Kinematic and electromyographic analysis of school children gait with and without load in the backpack

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Abstract   **Introduction:** Excessive load on the backpacks can lead to musculoskeletal injuries and gait alterations. The objective of this study was to analyze the electromyographic (EMG) activity in association to the kinematic during the stance and balance phases of gait performed with and without the use of the backpack. **Methods:** Twelve volunteers have executed a gait cycle in 3 tasks: without the school backpack (SM), with a backpack with load equivalent to 10% (M10) and 20% (M20) of the body weight (BW). It was evaluated the ankle, knee and hip angular excursion (AE), linear displacement (LD) of the toe and ankle, knee, hip, shoulder, head and EMG activity of the tibialis anterior (TA), vastus medialis (VM), rectus abdominis (RA), gastrocnemius lateral (GL), biceps femoris (BF) and spinal erector (EE) muscles. **Results:** In the LD in the stance phase there was an AP increase for the toe and ankle, hip and head (p<0.043). In the balance phase for VT (vertical) direction, the shoulder presented a smaller displacement as well as the toe, ankle, knee, hip, shoulder and head in the ML direction. In the AP direction, the toe displacement was smaller as well as the ankle (p < 0.038). The AE in both phases was smaller for the hip (p <0.006). In the balance phase the IEMG was higher for the RA (p = 0.034). **Conclusion:** These results suggest that the transport of school backpacks with loads of more than 10%BW causes changes in the kinematic and in the muscular recruitment pattern.

Keywords   Kinematic, Gait, Electromyography, Overload, School children.

Introduction

The majority of children in school age have been carrying backpacks with loads exceeding the limits recommended by the world Health Organization (10% of the body weight - BW) (Rodríguez-Oviedo et al., 2012; Sheir-Neiss et al., 2003). The transport of excessive load induces biomechanical changes on the musculoskeletal system, and then it modifies the posture and the human gait (Ries et al., 2012; Rodríguez-Oviedo et al., 2012). Ries et al. (2012) observed head in previous position to the shoulders with the increased load of the school

backpack above 10% BW. Modifications like the increase of the anteroposterior balance and anterior trunk inclination, the increased cervical lordosis and lumbar and asymmetry of the shoulders were also identified as a result of the transport of excessive loads in the school backpack (Bauer and Freivalds, 2009; Lee and Shim, 2015; Ries et al., 2012; Rodríguez-Oviedo et al., 2012).

Kinematic modifications in the gait have been showed as result of the central nervous system attempt to adapt itself to the new condition of postural change. Among the main modifications; it could be observed the reduced speed, step length and vertical displacement, besides an increased lateral displacement (Hung et al., 2013) and the frequency of the step (Pascoe et al., 1997). It was also remarked that variable loads (0%, 7.5%, 10%, 12.5% and 15% of BW) in adolescents reduce the speed and cadence, and also increase the time of double stance (Chow et al., 2011). The weight increased in their backpack can also produce previous tilt of the head and trunk during the gait (Grimmer et al., 1999). Therefore, the adequate displacement during the gait depends primarily on the amount of weight transported in a backpack (Rugelj and Sevsek, 2011).

All these modifications could lead to change in the electromyographic (EMG) activity and muscular recruitment. The external force and mechanical tension produced by load in school backpack increases the demands on the musculature of all joints of the lower limb (Chow et al., 2011) and provoke some compensatory adjustments in posture required to maintain the dynamic balance during the gait (Malhotra and Gupta, 1965). For example, Al-Khabbaz et al. (2008) observed EMG alterations in trunk muscles (rectus abdominis and spinal erector) during the transport of schoolchildren backpacks.

The interpretation of EMG is important since it can provide information about motor control and facilitate the understanding of the kinetic and kinematic aspects of locomotion (Ozgül et al., 2012). The majority of studies aimed only at gait changes (Chow et al., 2011; Holt et al., 2005; Hong and Brueggemann, 2000; Hong and Cheung, 2003), but a few analyses were associated with the quantification of the EMG activity in the lower limbs (Hong and Cheung, 2003) and trunk (Al-Khabbaz et al., 2008; Chow et al., 2011). Moreover, when muscles were considered in this analysis, the assessment of muscular involvement was addressed only in a descriptive way through interviews made with the participants (Brackley et al., 2009; Rodríguez-Oviedo et al., 2012). The non-quantification of this analysis could miss important information on variability of EMG activity (Granata et al., 2005).

