The Influence of Load Placement on Postural Sway Parameters

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Abstract — **School children, recreational backpackers, soldiers, fire-fighters carry a range of loads from 8 to 40 kg. Little is known about the extent to which carrying an external load on the body affects postural sway. The purpose of the present study was to investigate the effects of increasing load on postural sway in two different carrying positions: backpack and waist jacket.**

31 subjects (age 21.7 ± 1.9; 8 male and 22 female) in backpack group and 20 subjects (age 22.5 ± 1.9; 4 male and 16 female) in the waist jacket group participated in the study. The increment of additional load in both groups was 12, 21 and 30 kg. Stabilometry was used to assess the amount of postural sway. Data were collected by a force platform Kistler 9286 AA. The outlines of the measured data were determined by Fourier coefficients. The sway area, total path length, medio-lateral and antero-posterior path length of the centre of pressure were calculated.

In the backpack group the ratio between no load and additional load of 12 kg, 21 kg and 30 kg for total path length was 1.3, 1.6 and 1.7 respectively, for medio-lateral sway it was 1.3, 1.5 and 1.7 and for the antero-posterior sway 1.3, 1.6 and 1.8. The ratio for sway area was 1.8 at 12 kg, 2.5 at 21 kg, and 2.9 at the load 30kg. However, no significant change of the analyzed parameters was found while subjects carried additional load in the waist jacket.

Our results indicate that the participants' ability to maintain steady position while standing was altered by the external load carried in the backpack. The sway linearly increased for all of the measured parameters. Carrying weight in a backpack increases postural sway with increasing weight whereas carrying weight in the waist jacket does not influence the postural sway. The position of load is thus of significant importance for the postural sway.

Keywords — **Stabilometry, postural sway, load placement**

I. INTRODUCTION

Postural stability during load carriage is an important issue for different professions and/or activities. For instance, recreational backpackers carry a range of loads on their backs ranging from 8 to 35 kg [1], soldiers up to 50 kg [2], depending on mission requirements, and fire-fighters with their protective clothes and breathing apparatus with the weight of 26 kg [3]. School children of various age daily transport loads on their back ranging from 8.2 % of their body weight and this value increases with age to 12 % or even 20 % of their body weight [4,5].

Intensive studies were performed to discover the impact of load carriage on energy cost, the influence on gait parameters, effect of load distribution and sex differences – review of [6,7], for the soldiers. On the other hand the problem of stability while carrying heavy load has not been much investigated.

Postural steadiness is related to balance function. Intact and effective balance is important when a person is working on higher surfaces, in altered sensory conditions such as on the soft surfaces or in poorly lit or dark environments.

Postural stability is often assessed with stabilometry which defines the amount of postural sway and indicates the displacement of the centre of mass relative to the base of support. Centre of pressure (CoP) calculated from the ground reaction forces of standing subjects represents the outcome of the postural control. Measurement of the CoP movement with a force platform (stabilometry) is a standard procedure for assessment of postural stability. Subjects are asked to stand still on a special platform that is mounted on pressure sensors transmitting data to a computer where the time dependence of the trajectory of CoP (sway) can be monitored.

Little is known about the extent to which carrying an external load on the body affects postural sway parameters. The linear effect of load weight on the postural sway parameters has been observed in the population of young military service subjects [2]. Increased load challenged subjects' stability, reduced the randomness of postural sway and required greater muscle control in order to maintain balance. Altered sensory conditions (eyes closed) and additional load of 26 kg (full fire-fighters equipment) resulted in increased velocity of postural sway [3]. The position of the relatively small load - 12 kg [8] also influenced the amount of postural sway and subjects swayed more while holding the load above their heads as compared to shoulder or knuckle height.

The above studies did not record more than one load [8] and did not compare the load results to the no load conditions [2] or tested only one additional weight [3]. Majority of the research reports study young male population who are trained to carry weights on daily basis. However, recreational backpackers carry load on their backs as well and they differ in age, gender and physical fitness. Thus the purpose of present study was to investigate the effects of increasing load in a backpack upon postural sway as com-

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pared to increasing load in a waist jacket in a population of young college students.

II. Methods and materials

A. Methods

Stabilometry was used to assess the amount of postural sway. Data were collected by a force platform (Kistler 9286 AA) with 50 Hz sampling rate using BioWare program. Raw data were uploaded to a Linux server and analysed by specially developed software. A typical analysis of the stabilometric data started by data smoothing using moving averages over a chosen number of points (usually 10). It then proceeded by plotting the time and frequency distributions, determining the outline of the measured data, calculating its Fourier coefficients and the total path length of the CoP, medio-lateral and antero-posterior path lengths and finished by determining the total sway area [9].

The Statistical Package for Social Sciences (SPSS 15, SPSS Inc., Chicago, IL USA) was used for statistical analysis. Two sample t-test was applied to test the differences between the two groups for each of the load conditions whereas one way ANOVA was calculated to obtain the differences between the load conditions within a group and the significance level was set at 0.05.

