

The Effect of Backpack Carriage on Myoelectric Variables of Selected Lower Extremity Muscles in Girls and Boys with 7-10 Years Age during Forward and Backward Walking

Mohammadreza Najafian Najafabadi ^a, Heydar Sadeghi ^{b,c*}, Pedram Tehrani ^d

^a Department of Exercise Biomechanics, Physical Education Faculty, Islamic Azad University, Central Tehran Branch, Tehran, Iran; ^b Department of Sport Biomechanics and Injuries, Faculty of Physical Education and Sport Sciences, Kharazmi University, Tehran, Iran; ^c Department of Sport Biomechanics and Injuries, Kinesiology Research Center, Kharazmi University, Tehran, Iran; ^d Department of Mechanical Engineering, Islamic Azad University, Central Tehran Branch, Tehran, Iran

*Corresponding Author: Heydar Sadeghi, Department of Sport Biomechanics and Injuries, Faculty of Physical Education and Sport Sciences, Kharazmi University, Tehran, Iran; **E-mail:** sadeghih@yahoo.com

Submitted: 2020-09-02; **Accepted:** 2020-12-08; **Doi:** <https://doi.org/10.22037/jcpr.v6i1.32962>

Abstract

Introduction: Backpack is the most common tool for carrying school supplies in children and adolescents as their constant companion during the school year and even daily life. The aim of the present study was to investigate the effect of carrying backpacks with different weights on the electromyographic variables of selected lower-limb muscles of 7-10 years old girls and boys during backward and forward walking. **Methods and Materials:** A total of 26 healthy students (13 boys and 13 girls) were included in the present study using convenience sampling. Subjects performed forward and backward walking while carrying a backpack under different conditions: 0% (no weight), 10%, 15%, and 20% of their body weight. Electrical activity of the muscles of rectus femoris, biceps femoris, tibialis anterior peroneus longus, and gastrocnemius medialis muscles of the dominant leg was recorded. Repeated measures ANOVA along with Bonferroni correction coefficient test was used to compare the dependent variables under these four conditions ($P < 0.008$). **Results:** Overall, the results of the present study showed that normalized mean activation of lower-limb muscles was significantly increased while carrying the backpacks with 15% and 20% of body weight during backward and forward walking ($P < 0.008$); however, there was a significant reduction in the median frequency of the muscles under these two conditions during backward and forward walking ($P < 0.008$). In contrast, there was no significant difference between different backpack weights in terms of the co-contraction rate of the dominant knee and ankle joints during backward and forward walking ($P < 0.008$). **Conclusion:** It seems that increasing the activity level and decreasing the median frequency of selected lower-limb muscles while carrying backpacks with weighting 15% and 20% of body weight likely cause earlier fatigue and musculoskeletal injuries due to overwork; therefore, it is recommended that the backpack weight should be less than this range and close to 10% BW. Future studies are necessary to investigate other biomechanical aspects.

Keywords: Backpack; Electromyography; Lower limb; Walking

Please cite this paper as: Najafian Najafabadi M, Sadeghi H, Tehrani P. The Effect of Backpack Carriage on Myoelectric Variables of Selected Lower Extremity Muscles in Girls and Boys with 7-10 Years Age during Forward and Backward Walking. J Clin Physio Res. 2021; 6(1): e28. Doi: <https://doi.org/10.22037/jcpr.v6i1.32965>

Introduction

Backpack is the most common tool for carrying school supplies among children and adolescents as their constant companion during the school year and even in everyday life (1). Today, various features of carrying a backpack such as method of carrying it, type of backpack, backpack weight, and students' height have been considered by pediatricians, orthopedists, ergonomists, exercise researchers, physical education teachers

or even parents (2). It has been reported that in comparison with school bags for carrying loads, backpacks usually put less physiological pressure on the cardiovascular and metabolic systems and require the least muscular effort (3). However, carrying a heavy backpack can cause many musculoskeletal disorders and pain or various physical abnormalities (4).

Numerous studies have shown that heavy and inappropriate backpacks can result in localized pain and discomfort (5), fractures (6), fatigue, musculoskeletal injuries (2), increased

postural abnormalities (7), and motor dysfunctions in different areas of the body (2). The backpack weight is directly applied to the shoulders and spine, and the amount of load applied increases with increasing the students' academic level and the backpack weight so that backpacks are filled with books and other supplies such as sports equipment, after-school clothes or nutrition packages. However, the musculoskeletal system of children and adolescents is poorly growing and often cannot bear to carry heavy backpacks. To this end, it is important to be aware of the effects of different backpack weights and to prevent its negative effects on students.

