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Relationship between backpack load location, sex, anthropometric and body composition factors with postural sway in healthy young adults

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Objective: *Evaluate the effect of backpack load location on postural sway and correlate sway path length (PL) to anthropometrics and body composition.*

Methods: *Fifteen participants aged 18-25 stood on a force plate with backpack load located high (LH), low (LL) or without backpack (NL). Body composition and anthropometric variables were correlated to PL.*

Results: *Load increased PL, 95% confidence ellipse, and mean velocity while it reduced mediolateral SampEn (p<0.05). Females had increased mean velocity and PL of sway (p<0.05). Larger phase angles correlated with reduced PL under NL. Taller individuals correlated with reduced PL under LL. Greater mass correlated with reduced PL under LH.*

Relation entre la position de la charge du sac à dos, le sexe, les facteurs anthropométriques et de composition corporelle et le balancement postural chez les jeunes adultes en bonne santé

Objectif: *Évaluer l'effet de la position de la charge du sac à dos sur le balancement postural et corréler la longueur du chemin du balancement (PL) aux facteurs anthropométriques et à la composition corporelle.*

Méthodologie: *Quinze participants âgés de 18 à 25 ans se sont tenus debout sur une plateforme biomécanique, la charge du sac à dos étant placée à un niveau élevé (LH), bas (LL) ou sans sac à dos (NL). La composition corporelle et les variables anthropométriques ont été corrélées à la PL.*

Résultats: *La charge a augmenté la PL, l'ellipse de confiance à 95 % et la vitesse moyenne tout en réduisant la SampEn (entropie d'échantillon) médio-latérale (p<0,05). Les femmes avaient une vitesse moyenne et une PL de balancement plus élevées (p<0,05). Les angles de phase plus importants sont en corrélation avec une réduction de la PL sous NL. Les personnes plus grandes étaient en corrélation avec une réduction de la PL sous LL. Une masse plus importante est en corrélation avec une réduction de la PL sous LH.*

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DS and MW conceived the study. DS, MW designed, coordinated the study and drafted the manuscript. DS, MW were involved in the study-implementation, DS and MW performed the data analysis. DS, MW interpreted the findings. Both authors read and revised the manuscript critically and approved the final manuscript.

Conclusions: *Load carriage regardless of load location increased postural sway metrics except mediolateral SampEn. Females had greater PL and mean velocity compared to males. Select anthropometric and body composition variables correlated with postural sway under different load conditions.*

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KEY WORDS: posture, motor control, postural balance, backpack, body composition

Conclusions: *Le port de charge, quelle que soit la position de la charge, a augmenté les paramètres du balancement postural, à l'exception de la SampEn médio-latérale. Les femmes avaient une PL et une vitesse moyenne plus élevées que les hommes. Certaines variables anthropométriques et de composition corporelle sont en corrélation avec le balancement postural dans différentes conditions de charge.*

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MOTS CLÉS : posture, contrôle moteur, équilibre postural, sac à dos, composition corporelle

Introduction

Wearing a backpack induces a backward shift in one's center of mass (COM). This is compensated for by trunk forward lean in order to keep the COM vertically aligned over the pelvis to negate the posterior moment induced by the application of the load.[1] This finding is supported by numerous studies conducted involving both children and adults.[1] In addition to COM compensation, previous studies have found that carrying a loaded backpack increases postural instability (sway) as measured by center of pressure (COP) and has been suggested to induce greater balance impairment compared to no load.[1, 2] Interestingly, manipulation of load placement (high or low) in a backpack did not affect subjective and objective measures of postural stability in young adult participants[2] although the influence of sex was not specifically evaluated in this study.

While a loaded backpack seems to be consistently associated with greater postural sway and instability, the interaction of sex and backpack load on postural control appears to be less certain. Rugelj[3] did not find differences in postural response to the amount and configuration of load between male and female subjects using 12, 21 and 30 kg loads. Heller *et al*.[4] found that females carrying 18.1 kg of mass in a backpack experienced significant increase in COP sway but no males were assessed in their study. In a military study, overall load carriage injury risk for female and male soldiers were not different but female soldiers had twice the level of serious personal injuries as well as foot injuries, from carrying loads compared to male soldiers.[5] Findings from a recent systematic review regarding the impact of sex on postural stability were mixed[6], but that in two out of three studies, men tend toward better static postural stability compared to women. Clearly, the impact of sex with respect to load carriage and postural control is far from known and appears for the most part to have been largely neglected. Load will change the height of the center of mass of the 'human-backpack' system. It is reasonable that an increased distance between the center of mass and the ground would affect postural sway, as it would increase the moment of inertia around various points of rotation (ankles, hips etc). Since women and men have different distribution of mass in their upper and lower bodies, the effect of the load position may show differences in balance parameters between sexes.