According to what was previously observed, we believe that checking the EMG activity in association to kinematic would help better understand the changes caused by the use of the backpack with excessive load on schoolchildren during the gait; in parallel, it contributes positively with the diagnosis and early therapeutic interventions (Ries et al., 2012). The objective of this study was to analyze the EMG activity of major muscles of the lower limb including: tibialis anterior (TA), vastus medialis (VM), gastrocnemius lateral (GL), biceps femoris (BF) and major muscles of the trunk as rectus abdominis (RA) and spinal erector (EE) in association with the kinematic (angular excursion and linear displacement) data during a gait performed with and without the use of school backpack. The hypothesis of this study was that the transport of school backpacks with loads over 10% of BW would result in changes in the kinematic and in the EMG activity. This is particularly important, once the children are both in the period of physical and motor development (Bauer and Freivalds, 2009; Hong et al., 2008) and changes that are not identified in the childhood tend to persist and/or worsen in the adult life, becoming into chronic lumbar pain, muscle fatigue and spine deviations (Hong and Cheung, 2003; Ries et al., 2012; Rodríguez-Oviedo et al., 2012).

Methods

Subjects

Twelve male children participated of the study, they were between 9 and 11 years old and had neither been inflicted with a musculoskeletal nor neurological injury, fractures or use of prosthesis in the lower limbs, whose parents and/or guardians signed the Free and Informed Consent Term (FICT). The averages age, height and weight of the participants were respectively 9.0 ± 0.67 years old, 136.51 ± 4.6 cm and 33.7 ± 6.9 kg. This research has been approved by the Ethics Committee of the Federal University of Uberlândia (Protocol 857/11).

According to the World Health Organization (WHO), the male puberty starts at the age of 13 years old, while female puberty begins at around 9-10 years of age, and the puberty may be accompanied with various hormonal changes that cause musculoskeletal disorders as accelerated growth, extending the hips, appearance of breasts and changes in weight (Tanner et al., 1975). Considering the influence of these factors in gait and muscle activity (Aleixo et al., 2012; Sperotto et al., 2015), the authors decided to evaluate only male children before puberty.

Instrumentation

Electromyography

For the collection of EMG signal, the local of fixation for each electrode was cleaned with cotton soaked in 70% alcohol for 10 seconds, and, when necessary it was performed the hair waxing. The bipolar surface electrodes (DhT_EASD1: 20 gr; 2 cm × 0.6 cm × 2.5 cm; two parallel silver plates separated by 1 cm; Gain = 20x; Input impedance = 10 GΩ; Common mode rejection ratio = 90 dB) were connected to the electromyographic equipment (MyosystemBr1_P84: DataHominis Technology Ltda, Brazil; Gain = 100x (total gain = 2000x); Band-pass filter = 15 Hz to 1000 Hz; Sampling frequency = 2000 Hz; Data recorded in microvolts (µV)), which, in turn, was connected to a IBM-PC standard computer. The electrodes were positioned with a distance of 2 cm from each other and fixed with adhesive tape - adhesive plaster- on the tibialis anterior (TA), vastus medialis (VM), rectus abdominis (RA), gastrocnemius lateral (GL), biceps femoris (BF) and spinal erector (EE), according to the orientation of the 'Surface Electromyography for the Non-Invasive Assessment of Muscles – BIOMED II' (SENIAM) (Hermens et al., 2000) (Figure 1). For all volunteers and data acquisitions, the sites were identified and prepared by the same researcher.

Kinematics

The kinematic data were obtained by a computerized system, with eight infrared cameras (OptiTrack FLEX V100R2, Natural Point, Corvallis, Oregon) arranged
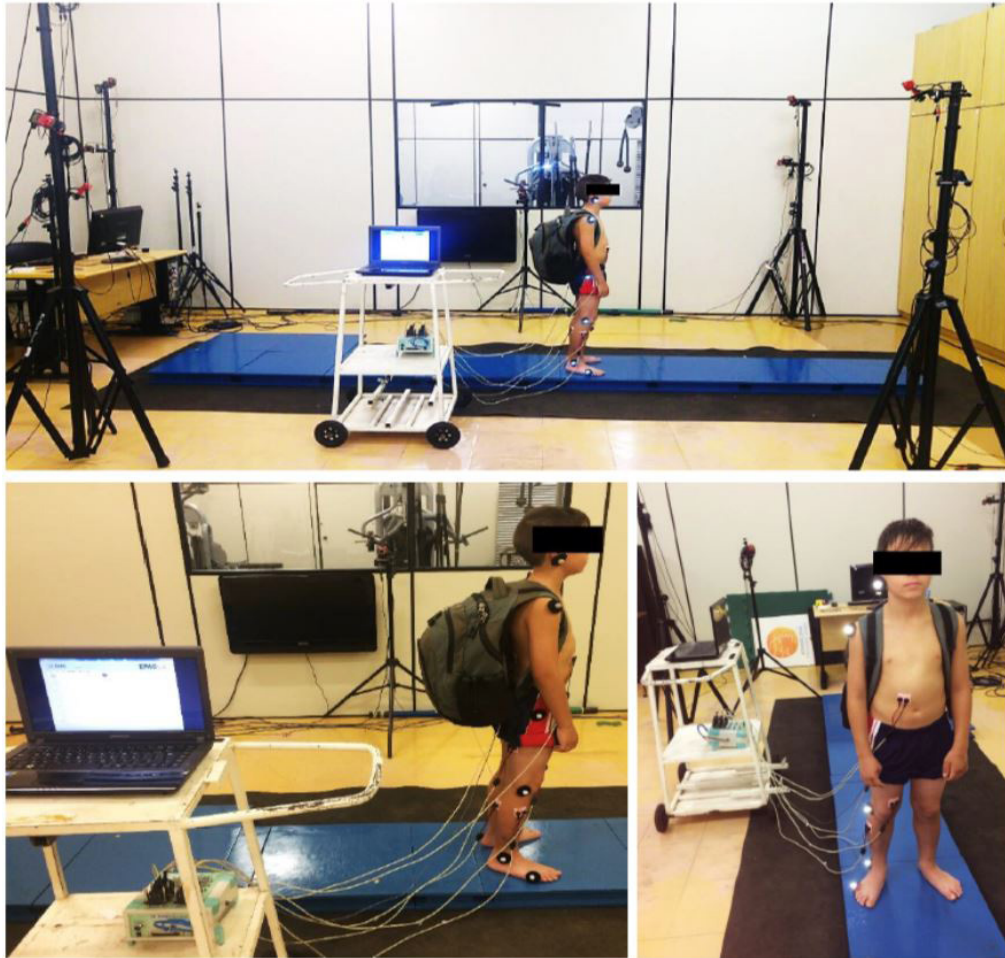
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Figure 1. Experimental protocol, showing electrodes and kinematic markers in place.