Although many studies have investigated the appropriate backpack weight; there is still disagreement among researchers about the proper backpack weight as a range of 5-10% body weight (BW), maximum of 10%BW, and 10-15% as backpack weight in different studies (3, 8). A study investigated the effect of backpack carrying on pulmonary-cardiac changes among Iranian adolescent students and researchers introduced the appropriate backpack weight range of 8% BW (9). In the other two studies, the appropriate backpack weight range was suggested about 7.5%BW (10) for Iranian students and about 5% BW (11) for Saudi students. In another study, researchers reported that backpack load, even at 5% BW, could significantly change the angles of the upper and lower limbs (12).

Gait is a fundamental and common motor activity in daily life performed with the aim of slowly advancing the body in the environment and with the mechanism of muscular forces and inertia (13). So far, many studies have investigated the effects of heavy backpacks on gait biomechanics, such as head and trunk forward inclination (14), increased trunk disorders (7), change in kinetic characteristics such as increase in vertical reaction force and braking and propulsive impulses (15), muscular fatigue (2), and change in various spatio-temporal features (14, 15). Overall, backpack carrying may cause various biomechanical changes. However, it should be noted that children use different gait strategies (such as backward and forward walking, hopping, *etc.*) while carrying a backpack from home to school (or even at school). However, most of studies on effects of backpacks in children have focused on normal forward walking, and the role of backward walking has received less attention, which may in turn reduce the generalizability of the results of this type of research to real environments. Besides, new electromyography (EMG) variables such as co-contraction are nowadays used in studies that can better show the mechanism of muscle contraction during various movements. To the best of my knowledge, no study was found on the effects of backpacks on the co-contraction rate of lower-limb muscles. On the other hand, when using backpacks with different weights, knowing the

various biomechanical effects can be useful and help to prescribe the appropriate backpack weight. Finally, it should be noted that considering the use of different statistical populations in previous researches, it is necessary to carry out further studies to better identify the effects of backpacks on activity of lower-limb muscles. According to the foregoing, the aim of the present study was to investigate the effect of backpack carrying on EMG variables of selected lower-limb muscles in boys and girls aged 7-10 years during forward and backward walking.

Methods and Materials

Subjects

The statistical population of the present quasi-experimental study included all student children aged 7-10 years in Isfahan (repeated measures design). The sample size was calculated 24 people using G-Power software (test power of 0.8 and P -value<0.05 for four measurement conditions) (16). Finally, in order to reduce the existing errors and increase the statistical power, 26 healthy students (13 boys and 13 girls) were enrolled in the present study using convenience sampling. The mean±SD of age, height, and weight of students were 8.54±1.07 years, 134.96±5.11 cm, and 32.31±3.83 kg, respectively. Attempts were made to select homogeneous students in term of age, height, weight, daily activity level, and *etc.* to control the effect of these factors as much as possible. Inclusion criteria included, the ability to carry a backpack weighing 20% of one's body weight properly for two minutes, and the daily use of backpacks in the school environment and shuttling back and forth between school and home. Students with musculoskeletal, neuromuscular, or cardiovascular problems, orthopedic injuries, specific physical abnormalities, or a history of surgery in the past year were excluded from the study (12, 14). Prior to laboratory tests, the informed consent forms were obtained from all students and their parents. The present research design was registered in the Ethics Committee of Kharazmi University Research Institute of Motor Sciences with the code IR.KRC.112/1000. During the tests, two instructors were responsible for supervising the movements and protecting the children against any possible danger.

Test procedure

This study was performed in the Biomechanics Laboratory of the Faculty of Rehabilitation, Isfahan University of Medical Sciences. To record the EMG signal of the selected lower-limb muscles, a 16-channel EMG (Myon Co.) was used with an accurate measurement of one microvolt (μ V) and a sampling frequency of 1000 Hz. The excess hair of the intended site was shaved, then cleaned with alcohol to prepare the subject's skin for the

installation of the Ag/AgCl electrodes. Then, the electrodes were arranged in a bipolar arrangement about 2 cm distance from each other according to the European protocol of surface EMG for non-invasive assessment of muscles (SENIAM), on the rectus femoris (50% distance between anterior superior iliac spine and patella), biceps femoris (between the line connecting the middle of gluteal fold to knee), tibialis anterior (upper third of line between fibula tip and medial malleolus tip), peroneus longus (25% distance on the line connecting the upper head of the fibula to the lateral malleolus) and gastrocnemius medialis (upper quarter distance between the medial part of the knee joint to the heel protrusion on the inner protrusion of the muscle) of the dominant leg (1). All electrodes were placed parallel to the muscle fibers and between the muscle innervation center and the terminal tendon. To prevent the electrodes from moving during the tests, a bandage was stretched around the electrodes. The ground electrode was installed on the tibia. A foot switch was used under the medial area of the heel of the right foot to determine the start and end time of each gait step. Then, the dominant foot of the subjects was determined using three tests: hit the ball, straight leg raise, and balance (at least 2 out of 3 tests) (17).