Body composition is an important health and performance metric.[7] For instance, previous research of ours found that in young, elite hockey players, higher body fat percentage predicted slower skating speeds[8], which could be used to develop targeted and effective training programs to improve on-ice skating speed. Similarly, body composition may be able to predict postural sway with and without load carriage. Body composition as assessed by bioelectrical impedance analysis can be a reasonable alternative for balance evaluation in the elderly.[9] This would be important given clinical concerns such as falls in the elderly[9, 10] and the potential for instability in children carrying heavy backpacks[11]. We are interested in factors that may be able to predict postural sway performance. To date, predictions of postural sway are sparse and we are aware of only one study that has related body composition as measured by bioelectric impedance analysis (BIA) to aspects of postural sway.[9] Phase angle, derived from BIA is a linear method of measuring the relationship between resistance and reactance in an electrical circuit and is an indicator of cell membrane health and integrity.[12, 13] This study by Bertolini and colleagues[9] used elderly men and women and found an inverse relationship between phase angle as measured by BIA and sway area, mediolateral sway velocity and one legged standing. Additionally, Bertolini and colleagues[9] suggested that resistance training could result in greater phase angle which is related to better health. Of note is that BIA is the only body composition technique that produces phase angle, which is correlated with the prognosis of various diseases.[7]

We aimed to investigate the following in healthy young adults: 1) if a load placed higher or lower in a backpack differentially influences postural sway compared to no load, particularly with respect to sex; 2) the relationship of anthropometric and body composition variables to postural sway. Hypotheses of the present study were: 1) load located higher in the backpack would create greater sway than load located lower in the backpack particularly for females compared with no load; 2) higher percent body fat and lower phase angle would be associated with greater sway.

Methods

Participants

Fifteen participants (8 males, 7 females) participated in this study. Subjects' age range was 19-23 (21.3 ± 1.2 years) (Mean±SD), body mass (76.1±17.0 kg), height (172.5±8.8 cm) participated in this study. Participants were recruited from undergraduate and graduate classes in the Department of Kinesiology, Nutrition and Health. The study protocol, all forms used and the informed consent documents were approved by the Human Subjects Institutional Review Board at Miami University. All participants read and voluntarily signed a written informed consent document and completed a health history questionnaire. Our inclusion criteria were undergraduate and graduate students at our institution. Participants were excluded if they were not able to stand without pain while wearing a weighted backpack for 30 seconds.

Design and procedure

Each participant came to the biomechanics laboratory once for a 20-minute session. Participants wore athletic shorts and a t-shirt during the test. Each participant completed 3 tasks: force plate assessment with or without backpack (with high and low load); and anthropometric and body composition analysis. These tasks are described below.

We used a mixed design with one between-subjects factor and one within-subjects factor consisting of sex and load condition respectively. The repeated measures nature of the study was used to control for the potential influence of individual differences on load carriage. Given the within-subjects design, the sample size was estimated based on similar studies involving load carriage on postural control.[10, 14, 15] Specifically, a large effect size has been noted for the influence of load on path length (AP and ML) in elderly individuals[10] and load on NeuroCom balance scores in young adults[15].

Force plate assessment of postural sway

We asked participants to perform three, 30 second standing trials on a Balance Tracking System force plate (BTrackS™ , San Diego, CA), with eyes open. Standing involved normal upright standing with feet approximately shoulder width apart and arms by their sides. Data were acquired through the Explore Balance software application (Balance Tracking Systems, version 2.0.4) at 100 Hz. Data was filtered using a second order, digital Butterworth low-pass filter (point by point) implemented with Labview code block with a cut-off frequency of 4 Hz. The first 10 points of the signal were removed to account for lag. The entropy calculation used the parameters m=2 (subseries length), r=0.2 (similarity tolerance) and N=3000 (data length). Sample entropy was derived from the center of pressure time-series data. Each participant stood for their first trial without a backpack (NL). The other two trials were performed in alternating order between subjects beginning with the load low (LL) in the backpack, then the load high (LH). The next participant began with the load high in the backpack then the load low and so on. This was for convenience as to not keep taking the load out of the backpack. The amount of rest between trials was based on participant fatigue and time needed to load the backpack. Participants were asked to step off of the force plate between trials. Loading and unloading the backpack took a couple of minutes. Participants were regularly asked about fatigue and offered more rest if they were noticing fatigue. Since the protocol only required them to stand still 3 times for 30 seconds we did not consider fatigue to be a factor that would impact our results.