so that they could capture the trajectory in 3D and register the linear displacement of gait by means of identification of circular reflexive markers fixed on the skin to a frequency of 100 Hz. The reflexive markers could capture and reflect the infrared light, which is then captured by the camera lens. The local of fixation of each reflective marker was cleaned by a cotton cloth soaked in 70% alcohol for 10 seconds. When necessary, it was also performed the hair waxing. The markers were fixed on the following anatomic points: ear pinna (ear lobe - head); the lateral aspect of the acromion (shoulder); the greater trochanter of the femur (hip); lateral epicondyle (knee); lateral malleolus (ankle) and; the fifth metatarsal head (toe) (Figure 1).

Procedures

It was initially performed the evaluation of the personal data (name, age) and anthropometric data (weight and height collected by mechanical anthropometric scale) of the participants.

Then the cameras were calibrated and synchronized so that they could begin capturing images simultaneously. The system of cameras and the electromyograph was synchronized to start the images capture and the muscular activities at the same time, from the same manual shot (trigger) performed by the same researcher. A single school backpack was used for all the samples. She had bilateral shoulder handles, upholstered and adjustable, as well as a waist belt also adjustable. The backpack was weighed and then calculated the load according to the percentage of BW of each participant.

The data collection was carried out with the participants who were wearing only swimming shorts and they were barefoot. The EMG and kinematic data were captured during a gait step. The step was on a flat ground during three different tasks: without the backpack (SM); with a backpack loaded with 10% BW of the participant (M10) and with a backpack loaded with 20% BW (M20). Before the data capture, the participants had

gotten familiar with the procedure in order to obtain the gait performed as natural as possible. Each task lasted 4 seconds and they were repeated three times with a rest period of 30 seconds, being ordered randomly (using the software Excell 2003). At the end of each task, the participant was repositioned in demarcated position on the ground for the beginning of the new task.

Data processing

Data was processed offline by Excel (Microsoft, Office XP 2003) and KaleidaGraph (Synergy software, version 3.08). From the kinematic coordinates in 3D of the gait trajectory, the linear displacement (LD) it was calculated in anteroposterior (AP), vertical (VT) and mediolateral (ML) directions. A low-pass filter with cut-off frequency of 5 Hz filtered the kinematic data and subsequently the hip, knee and ankle angle displacement were calculated. The EMG signals were rectified (full wave), aligned, filtered at 25 Hz, and normalized by peak of EMG activity. All procedures using the KaleidaGraph (Synergy software, version 3.08), and all kinematic data were normalized at the time by the gait cycle from 0% (first heel stride) to 100% (second heel stride) of the same foot (Figure 1). The average of three repetitions was calculated; from this average, it could be calculated the maximal LD, angular excursion - AE (maximal minus minimal angular displacement) of each task and the integral of the EMG activity (IEMG) during the stance and balance gait phases. These phases were defined by visual inspection (Ghoussayni et al., 2004) taking into account the analysis of the linear displacement of the marks of the ankle and the tiptoe (Figure 2).
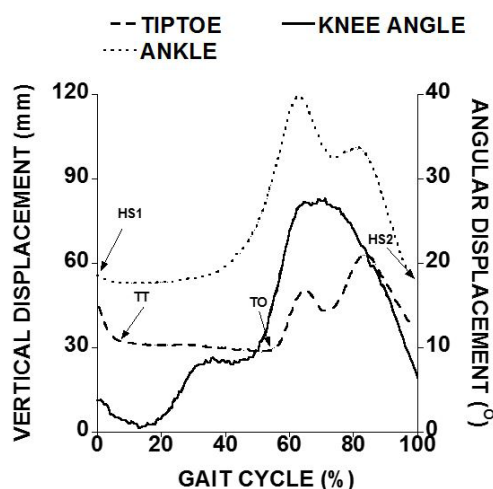
Figure 2. Vertical displacement and angular displacement of the gait cycle, from 0% (first heel stride) to 100% (second heel stride) for the same foot. HS1: first heel stride; HS2: second heel stride; TT: tiptoe touch; TO: removal of tiptoe.