Prior to the test, the subject practiced the correct way of backward and forward walking for 6 minutes (3 minutes each) on a treadmill. To prevent the subjects from falling and the possible dangers, they could put their hands on special handles while backward and forward walking on the treadmill. Considering the difference in height and body size of the subjects, the speed of backward and forward walking on the device was determined by subjects themselves and this speed was constant to each subject in all other backpack carrying conditions. Subjects were asked to try to walk backward and forward naturally in order to perform the tests. In addition, the load location was considered as the middle position of the load by adjusting the lower load line in the twelfth thoracic vertebra (twelfth rib) (18). In the present study, a double-strap backpack (Model: Scott Easy) with a mass of 1.25 kg was used for carrying loads. The entire backpack was raised as high as necessary by manipulating its straps to keep it fixed during movement. To finetune the backpack load at the line of the above-mentioned places, attempts were made to adjust the backpack load by placing fiber at the backpack bottom to an appropriate level (18). The gait test was performed 4 times for each subject (at 0%, 10%, 15%, and 20% BW). All tests were performed in one day and the order of gait test with backpacks of different weights was carried out to prevent systematic errors (1). The subjects were given enough time to rest between the tests and eliminate the fatigue. The gait test lasted one minute for each condition and, data were recorded for 20

seconds at the second minute while making sure that students did not notice this (18). For each gait condition, 6 successful trials were recorded in order to calculate the mean value of the dependent variables. Subjects wore their own shoes while walking. To adjust the backpack weight in proportional to the percentage of each person's weight, the everyday items used by the students, including books and notebooks, water bottles, stationery, food, and other supplies were utilized inside the backpack while trying to keep a balance on the frontal and sagittal planes (18).

At the end of the tests and after adequate rest, the subjects took maximum voluntary isometric contraction (MVIC) (two attempts for each muscle). With regard to the rectus femoris, the subject sat on a chair, and after fixing his/her ankle with a belt, he/she was asked to bring his/her knee into an extension position and external resistance was applied against the movement using a belt (19). With regard to the biceps femoris muscle, the person's leg was bent about 45 degrees from the knee joint in the standing position, and then he/she was asked to move his/her leg to a more flexed posture and resistance was applied against the movement (19). Concerning tibialis anterior, the person was placed in a standing position, resistance was applied against the dorsiflexion, and he/she was asked to produce maximum contraction (19). Regarding peroneus longus, the person was placed in a supination position in a sitting position and he/she was asked to put his/her leg in the pronation position and resistance was applied to the movement (19). With regard to gastrocnemius medialis, the person sat on the floor with his/her back to the wall, and then resistance was applied to the plantar flexion. In this case, person was asked to do his/her best to create maximum plantar flexion (19).

Data processing

First, the raw signal of muscle activity was cut for each gait movement using the software (mega win 3.0.1) (from the beginning to the end of walking). Then, to eliminate movement noise and other noises combined with the electrical signal of the muscles, the raw data were filtered using a band-pass filter (15-500 Hz) and then the signal underwent full-wave rectification. Next, the activity signal of each muscle was normalized using the maximum muscle activity in 5-sec of maximal voluntary isometric contraction of the same muscle so that the data could be compared between the different efforts of one subject or between the efforts of several subjects. On the other hand, the median frequency index of raw EMG signals was calculated using the Fast Fourier Transform (FFT) spectrum analysis program in MATLAB ver. 2015. This feature is an indicator of the displacement and transmission of the frequency spectrum and can indicate motor unit recruitment speed (20). Also, muscle co-contraction indicates the

Table 1. Results of intra-class coefficient (ICC) for electromyography variables during backward and forward walking

variable	muscle	Forward walking	Backward walking
Normalized mean activation	Rectus femoris	0.72	0.74
	Biceps femoris	0.78	0.77
	Tibialis anterior	0.75	0.74
	Peroneus longus	0.71	0.76
	Gastrocnemius medialis	0.77	0.79
Maximum normalized activity	Rectus femoris	0.74	0.71
	Biceps femoris	0.76	0.78
	Tibialis anterior	0.72	0.76
	Peroneus longus	0.75	0.72
	Gastrocnemius medialis	0.79	0.77
Median frequency	Rectus femoris	0.80	0.83
	Biceps femoris	0.78	0.82
	Tibialis anterior	0.81	0.76
	Peroneus longus	0.83	0.77
	Gastrocnemius medialis	0.76	0.79
Co-contraction	Knee joint muscles	0.83	0.79
	Ankle joint muscles	0.80	0.83

All values haveno unit

achievement of motor skills without inhibition of additional movement-dependent muscle activity considered as the inefficiency of human movements. The following equation was used to determine the directed co-contraction values (in total movement) (21).