The type of backpack used for this study was an Osprey Aether 70 (mass 2.49 kg, volume 73 liters, dimensions in cm 85h x 40w x 34d). The load added to the backpack consisted of 18.1 kg in the form of weighted plates. We chose this load for its ecological validity as backpacking and military applications do not use relative loads. We divided the backpack into two compartments of upper, and lower using high-density foam. The low load location consisted of putting the weighted plates at the bottom of the backpack while the load high condition had the plates at the top of the backpack with the high-density foam beneath to ensure both stability and common load placement across participants. Consistent with Golriz *et al.*[2], weights were placed in the backpack as close to the spine as possible and distributed evenly across the right and left sides of the backpack. The position of the weights were consistent across the participants and placed by a single investigator (MW) who used the same location relative to the shoulders with the top of the backpack just beneath the occiput on all participants. The backpack had adjustable hip and shoulder straps and the standard fitting procedure was followed to adjust the backpack for each of the participants. Participants further adjusted backpack straps to their own body and comfort level for pragmatic purposes. Participants were instructed to look at an eye level visual target at a distance 1.5 meters in front of them (Figure 1).

Figure 1.
Experimental force plate setup. Participants wore a backpack while standing on a portable force plate that was 1.5 m from a wall with a visual target. The yellow oval and pink oval represent the load high and load low conditions respectively.

Outcome measures used in this study derived from the force plate included: path length (PL), 95% confidence ellipse (95% CE), mean velocity, anteroposterior sample entropy (AP SampEn) and mediolateral sample entropy (ML SampEn).

Anthropometric and body composition variables

Height was measured in centimeters (cm) using a laboratory stadiometer. The rest of the variables were measured using an InBody 770 Body Composition Analyzer (Cerritos, CA, USA) multi-frequency bioelectrical impedance (BIA) device. Participants stood on the BIA platform barefoot with the soles of their feet on the metal electrodes. Participants then grasped the handles of the InBody 770 with their thumb and fingers contacting the electrodes. They then stood still for approximately one minute while maintaining their elbows fully extended and their shoulders slightly flexed and abducted as instructed by the device.

Outcome measures used in this study derived from the stadiometer and InBody 770 BIA included: height (cm), mass (kg), phase angle, and percent body fat.

Data analysis

Statistical analyses for postural sway were computed using a mixed ANOVA with the within subjects factor (load) consisting of three levels (NL, LL, LH) and the between subjects factor being sex. In the event of a significant interaction, post hoc tests were performed using Bonferroni corrected pairwise comparisons. Shapiro-Wilk test was run as a test of normality for each postural (e.g., dependent) variable as a combination of the levels of the between- and within-subjects factors across NL, LL and LH conditions. For any data that violated the assumption of sphericity as assessed by Mauchly's test, the Greenhouse–Geisser correction was applied. All analyses were conducted using IBM SPSS Statistics for

Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at an alpha value of 0.05.

Body composition and anthropometric variables were related to the PL of postural sway using Pearson correlation coefficients and multiple linear regression. To quantify the strength and direction of the above bivariate relationships, Pearson correlation coefficients were calculated. Statistically significant correlations were observed with $p \leq 0.05$. Independence of residuals was assessed for each regression by a Durbin-Watson statistic. The assumption of normality was assessed by inspection of histograms of standardized residuals and by P-P plots. To establish correlates of anthropometric and body composition variables with PL, multiple regression analyses were conducted using stepwise forward selection.[8] Separate regression analyses were run for each of the load conditions. Our goal was to identify from a limited number of anthropometric and body composition variables the factor(s) that account for the greatest variance (i.e., R^2) in postural sway and therefore optimize the prediction of path length. At each step in the forward selection, a p value of ≤0.05 was the statistical significance criterion to enter variables. All analyses were conducted using SPSS version 25.0.

Results

Effect of load and sex on postural sway

Means and standard deviations of postural sway variables are provided in Table 1. There were no violations to the assumption of normality ($p > .05$) for any dependent measure. Mauchly's test of sphericity indicated that the assumption of sphericity was met for 95% confidence ellipse, and AP SampEn ($p>0.05$). Sphericity was not met for ML SampEn, mean velocity and path length ($p<0.05$), so we used the Greenhouse-Geisser correction to interpret the main effect of load and interactions for these variables.