Statistical analysis

The average of linear displacement, AE and the IEMG activity of all participants were organized in tables. The Shapiro-Wilk W test (Ghasemi and Zahediasl, 2012) did not confirm the normal distribution for all variables. So, they were applied the Wilcoxon test, in order to compare the tasks with and also without the load. The significance level was considered ≤ 0.05.

Each participant was used for his own comparison, and therefore, we used a repeated measure test (General Linear Model) with Bonferroni adjustment. We used three level factors (conditions [M, M10, and M20] x [linear displacement, AE or IEMG]), for each phase (stance and balance) separately. When there was a significant condition effect, the post hoc comparison was used comparing two factors separately [M × M10], [M x M20] and [M10 x M20]. All the tests were performed in IBM© SPSS© (version 22) and we used, for statistical, significance level at 0.05 for all comparisons.

Results

Linear displacement

The results showed that, in the stance phase, when the three conditions were compared for VT and ML direction, there was no significant difference (Table 1). However, for AP direction there were significant differences between the conditions. The post hoc showed that the AP direction was larger for toe and ankle in M20 condition compared with SM condition. Similar to that, M20 was larger for hip compared with M10 condition. Although, for head in AP direction, SM condition showed larger displacement compared with M10 and M20 conditions (Table 1).

In the balance phase the results reveled that in VT direction no differences were shown for toe, ankle, knee, hip and head; whereas shoulder presented difference. The shoulder displacement was smaller in M20 compared with M10 condition (Table 2). The AP and ML directions were different between conditions. The post hoc showed that M20 condition was smaller than M10 condition for toe, ankle, knee, hip, shoulder and head ML direction. In AP direction, during M20 condition, toe displacement was smaller compared to SM condition; in M20 condition and ankle displacement, it was also smaller compared to M10 condition (Table 2).

Angular excursion - AE

The AE during stance phase was similar for ankle and knee joints, although hip showed differences. In SM condition, the AE was smaller than M10 and M20 conditions (Figure 3; Table 1). The same results were observed during the balance phase, and hip AE was smaller in SM condition, compared with M10 and M20 conditions (Table 2).

Table 1. Mean and standard deviation of kinematic variables for stance phase.

Variables	Conditions			Statistics					
Stance Phase	*SM*	*M10*	*M20*	**SM vs M10**		**SM vs M20**		**M10 vs M20**	
Linear displacement (mm)									
				F	*P*	*F*	*p*	*F*	*p*
Toe ML	-60.83 (75.75)	-57.05 (80.89)	-53.18 (77.34)	NS					
Toe AP	-154.04 (57.75)	-172.00 (52.69)	-188.35 (57.92)	1.218	0.293	6.547	**0.027**	2.278	0.159
Toe VT	32.85 (3.33)	31.93 (3.19)	32.11 (3.50)	NS					
Ankle ML	-74.32 (87.19)	-68.85 (89.99)	-64.15 (86.64)	NS					
Ankle AP	-250.04 (54.94)	-268.43 (48.62)	-284.54 (52.67)	1.283	0.282	6.882	**0.024**	2.219	0.164
Ankle VT	57.17 (7.25)	57.23 (7.53)	56.28 (7.16)	NS					
Knee ML	-60.75 (71.47)	-59.59 (72.99)	-53.97 (66.69)	NS					
Knee AP	-209.89 (64.10)	-216.61 (65.60)	-236.77 (67.33)	0.161	0.696	2.994	0.112	3.455	0.090
Knee VT	404.25 (17.63)	403.21 (18.09)	402.35 (18.15)	NS					
Hip ML	-31.42 (49.73)	-30.67 (49.69)	-23.35 (41.98)	NS					
Hip AP	-226.57 (59.86)	-228.44 (56.70)	-250.88 (51.49)	0.013	0.912	2.719	0.127	5.224	**0.043**
Hip VT	715.13 (31.66)	714.29 (31.93)	713.83 (32.55)	NS					
Shoulder ML	-11.09 (38.12)	-10.23 (33.45)	-5.20 (22.39)	NS					
Shoulder AP	-207.50 (69.06)	-179.45 (56.48)	-188.17 (48.29)	3.022	0.110	1.906	0.195	0.988	0.342
Shoulder VT	1087.32 (39.86)	1080.34 (39.24)	1077.68 (40.11)	NS					
Head ML	-91.22 (84.85)	-94.50 (86.14)	-92.00 (78.40)	NS					
Head AP	-161.11 (67.10)	-114.36 (49.18)	-124.79 (51.07)	7.891	**0.017**	5.829	**0.034**	1.103	0.316
Head VT	1216.51 (44.02)	1176.75 (133.47)	1202.86 (43.95)	NS					
Angular excursion (degree)									
Ankle	17.84 (5.06)	17.85 (2.93)	18.84 (5.59)	NS					
Knee	6.70 (2.97)	6.48 (2.98)	6.50 (2.27)	NS					
Hip	11.61 (4.59)	17.37 (7.30)	19.02 (6.11)	11.586	**0.006**	36.431	**0.000**	1.455	0.253