Muscle co-contraction=1-(mean agonist muscle activity/mean antagonist muscle activity)

In this regard, the closer the number is to zero, the higher the co-contraction rate will be, and the closer the number is to 1 and -1, the lower the co-contraction will be. Overall, normalized mean activation, median frequency, and co-contraction rate of lower-limb muscles during walking were calculated as EMG indices.

Statistical analysis

First, to calculate the reliability of dependent variables between 6 repetitions of walking with backpacks of different weights, the intra-class coefficient (ICC) test and Munro's classification method were used (22). Normal data distribution and homogeneity of variances were confirmed using Shapiro-Wilk and Levene' tests, respectively. Then, to determine the effects of carrying backpacks of different weights (0%, 10%, 15%, and 20% BW), repeated measures ANOVA was utilized ($P < 0.05$). Bonferroni correction was also used to identify different conditions so that 6 comparison modes were created for 4 backpack positions. In this case, the correction coefficient was calculated 0.008 by dividing 0.05 to 6. Data analysis was performed using SPSS ver. 18.

Results

Reliability of EMG variables during backward and forward walking

The results showed ICC of 0.7-0.9 for EMG variables of selected lower-limb muscles during 6 movements of backward and forward walking while carrying backpacks of different weights. This means that all of these indices had high reliability (Table 1).

The effect of carrying a backpack on the normalized mean activation of selected lower-limb muscles while walking backward and forward

The results of repeated measures ANOVA showed a significant increase in normalized mean activation at 15% BW ($P=0.001$) and 20% BW ($P=0.001$) compared to 0% BW as well as at 20% BW compared to 10% BW ($P=0.003$) for rectus femoris; at 15% BW ($P=0.005$) and 20% BW ($P=0.001$) compared to 0% BW for biceps femoris; at 20% BW compared to 0% BW ($P=0.002$) for peroneus longus; at 15% BW ($P=0.001$) and 20% BW ($P=0.001$) compared to the 0% BW for gastrocnemius medialis while walking forward. The results also demonstrated a significant increase in the normalized mean activation at 15% BW ($P=0.001$) and 20% BW ($P=0.001$) positions compared to 0% BW as well as at 20% BW compared to 10% BW ($P=0.004$) for rectus femoris; at 20% BW compared to 0% BW ($P=0.001$) for the biceps femoris; at 10% BW ($P=0.001$), 15% BW ($P=0.002$), and 20% BW ($P=0.001$) compared to 0% BW for tibialis anterior;

Table 2. Comparison of the mean \pm standard deviation of the normalized mean activation of the selected lower-limb muscles of the dominant leg between different backpack weights while backward and forward walking

Type of movement	Muscle	0%	10%	15%	20%
Forward walking	Rectus femoris	22.68 (5.59)	25.88 (6.48)	25.81 (5.79)*	30.89 (6.13)*#
	Biceps femoris	22.63 (6.34)	30.58 (7.26)	32.14 (6.85)*	34.52 (7.44)*
	Tibialis anterior	16.44 (4.28)	17.95 (4.72)	18.32 (5.06)	19.1 (5.44)
	Peroneus longus	19.78 (4.97)	23.42 (5.76)	22.68 (5.35)	24.77 (6.09)*
	Gastrocnemius	24.48 (5.36)	27.83 (6.30)	29.80 (5.87)*	31.13 (6.38)*
Backward walking	Rectus femoris	28.93 (6.00)	33.27 (7.35)	38.18 (6.25)*	39.91 (7.29)*#
	Biceps femoris	30.41 (6.87)	33.88 (7.50)	34.74 (8.09)	38.63 (8.2)*
	Tibialis anterior	22.19 (5.23)	26.77 (6.29)*	28.16 (6.77)*	29.75 (5.91)*
	Peroneus longus	24.01 (5.23)	27.76 (6.12)	28.63 (6.49)	29.57 (6.09)*
	Gastrocnemius medialis	19.83 (4.79)	21.89 (5.31)	24.32 (5.86)	26.30 (5.07)*#

The unit of normalized mean activation is shown in MVIC; the * sign indicates a significant difference between 0% BW and other backpack weights ($P < 0.008$); the # sign indicates a significant difference between 10% BW and other backpack weights ($P < 0.008$).