B. Participants

Fifty-one healthy college students with no history of musculoskeletal injuries participated in this study. Minimal required body weight was 50 kg - lighter volunteers were not included. 31 subjects were assigned to the backpack group and 20 subjects to the waist jacket group (Table 1). The study was approved by the National Medical Ethic Committee and the participants gave their informed consent prior to the participation in this study.

Table 1 Demographic data of the participants in the study.

	Backpack group	Waist jacket group
	mean (SD)	mean (SD)
No. of participants	31	20
Age (years)	22.54 ± 4.9	22.45 ± 3.5
Height (cm)	171.96 ± 8.5	173.4 ± 7
Weight (kg)	67.16 ± 10.1	65.6 ± 12.6
Gender (m, f)	8 m, 23 f	4 m, 16 f

C. Procedure

Each participant was tested with three additional loads in a backpack or waist jacket: 12 kg, 21 kg and 30 kg. Participants were instructed to stand as still as possible on the force platform with their feet close together, arms at their sides and looking to a point on the wall 2 m away. All of the participants were tested in five consecutive trials, each lasting for 60 seconds.

The backpack group were carrying a Karrimor backpack with the capacity of 45 litres and were instructed to fix it on the pelvis and to adjust the shoulder straps to fit the backpack as comfortable as possible. Parameters of the body sway were measured first without additional load, then 12 kg sand bags were placed into the backpack. Afterwards the sand bags were added to the backpack to reach the weights of 21 and 30 kg. The last test was a repeated measurement without any additional load.

The subjects in the waist jacket group wore a jacket which consisted of pockets where diving weights (8x5x3 cm, 2 kg) could be placed at the hip, waist and chest height. For the purpose of our study the weights were placed around the waist, half anteriorly and the other half posteriorly. The measurements were performed in the five different load conditions with the same protocol as used for the backpack group.

III. Results

A. Backpack group

The parameters of the postural sway: total path length of the CoP, medio-lateral and antero-posterior path lengths and the sway area significantly increased with the added load in

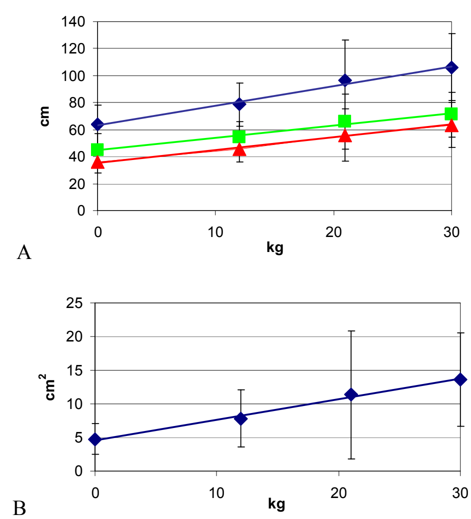

Fig. 1 Linear relationship between four different load conditions for CoP excursions at different loads in the backpack group: (A) total path length (diamond), mediolateral path (square) and anteroposterior path (triangle); (B) total sway area.

a backpack as compared to the no load conditions ($p < 0.01$). Compared to no load, 12, 21 and 30 kg loads resulted in the increase of the total path length by 27.1 %, 55.9 % and 70.9 %, respectively, whereas the medio-lateral sway increased by 26.4 %, 54.2 %, 66.3 % and the antero-posterior sway by 30 %, 60.8 % and 80.4 %. Sway area increased even more with the load: 84.5 % at 12 kg, 154.6% at 21 kg, and 289 % when the load was 30 kg (Fig 1).

Linear regression showed that the total path length increased by 1.6 cm per kg ($R^2 = 0.99$), medio-lateral sway by 0.9 cm/kg ($R^2 = 0.98$), antero-posterior sway by 0.94 cm/kg ($R^2 = 0.99$) and the sway area by 0.3 cm^2/kg ($R^2 = 0.99$). These relations were well reproduced by the linear function as seen from Fig. 1.

B. Waist jacket group

The statistical analysis of the waist jacket results showed that the parameters of the postural sway did not significantly differ between the four load conditions with the p values ranging between 0.306 and 0.938 (Fig. 2).

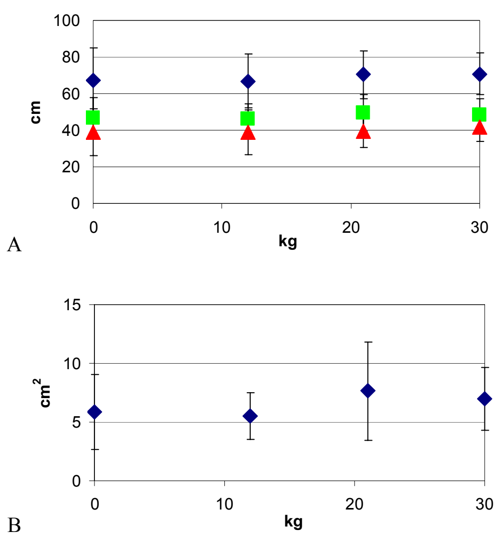

Fig. 2 Mean and standard deviation values for CoP excursions at different loads in the waist jacket group: (A) total path length (diamond), mediolateral path (square) and anteroposterior path (triangle); (B) total sway area.

