results revealed that the decrease in the SSP angle while carrying backpack is accompanied with decrease in the F5, which indicates that the rounding of shoulder (as the SSP decrease the shoulder rounding increases) would be accompanied with a decrease in the F5. It reflects that with the rounding shoulder, the posterior propulsive force decreases.

There are some limitations of this study. First, the weight of backpack was 7.5% of the body weight, may be considered as light weight, and the results may be different if the study was conducted at heavier weight. Secondly, the medial and lateral ground reaction forces were not measured in this study because their values were very small as they represent 5% to 7% of body weight, and so, in the children with their weight, these forces were of no significant value or difference[27].

CONCLUSION

Carrying backpack as the most common style of load carriage even with light weight 7.5% of body weight would be heavy for the child to maintain normal cervical and head posture. Moreover, during backpack condition there was positive correlation between ground reaction force (F5) and the shoulder sagittal posture.

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الملخص العربي

العنوان

الغرض من هذه الدراسة : تقييم تأثير حمل الحقيبة العادية على زوايا الرقبة ، و قوة رد فعل الأرض (GRFs) وعمل علاقة ما بين زوايا القبة و القوة المختلفة لرد فعل الارض . **التجربة :** أجريت هذه التجربة على مجموعة من الأطفال الطبيعيين وعددهم ثلاثون طفل تتراوح أعمارهم بين8-12 سنة . **الاختبار الأول :** من وضع الوقوف ثابتاً لتحديد زوايا الرقبة أثناء (حمل الحقيبة الظهرية المعتادة ، حمل الحقيبة المعدلة ذات الجانبين ، عدم حمل أي ثقل) . **الاختبار الثاني :** وهو الاختبار الحركي ويتضمن قياس قوة رد فعل الأرض في الاتجاه الرأسي والأمامي – الخلفي في كل من الأوضاع السابقة أثناء سير الطفل على الممشى والضغط على بلاطة قياس رد فعل الأرض وتضمنت القياسات رد فعل الأرض وقياس زوايا الرقبة عن طريق 3 كاميرات تحت الحمراء . **النتائج :** قد أكدت النتائج عدم وجود فروق ذات دلالات بين حمل الحقيبة و من دونها في كل من زاوية العنق الأفقية و زاوية الكتف الجانبية (p= 0.153 و 0.272) ، بينما كان هناك وجود فروق ذات دلالات في زاوية القحفي الفقري بين حمل الحقيبة و من دونها (p=) . كان هناك زيادة كبيرة في جميع قيم رد فعل الأرض في الوضعين السابقين (P > 0.032). كان هناك علاقة إيجابية ذات دلالة إحصائية بين زاوية الكتف الجانبية و F5 (p= 0.030) في حالة حمل حقيبة الظهر . **الاستنتاج :** حمل حقيبة الظهر بوزن 7.5 ٪ من وزن الجسم تكون يمثل عبء على جسم الطفل مما لا يمكنة من الاحتفاظ بوضع رأسه وعنقه في الوضع الصحيح .

كلمات البحث : حمل الثقل ؛ زوايا الرقبة ؛ قوة رد فعل الأرض ، والأطفال .