Table 3. Comparison of the mean (standard deviation) of the median frequency of selected lower-limb muscles of the dominant leg between different backpack weights while walking backward and forward

Type of movement	Muscle	0%	10%	15%	20%
Forward walking	Rectus femoris	107.32 (22.06)	101.28 (25.12)	97.23 (26.17)	92.41 (23.58)
	Biceps femoris	114.5 (24.79)	101.53 (23.14)	95.88 (26.51)*	88.82 (20.43)*#
	Tibialis anterior	106.66 (19.56)	101.94 (25.83)	90.23 (23.78)*	94.08 (22.14)*
	Peroneus longus	98.89 (23.77)	91.02 (19.63)	90.55 (22.70)	85.70 (24.82)
	Gastrocnemius	125.63 (27.91)	113.89 (21.68)	117.83 (24.30)	106.06 (26.02)*
Backward walking	Rectus femoris	102.38 (26.52)	104.30 (21.76)	95.65 (23.94)	90.75 (20.19)
	Biceps femoris	118.99 (29.51)	108.15 (24.02)	101.85 (26.16)	97.21 (25.05)*
	Tibialis anterior	99.26 (21.09)	97.13 (22.76)	86.35 (24.18)*	86.97 (20.18)*
	Peroneus longus	104.17 (25.99)	97.19 (20.54)	92.03 (22.42)*	89.66 (23.28)*
	Gastrocnemius	117.97 (28.70)	113.08 (21.08)	111.96 (27.30)	106.05 (23.21)*

The unit of median frequency is in Hertz (Hz); the * sign indicates a significant difference between 0%BW and other backpack weights ($P < 0.008$); the # sign indicates a significant difference between 10% BW and other backpack weights ($P < 0.008$).

at 20% BW compared to 0% BW ($P=0.002$) for peroneus longus; and finally, at 20% BW compared to 0% BW ($P=0.001$) and 10% BW ($P=0.001$) for gastrocnemius medialis while walking backwards (Table 2).

The effect of backpack carrying on the median frequency of selected lower-limb muscles while walking backward and forward

The results of repeated measures ANOVA indicated a significant increase in median frequency at 15% BW ($P=0.006$) and 20% BW ($P=0.001$) compared to 0%BW as well as at 20% BW compared to 10% BW ($P=0.003$) for biceps femoris; at 15% BW ($P=0.004$) and 20% BW ($P=0.005$) compared to 0% BW for tibialis anterior; at 20% BW compared to 0% BW ($P=0.004$) for gastrocnemius medialis while walking forward. On the other hand, the results indicated a significant increase in the median frequency at 20% BW compared to 0% BW ($P=0.004$) for biceps femoris; at 15% BW ($P=0.003$) and 20%BW ($P=0.003$) compared to 0% BW for tibialis anterior; at 15%BW ($P=0.006$) and 20%BW ($P=0.004$) compared to 0%BW for peroneus

longus; and finally, at 20% BW compared to the 0% BW ($P=0.002$) for gastrocnemius medialis while walking backwards. In contrast, there was no significant difference between different backpack weights in terms of the mean frequency in rectus femoris and peroneus longus while walking forward ($P > 0.008$) and the rectus femoris while walking backward ($P > 0.008$) (Table 3).

The effect of backpack carrying on co-contraction rate of agonist and antagonist muscles of the knee and ankle joints while walking backward and forward

Repeated measures ANOVA showed no significant difference between different backpack weights in terms of the co-contraction rate of the knee and ankle joints in dominant leg while walking forward ($P > 0.008$). There was also no significant difference between the different backpack weights in terms of the co-contraction rate of the dominant knee and ankle joints while walking backwards ($P > 0.008$) (Figure 1).