The statistics include post hoc results comparing two factor separately using repeated measures SM vs M10, SM vs M20 and M10 vs M20 conditions, task without the school backpack (SM), with a backpack loaded equivalent to 10% (M10) and 20% (M20) of body weight (BW). When repeated measures, testing the main effect, were not significant (p>0.05), post-hoc tests were not conducted (NS). Bold values indicate significant differences (p<0.05). ML: mediolateral; AP: anteroposterior; VT: vertical.

Table 2. Mean and standard deviation of kinematic variables for the balance phase.

Variables	Conditions			Statistics					
Balance Phase	*SM*	*M10*	*M20*	**SM vs M10**		**SM vs M20**		**M10 vs M20**	
Linear displacement (mm)									
				F	*P*	*F*	*p*	*F*	*p*
Toe ML	-58.32 (72.04)	-60.02 (75.21)	-44.55 (68.14)	0.157	0.700	3.206	0.101	5.423	**0.040**
Toe AP	222.99 (78.73)	200.20 (76.12)	170.88 (60.80)	1.582	0.235	5.975	**0.033**	2.917	0.116
Toe VT	52.19 (5.21)	51.08 (4.94)	50.52 (6.34)	NS					
Ankle ML	-73.01 (83.40)	-74.25 (85.40)	-58.71 (78.99)	0.081	0.782	3.217	0.100	5.853	**0.034**
Ankle AP	141.29 (76.28)	118.44 (70.57)	90.98 (56.92)	1.594	0.233	5.571	**0.038**	2.560	0.138
Ankle VT	96.52 (8.05)	96.27 (8.75)	96.13 (9.26)	NS					
Knee ML	-65.92 (73.83)	-75.57 (73.61)	-56.90 (69.32)	1.948	0.190	1.503	0.246	7.871	**0.017**
Knee AP	230.66 (83.27)	213.62 (77.25)	190.68 (71.32)	0.903	0.362	4.055	0.069	1.915	0.194
Knee VT	413.09 (18.66)	412.49 (18.60)	410.92 (18.22)	NS					
Hip ML	-57.66 (61.00)	-63.61 (57.48)	-44.91 (55.70)	1.054	0.327	2.601	0.135	10.798	**0.007**
Hip AP	180.25 (92.92)	167.78 (59.55)	146.19 (58.97)	0.554	0.472	3.784	0.078	2.250	0.162
Hip VT	717.27 (33.44)	718.81 (31.23)	717.66 (32.04)	NS					
Shoulder ML	-52.27 (51.87)	-60.46 (47.79)	-39.80 (47.49)	2.179	0.168	1.552	0.239	10.012	**0.009**
Shoulder AP	188.25 (92.92)	204.39 (57.81)	200.11 (61.58)	0.673	0.429	0.305	0.592	0.088	0.772
Shoulder VT	1098.14 (41.06)	1091.63 (39.45)	1087.46 (38.04)	5.044	**0.046**	11.113	**0.007**	1.628	0.228
Head ML	-139.82 (106.39)	-151.91 (105.26)	-131.46 (105.07)	3.058	0.108	0.848	0.377	8.428	**0.014**
Head AP	235.34 (86.15)	260.52 (68.39)	263.63 (69.85)	1.351	0.270	1.678	0.222	0.045	0.835
Head VT	1221.48 (45.96)	1184.52 (135.02)	1210.98 (43.34)	NS					
Angular excursion (degree)									
Ankle	19.78 (5.16)	19.15 (2.57)	21.54 (3.79)	NS					
Knee	39.01 (10.40)	38.71 (9.60)	38.29 (9.07)	NS					
Hip	15.11 (5.49)	19.07 (5.42)	20.69 (6.32)	12.244	**0.005**	17.644	**0.001**	2.862	0.119