C. Between group analysis

The t-test revealed that the difference between the backpack and waist jacket groups was not significant at the no load conditions (the first and the last measurements) while the differences between the two groups were statistically significant for the loads of 12 kg ($p = 0.011$) and even more so for 21 kg and 30 kg ($p < 0.001$) as shown in Fig. 3.

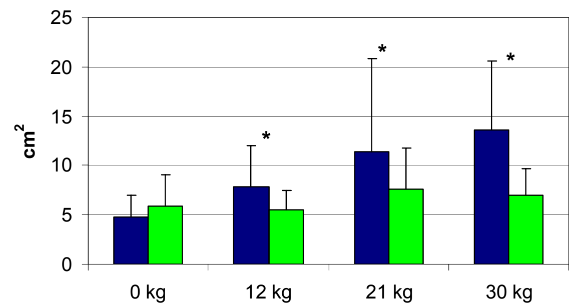

Fig. 3 The influence of two different placements of loads on the sway area for the backpack (left) and the waist jacket groups (right).

IV. Discussion

In the present study we investigated the influence of increased load carriage on the postural sway parameters. Additionally we investigated the influence of two different load placements. Our study design differed from the previous ones in the volunteers sample. Namely, majority of the reported studies investigating parameters of postural sway and other related studies were performed on young, fit soldiers who were trained to carry different loads, whereas our participants were young college students who reported to participate in recreational activities on the average only three times a week.

Our results indicate that the participants' postural steadiness, while standing with different loads in a backpack, was altered. The sway measures showed significant linear increase in the length of CoP excursions in the antero-posterior and medio-lateral directions as well as the sway area. Similar linear dependency on the increasing load was described for young soldiers for all of the postural sway parameters [2]. However, that study did not compare the results to the no additional weight situation. Besides, in our study we repeated the no load condition as the last one in the series of five measurements. Namely, the random nature of the CoP movements, which results in the variability of the postural sway [10], led us to design the additional control measurement. It has shown that there was no statistically significant difference between the both no weight measurements which allows us a higher level of confidence in the linear relationship between the additional load and the amount of postural sway. Similar conclusions were obtained by Punakallio et al [3] for professional fire-fighters carrying 15.5 kg steel air bottles on their backs - their weight was found to significantly impair both postural and functional balance.

Besides, the position of the load has been shown to influence subjects' energy expenditure: evenly distributed load in a double pack [7] required less energy as compared to a backpack. Our results of stabilometry showed similar relationship for the postural sway parameters - increased weight placed evenly around the waist did not influence the size of CoP movements contrary to the case when the weight was carried in a backpack. The comparison of the results at the same additional weight in different positions showed no differences of the postural sway parameters in both no load conditions whereas with all other weights (12 kg, 21 kg and 30 kg) the differences between the two weight positions were statistically significant (except for the antero-posterior sway at 12 kg).

The control of the centre of mass position is expected to differ with the position of load on the body. For instance, load in the backpack requires more forward body lean and more forward rotation about the hips and ankle [11] and the moment at the joints is greater when the load is placed higher on the body [12]. The difference between the sizes of CoP displacements could be attributed to larger rotational inertia of the load that is higher an not evenly distributed around the torso.

The variability of CoP fluctuations and increased postural sway has been traditionally considered as a sign of loss of control, usually related to the deterioration due to age or disease. More recently this variability has become considered an essential element of the movement parameters that are under direct control of the central nervous system [13,14]. In the waist jacket group the variability between the subjects, expressed as standard deviation, decreased with the increasing load (Fig.2). These results indicate that with increasing weight most of the subjects adopted similar strategy. Decreased variability could also be attributed to increased stiffness of the postural muscles. On the other hand, in the backpack group the sway parameters and the variability between the subjects increased with increasing load which may indicate different control strategy in the situation when the load is placed in the backpack, which shifts the centre of mass posteriorelly, as compared to the load placed in the waist jacket where its position is not changed.

V. Conclusions

Maintaining of balance in a situation of additional weight carried on the persons back is important for different occupations as well as for the recreational purposes. Carrying weight in a backpack linearly increases postural sway parameters with increasing weight whereas evenly distributed weight does not affect the sway parameters. Weight distribution is thus an important parameter that influences postural sway and balance maintenance. For the prevention of balance related injuries it is advisable to consider not only the size of the carried weight but also its distribution.

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