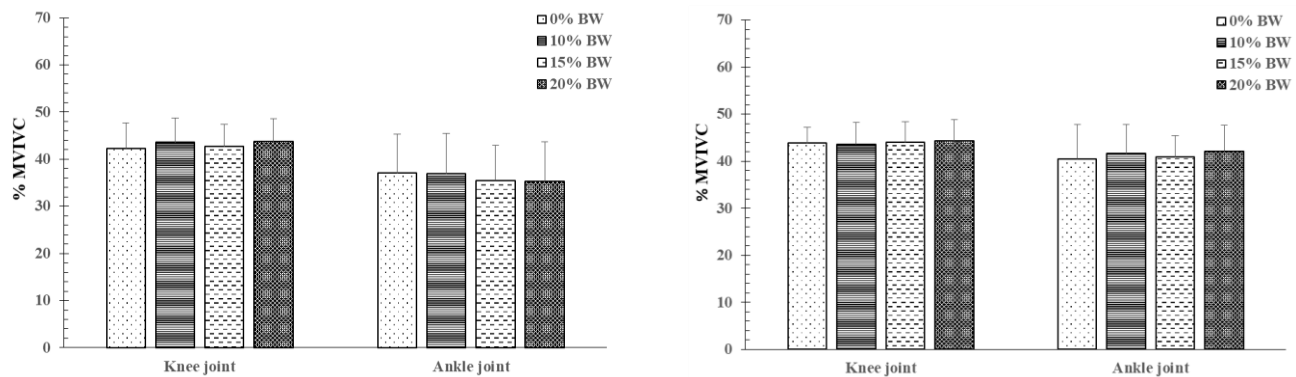


Figure 1. Co-contraction rate of the dominant knee and ankle joints between different backpack weights while walking forward (left) and walking backward (right)

Discussion

The aim of the present study was to investigate the effect of carrying a backpack with different weights on selected biomechanical variables during normal walking among girls and boys aged 7-10 years. The results showed that carrying a backpack with higher weights (especially 15% and 20% BW) increased the normalized mean activation of selected lower-limb muscles of the dominant leg while walking backward and forward. These results are consistent with the results of studies by Hong *et al.* (23), Simpson *et al.* (24), Javadipour and Fatemi (25), and Ghamariet *al.* (1). For example, Javadipour and Fatemi (25) reported that when bag weight increases to 10, 15, and 20% of the body weight, the electromyographic activity of the rectus abdominis, pectoralis major, upper trapezius, and erector spinae increases (25). Ghamari *et al.* (1) also observed that EMG activity of the quadriceps muscle group was increased by increasing the backpack weight to 15% and 20% BW. It should be noted that due to the use of different statistical populations in previous research, it is necessary to carry out further studies in this field to achieve a better understanding of the effects of backpacks on lower-limb muscle activity. Overall, increased activity of the lower-limb muscles during walking with a backpack may be due to a variety of reasons. One of these reasons, as suggested by some previous research, is the greater muscular effort by the subjects to overcome the backpack load, which occurred at 15% and 20% BW. Another reason may be the extra effort of the muscles to maintain the body stability (26). This seems likely that some research has shown the effects of carrying a backpack on reducing body stability (26). Also, another possible reason is lower-limb muscle fatigue. Increasing backpack load requires more muscular effort, which can lead to faster muscle fatigue. In this regard, Hong *et al.* (23) showed that trapezius fatigue occurs faster while walking with

backpacks weighting 20% BW. Overall, increasing the lower-limb muscle activity while carrying a backpack may increase the load applied on the muscle and cause fatigue sooner, thereby resulting in increased musculoskeletal pain and the prevalence of various abnormalities (2, 27). However, the present study did not investigate the relationship between backpack carrying with musculoskeletal pain or the prevalence of various abnormalities, therefore, it seems necessary to carry out future studies. On the other hand, Naderi *et al.* (27) stated that less than 10% BW was the best backpack weight for male students aged 10-12 years. Overall, considering that muscle activity mainly changed at 15% BW and 20% BW, it seems that the backpack weighting 10% BW is more suitable.

In contrast, the results of the present study on the effects of backpack weight on the selected lower-limb muscle activity are inconsistent with the results of the studies of Motmens *et al.* and Al-Khabaz *et al.* (28, 29). Motmens *et al.* (28) investigated the activity of trunk muscles when carrying a backpack and did not observe a significant difference in the EMG activity of trunk muscles between two conditions of carrying no backpack and the carrying a two-compartment backpack. In a study of the effects of backpack weight on the activity of trunk and lower-trunk muscles of male students, Al-Khabaz *et al.* (29) showed that carrying a backpack with different weights had no significant effect on biceps femoris, vastus medialis, and spinal erector and only activity of rectus abdominis was increased in proportion to the backpack weight. Some of the reasons for this discrepancy in the results of studies can be due to differences in the way of backpack carrying (one versus both shoulder), change in the duration and distance of backpack carrying (short versus long-term) (24, 27), and location of the backpack on the spine (lower, middle or upper part of the spine) (27). In addition, differences in the statistical population of studies (such as age, sex, level of physical activity,

geographical location, lifestyle, etc.), differences in the type of motor function (walking on the ground vs. a treadmill), and changes in the examined muscles (trunk muscles or upper-trunk versus lower-trunk) may also be other possible reasons for these conflicting results. Also, different methods of EMG signal analysis can change the mean and maximum muscle activity (30).