The statistics include post hoc results comparing two factors separately using repeated measures SM vs M10, SM vs M20 and M10 vs M20 conditions; task without the school backpack (SM), with a backpack with load equivalent to 10% (M10) and 20% (M20) of body weight (BW). When repeated measures, testing the main effect, were not significant (p>0.05), post-hoc tests were not conducted (NS). Bold values indicate significant differences (p<0.05). ML: mediolateral; AP: anteroposterior; VT: vertical.
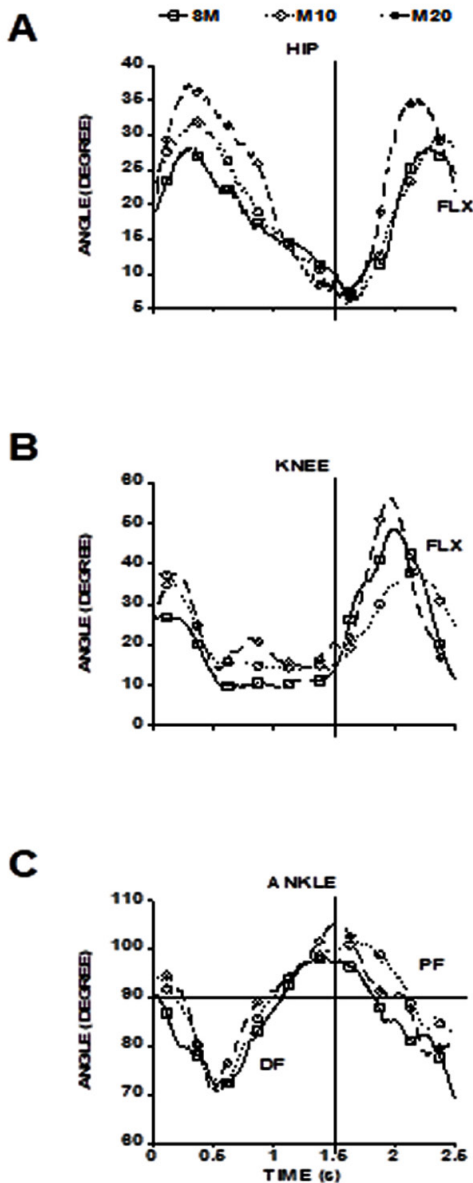
Figure 3. Time series of the hip average (A), knee (B) and ankle (C) angle displacement performed by one of volunteer executing a task without the school backpack (SM), carrying a backpack with the load equivalent to 10% (M10) and 20% (M20) of body weight (BW). The vertical line in each plot represents the toe off event. FLX: flexion; DF: dorsiflexion; PF: plantar flexion.

Electromyographic activity

The integral of the electromyographic signal (IEMG) showed that there were no differences during stance and balance phases between the muscles studied, except for RA during the balance phase. The IEMG was larger in SM condition compared with M20 condition (Figure 4; Table 3).

Table 3. Integrated electromyographic signals (IEMG) in the gait balance phase in the different tasks.

Median (Percentile 25-75) (Wilcoxon)		
Variables	**Balance phase**	**p value**
TA		
SM	13.65 (11.07-15.65)	0.209$^\&$
M10	11.85 (9.47-15.02)	0.079*
M20	10.55 (9.20-12.80)	0.480$^\Omega$
GL		
SM	13.12 (11.87-17.05)	0.875$^\&$
M10	15.39 (10.89-17.50)	0.875*
M20	13.39 (11.23-16.00)	0.307$^\Omega$
RA		
SM	33.00 (22.31-41.02)	0.099$^\&$
M10	24.39 (20.86-35.56)	**0.034***
M20	20.52 (15.66-37.99)	0.157$^\Omega$
EE		
SM	18.76 (13.29-22.89)	0.937$^\&$
M10	16.39 (13.10-27.82)	0.307*
M20	15.53 (10.07-22.63)	0.307$^\Omega$
VM		
SM	18.37 (13.75-23.82)	0.637$^\&$
M10	16.95 (14.61-21.09)	0.084*
M20	16.16 (11.75-20.45)	0.388$^\Omega$
BF		
SM	24.52 (18.29-27.41)	0.875$^\&$
M10	24.13 (21.14-28.42)	0.753*
M20	22.80 (20.51-26.07)	0.530$^\Omega$

$^\&$ = SM vs M10; * = SM vs M20; $^\Omega$ = SM vs M20. Task without the school backpack (SM), with a backpack loaded equivalent to 10% (M10) and 20% (M20) of body weight (BW); TA: Tibialis anterior; GL: Gastrocnemius lateral; RA: Rectus abdominis; EE: Spinal erector; VM: Vastus medialis; BF: Biceps femoris. P < 0.05 significant difference for the electromyographic activity between tasks.

Discussion

The objective of this study was to analyze the EMG activity in association with the kinematics during a gait performed with and without load in the backpack.

During the stance phase, the results showed larger LD for foot, ankle and hip, but reduced for head in AP direction with increased load. There were no differences in the VT and ML displacements on the comparison among the conditions. The increased load in the backpack produced a vector force in the inferior and posterior direction, which is maximum during double stance phase (Xu et al., 2009) pushing down the posterior and limiting the upper body movements.