On the other hand, the results of the present study showed that carrying a backpack with heavier weights (especially 15% and 20% BW) reduced the median frequency of selected lower-limb muscles of the dominant leg while walking forward on a smooth surface. These results are consistent with the results of a study by Ghamari *et al.* (1). They investigated the effects of backpack weight on EMG variables of selected lower-limb muscles among 15 students aged 9-11 years in Hamedan and showed that the median frequency of lower-limb muscles was decreased by increasing the backpack weight to 15% and 20% BW (1). However, only forward walking was investigated in their study, and walking backwards used in students' daily lives, were not investigated. Overall, the decrease in median frequency of the muscles is due to the reduction in the conduction velocity of the action potential of the muscle fibers and the increase in the duration of the action potential of the motor unit and can be associated with reduced force produced in the muscle as well as decreased muscle performance (20). It should be noted that the decrease in the muscle median frequency is a clear sign of fatigue (20), which can indicate the occurrence of fatigue while carrying backpacks weighting 15 and 20% BW. In this regard, Hong *et al.* (23) observed that fatigue in trapezius muscle was created only after the first five minutes of carrying the backpack weighting 20% BW for 15 minutes. According to these studies, fatigue seems to be the reason for increasing activity and decreasing the median frequency of the lower-limb muscles while carrying a backpack weighting 15 and 20% BW. However, variables indicating general and muscular fatigue were not examined in the present study, which requires future research. Anyway, fatigue from carrying a heavy backpack can result in musculoskeletal pain or various abnormalities in different parts of the body (especially during childhood and adolescence) (2, 23). Awareness of these negative effects of carrying a heavy backpack should be considered by parents, educators, teachers, as well as students themselves.

Furthermore, the results of the present study showed that carrying a backpack with different weights did not change the co-contraction rate of the knee and ankle joints of dominant leg while walking backward and forward. Today, new EMG variables, such as co-contraction, are used in studies that can better show the mechanism of muscle contraction during various movements. Unfortunately, we found no study on the effects of carrying a

backpack on the co-contraction rate of the knee and ankle joints. However, considering that muscle co-contraction also indicates the performance of the neuromuscular system during each movement (21, 31), it seems that effects of carrying backpacks with different weights have been only created on the muscular characteristics and have not made major changes in the nervous system that controls the lower-limb muscles.

In the present study, the effect of backpack carrying on the body stability was not investigated, therefore further studies are warranted. Also, the kinematic and kinetic aspects and their relationship with the EMG aspect of the lower-limb muscles during backpack carrying were not addressed in the present study, which are suggested as new research fields in future research. On the other hand, considering small number of studies on the effects of backpack carrying on the muscle co-contraction rate, it is necessary to conduct more studies to investigate this biomechanical aspect as closely as possible.

Conclusion

The results of the present study showed that increasing backpack weight (especially at 15% and 20% BW) increased the activity and decreased the median frequency of the selected lower-limb muscles. These changes likely cause earlier fatigue in students and increase the risk of musculoskeletal injuries. In contrast, carrying backpacks with different weights did not change the co-contraction rate of the dominant knee and ankle joints of 7-10-years old students while walking backward and forward. It seems that a change in backpack weight only affects the muscular characteristics of the lower limbs, but not major changes in the control of the nervous system of these muscles. On the other hand, due to small biomechanical changes under the conditions of carrying a backpack weighting 10% BW, this weight range is suitable for a backpack.

Acknowledgments

None

Conflict of interest:

None

Funding support:

None

Authors' contributions:

All authors made substantial contributions to the conception, design, analysis, and interpretation of data.