Studies by Pau et al. (2012; 2013; 2015; 2016) observed an increase in the plantar pressure peak after increasing the backpack weight, which expresses the influence of the load generating downward force against the ground. For these authors, the impact of backpack
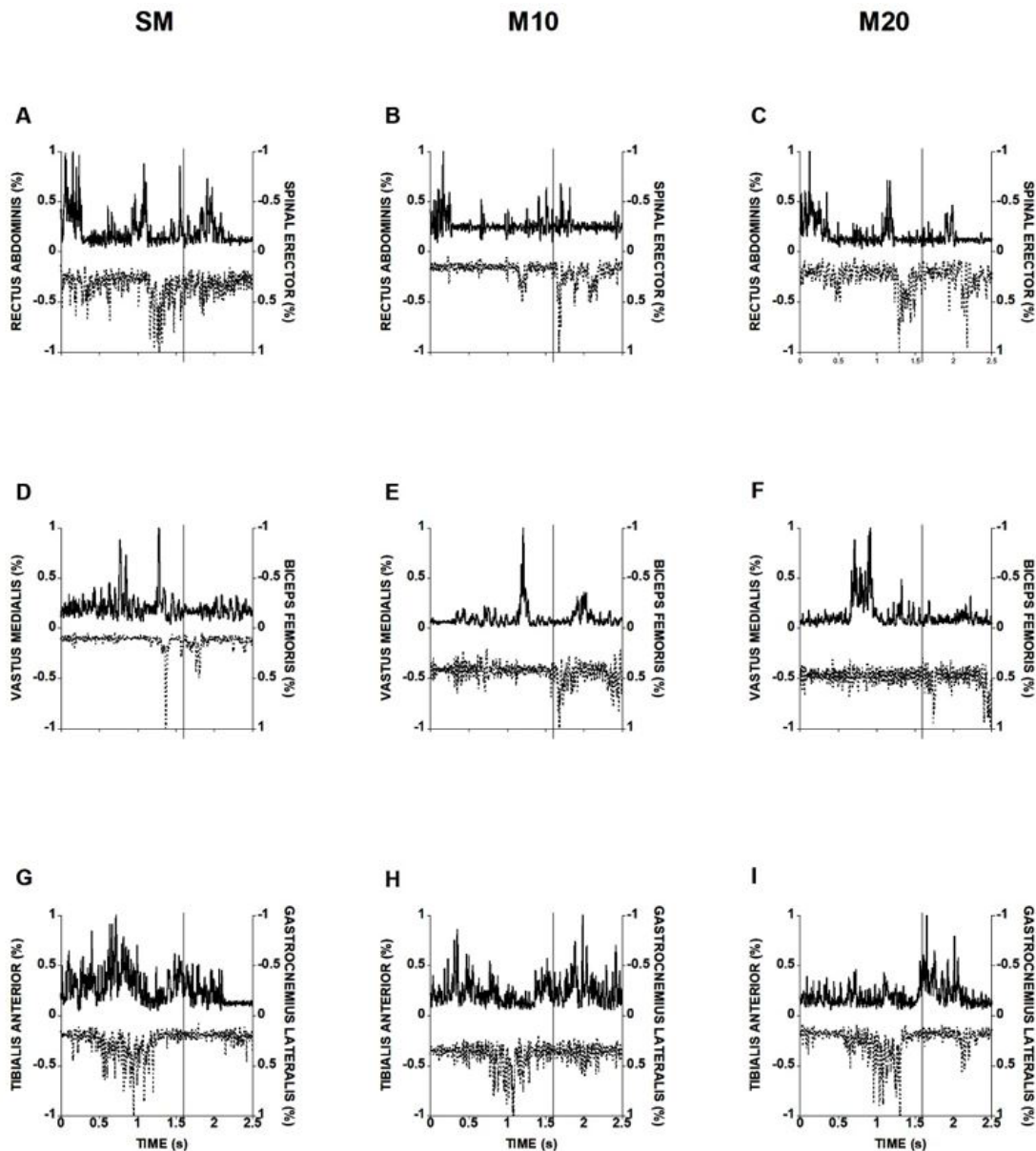
Figure 4. Time series of the averaged normalized EMG (percent of peak) for RA and EE (A-C), VM and BF (D-F) and TA and GL (G-I) performed by one of the volunteers. The vertical line in each plot represents the toe of the event. It is also shown the task without the school backpack (SM), with a backpack with the load equivalent to 10% (M10) and 20% (M20) of body weight (BW).

transport is more evident in the foot/ground interaction than on short-term gait characteristics. The larger LD in the AP direction for foot, ankle and hip with load observed in this study could be related with the deceleration of movement and the forward movement to the next step. One of the main functions of the motor control is to guide the body in space, which involves the posture maintenance to minimize the disturbance of the balance and maintain stabilized the center of gravity. When the backpack with excessive load is transported, the center of mass is pulled to posterior direction. In the attempt

to return to the appropriate position, similar to no load condition, the trunk moves to the opposite side tilting then forward, such adjustment helps the body minimize energy costs and increase the efficiency of the gait when carrying weight (Bloom and Woolhull-McNeal, 1987; Hong and Cheung, 2003).