References

1. Ghamari Hss, Babakhani F, Anbarian M, Hajiloo B. Effect of carrying backpack with different loads on electromyography activity of selected lower limb muscles during walking in elementary school students in Hamedan city. 2016.
2. Whittfield J, Legg S, Hedderley D. Schoolbag weight and musculoskeletal symptoms in New Zealand secondary schools. *Applied ergonomics*. 2005;36(2):193-8.
3. Mohammadi S, Mokhtarinia HR, Tabatabaee F, Nejatbakhsh R. Surveying ergonomic factors of backpack in tehranian primary school children. *Razi Journal of Medical Sciences*. 2012;19(102):1-11.
4. Safar Dezfooli M, Amiri M, Mortezaei SR. User Centered Approach to Designing an Ergonomics Backpack for Student Aged 7-9. *Honar-Ha-Ye-Ziba: Honar-Ha-Ye-Tajassomi*. 2012;4(47):75-85.
5. Noll M, Candotti CT, Rosa BNd, Loss JF. Back pain prevalence and associated factors in children and adolescents: an epidemiological population study. *Revista de saude publica*. 2016;50:31.
6. Birrell SA, Haslam RA. The effect of load distribution within military load carriage systems on the kinetics of human gait. *Applied ergonomics*. 2010;41(4):585-90.
7. Chow D, Leung K, Holmes A. Changes in spinal curvature and proprioception of schoolboys carrying different weights of backpack. *Ergonomics*. 2007;50(12):2148-56.
8. Mackie HW, Stevenson JM, Reid SA, Legg SJ. The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure. *Applied ergonomics*. 2005;36(2):199-206.
9. Daneshmandi H, Rahmani-Nia F, Hosseini S. Effect of carrying school backpacks on cardio-respiratory changes in adolescent students. *Sport Sciences for Health*. 2008;4(1-2):7-14.
10. Namazizadeh M, Ebrahim K, Sarreshte M, Salehi H. Kinematic effects of carrying backpack on walking and postural status in adolescents. *Journal of motion (Harekat)*. 2003;16:5-23 (In Persian).
11. Al-Hazzaa HM. School backpack. *Saudi medical journal*. 2006;27(10):1567-71.
12. Ramprasad M, Alias J, Raghuvver A. Effect of backpack weight on postural angles in preadolescent children. *Indian pediatrics*. 2010;47(7):575-80.
13. Oatis Carol A, PT P. *Kinsiology the mechanics and pathomechanics of human movement*. Champaign (IL): Human Kinetics; 2009.
14. Orantes-Gonzalez E, Heredia-Jimenez J, Beneck GJ. Children require less gait kinematic adaptations to pull a trolley than to carry a backpack. *Gait & posture*. 2017;52:189-93.
15. Liew B, Morris S, Netto K. The effect of backpack carriage on the biomechanics of walking: a systematic review and preliminary meta-analysis. *Journal of applied biomechanics*. 2016;32(6):614-29.
16. Erdfelder E, Faul F, Buchner A. GPOWER: A general power analysis program. *Behavior research methods, instruments, & computers*. 1996;28(1):1-11.
17. Hoffman M, Schrader J, Applegate T, Koceja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *Journal of athletic training*. 1998;33(4):319.
18. Jadidian AA, Shirzad E. The Effect of the Height of Placement of Two Types of Backpacks on Gait Kinetic and Kinematic Parameters in Schoolchildren Aged between 8 and 11. *Journal of Exercise Science and Medicine*. 2018;10(1):91-110.
19. Tabard-Fougère A, Rose-Dulcina K, Pittet V, Dayer R, Vuillerme N, Armand S. EMG normalization method based on grade 3 of manual muscle testing: Within-and between-day reliability of normalization tasks and application to gait analysis. *Gait & posture*. 2018;60:6-12.
20. Hall JE, Hall ME. *Guyton and Hall textbook of medical physiology e-Book: Elsevier Health Sciences*; 2020.
21. Kellis E, Arabatzi F, Papadopoulos C. Muscle co-activation around the knee in drop jumping using the co-contraction index. *Journal of Electromyography and Kinesiology*. 2003;13(3):229-38.
22. Ghasemi MH, Anbarian M, Esmaeili H. Immediate effects of using insoles with various wedges on activation and co-contraction indices of selected trunk muscles during load lifting. *Applied Ergonomics*. 2020;88:103195.
23. Hong Y, Li J-X, Fong DT-P. Effect of prolonged walking with backpack loads on trunk muscle activity and fatigue in children. *Journal of Electromyography and Kinesiology*. 2008;18(6):990-6.
24. Simpson KM, Munro BJ, Steele JR. Backpack load affects lower limb muscle activity patterns of female hikers during prolonged load carriage. *Journal of Electromyography and Kinesiology*. 2011;21(5):782-8.
25. Javadipor M, R F. Electromyography changes in trunk muscles of student bodys at 12 years old on carrying bag with different weight. *J pazhuheshdarolumvarzeshi*. 2010:55-6.
26. Singh T, Koh M. Lower limb dynamics change for children while walking with backpack loads to modulate shock transmission to the head. *Journal of biomechanics*. 2009;42(6):736-42.
27. Naderi A, Shaabani F, Malki F, Khosravi F. Kinematic changes of body alignment resulting from backpack weight, location and carrying duration in 10 to 12 years old boy schoolchildren. *Journal of Applied Exercise Physiology*. 2017;13(25):25-36.
28. Motmans R, Tomlow S, Vissers D. Trunk muscle activity in different modes of carrying schoolbags. *Ergonomics*. 2006;49(2):127-38.
29. Al-Khabbaz YS, Shimada T, Hasegawa M. The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. *Gait & posture*. 2008;28(2):297-302.
30. Hug F. Can muscle coordination be precisely studied by surface electromyography? *Journal of electromyography and kinesiology*. 2011;21(1):1-12.
31. Robertson DGE, Caldwell GE, Hamill J, Kamen G, Whittlesey S. *Research methods in biomechanics: Human kinetics*; 2013.