Also, increasing AE of hip and smaller head LD during stance phase suggests a retraction of the shoulders as compensation to the previous inclination of the trunk during the movement. Although our results did not show

differences in the shoulder similar to the study and Mosaad and Abdel-Aziem (2015), it is known that the backpack load weight generates larger forces of tension under the shoulder straps exerting increased pressure in the lower direction while its movement is limited (Hadid et al., 2012; Mackie et al., 2005). Thus, we can assume that the addition of load limits the displacement of the head as it has been suggested in several studies (Khallaf et al., 2016; Kistner et al., 2012) carried out without dislocation of the shoulder and analysis of the influence of load.

In the balance phase, the lowest VT shoulder LD expressed the limitation of movement imposed by the load (Hadid et al., 2012; Mackie et al., 2005; Xu et al., 2009). At this phase, there was a reduction in the ML displacement for all joints with larger load, which is justified by the need of the body to increase the entire abduction of the lower extremity in order to amplify the base of stance and then keep the balance to the next stance phase. This finding corroborates the study of Pau and Pau (2010) that also noted greater ML displacement caused by the weight of the backpack, suggesting that the load use could provoke a poor balance, increasing in children the risk for accidental falls.

On this phase yet, there was a reduction of AP displacement of the ankle and toe, as observed by Pascoe et al. (1997). According to England and Granata (2007), one shorter step favors the correction by the nervous system of the posture during the gait, being commonly adopted to compensate kinematic disorders or control errors. Besides the influence of load (Pascoe et al., 1997) and attempt to postural correction (England and Granata, 2007), all conditions were made barefoot, which produces short step length (Dames and Smith, 2015). In relation to the AE, the results at this phase (balance) are similar to the previous phase, and this is justified again by larger retraction of the shoulders due to the addition of load in the backpack.

The RA muscle showed decreased EMG activity in the balance phase when it was compared to SM and M20 tasks, which can be explained by the compensatory postural mechanism retraction of the shoulder, as it has already been suggested in this study. Thus less RA muscle activity was required and possible increase in EMG activity for other muscles that were not evaluated in this study, like pectoralis major. Previous study (Habibi, 2012) strengthens the hypothesis of the measure identifying maximum upper trapezius muscle activation and minimum for muscle RA. Hong et al. (2008) also found similar results, demonstrating an increase in EMG activity and the presence of muscle fatigue in trapezius (upper and lower fiber), indicating greater weight directed toward the shoulder girdle region, while not EMG significant change to the RA muscle, even in gait long distance.

Kim et al. (2008) also suggest that the backpack load tends to overload the scapular waist and shoulders, with the stance made by muscles like the pectoralis major, not evaluated in this study. For Rugelj and Sevsek (2011), Hong et al. (2008) and Ramprasad et al. (2010), the weight directed to scapular waist associated with trunk inclination commonly manifest as a way of adapting to the new position, aiming to stabilize the trunk. The results of this study revealed the absence of significant EMG alteration to the EE muscle in both phases of the gait. These results are similar to those observed by Hong and Cheung. (2002). For Knapik et al. (1996), the increase of the EMG activity of EE muscles is only pronounced when the mass of the load exceeds 30-40 kg, once higher loads generate greater trunk posterior trunk inclination.

For the other muscles of the lower limb, VM and BF, those findings are in accordance with the study of Simpson et al. (2012), who suggested that the muscle activation of the lower limbs is relatively unchanged, even during prolonged transport. For Al-Khabbaz et al. (2008), the lack of EMG change suggests that the external load has little effect on the muscles of the lower limbs. EMG activity is not a response to mechanical work itself, but it is highly dependent on other factors, such as the speed of the step, frequency and distance of the load transport (Bobet and Norman, 1982; 1984), which could explain the absence of muscle activity. So, our initial hypothesis was not supported.

Some limitations may be observed in this study. First, the sample could be considered smaller; however, some similar studies had compatible samples with ours (Granata et al., 2005; Hong et al., 2008). The gait analysis, in a single stride, was also performed in several studies being described as sufficient to present important results on kinematic and EMG alterations (Brackley et al., 2009; Holt et al., 2005; Hong and Brueggemann, 2000; Hong and Cheung, 2003; Hong et al., 2008). The absence of analysis and control about the gait speed could also be considered another limitation, but the objective of this study was to simulate a situation of trips normally used in the school routine. In these aspects, it is important to emphasize that those limitations were also observed in previous studies (Bauer and Freivalds, 2009; Granata et al., 2005; Hong and Cheung, 2002; Hong et al., 2008; Kim et al., 2008). Finally, the electromyographic analysis was also insufficient in this study, but enough to present significant results to the proposed question. It is suggested that new studies are performed with a richer electromyographic analysis during the gait.

The findings of this study suggest that the backpack transport with a load of 10% of body weight of schoolchildren causes significant kinematics changes during both phases of the gait, but EMG activity changes only for RA muscle during the balance phase.

Acknowledgements

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