Table 1.
Means and standard deviations of postural sway variables.

Variable	No Load (NL)		Load Low (LL)		Load High (LH)	
	Males	Females	Males	Females	Males	Females
Path Length	36.18 (3.77)	46.87 (4.36)	42.18 (7.48)	54.94 (11.22)	42.49 (3.66)	50.86 (4.40)
95% CE	0.79 (0.33)	1.16 (0.66)	1.89 (0.71)	3.21 (2.26)	1.89 (0.63)	2.33 (1.28)
Mean Velocity	1.21 (0.13)	1.56 (0.15)	1.41 (0.25)	1.83 (0.37)	1.42 (0.12)	1.70 (0.15)
AP SampEn	0.10 (0.04)	0.11 (.03)	0.09 (0.04)	0.10 (0.03)	0.08 (0.03)	0.10 (0.02)
ML SampEn	0.33 (0.15)	0.32 (0.12)	0.17 (0.03)	0.19 (0.07)	0.20 (0.05)	0.22 (0.12)

M (*SD*) values are listed for each condition. Path length is measured in centimeters (cm). 95% CE=95% Confidence Ellipse (cm2). Mean velocity is measured in cm/s. Sample entropy (SampEn) is measured in bits.

Table 2.
Summary of ANOVA results for postural sway variables.

	Path Length			95% CE			Mean Velocity			AP SampEn			ML SampEn		
Source	F	*p*	ηp^2	F	*p*	ηp^2	F	*p*	ηp^2	F	*p*	ηp^2	F	*p*	ηp^2
Load	6.62	.014	.337	16.7	<.001	.563	6.58	.014	.336	1.11	.345	.079	13.3	.001	.506
Sex	20.6	.001	.614	2.11	.170	.139	20.5	.001	.612	1.47	.247	.102	.046	.833	.004
Load x Sex	.602	.493	.044	1.78	.189	.120	.574	.507	.042	.169	.846	.013	.330	.642	.025

Separate mixed ANOVAs were conducted for each variable (Path Length, 95% CE, Mean Velocity, AP SampEn, ML SampEn) with load as the within subjects factor and sex as the between subjects factor. No load by sex interactions were significant. Significant *p* values (<.05) are bolded. Greenhouse-Geisser corrections were applied to ML SampEn, Mean Velocity and Path Length.

Table 2 presents the results of the mixed ANOVA's for each postural variable. There was a main effect of load for each postural variable except AP SampEn. Load increased PL, mean velocity and 95% confidence ellipse. Load reduced ML SampEn, yet had no effect on AP SampEn. There were no significant pairwise comparisons between LH and LL for any postural variable. The load effect was explained by significant differences between NL and LL as well as NL and LH for each postural variable except for AP SampEn.

A main effect of sex and assessment of pairwise comparisons indicated an increase in both PL and mean velocity of sway with each load condition (NL, LL and LH) for females relative to males. There was no load by sex interaction for any postural variable (Table 2).

Anthropometric and body composition related to sway PL

A matrix of intercorrelations, which presents the correlation coefficients for pairs of variables, is shown in Table 3. Not surprisingly, the path length variables at different loads were strongly related to each other. For instance, PL NL and PL LH were strongly correlated (r = 0.77), indicating that PL NL could account for approximately 59% of the variance in PL LH sway and vice versa. Both percent body fat and age had no significant correlations with any other variable. Phase angle, height and mass were significantly related to each variable except age and percent body fat.

Multiple regression was run to assess predictors[16] (height, age, mass, phase angle, percent body fat) of path length (PL) under each load condition (NL, LL, LH). There was independence of residuals, for each regression as assessed by a Durbin-Watson statistic of 1.45 (NL), 1.79 (LL) and 2.08 (LH). The assumption of normality was met, as assessed by inspection of histograms of standardized residuals as they appear to be approximately normally distributed with means approximating zero and standard deviations of 1. P-P (expected cumulative probability vs observed cumulative probability) plots for each regression demonstrated points that were closely aligned along the diagonal line confirming the assumption of normality.

The multiple regression analysis of PL NL yielded phase angle as the only significant variable, $F(1,13) = 30.78$, $p<0.001$. The multiple correlation coefficient was -0.84 with an adjusted R^2 of 0.70 indicating that conservatively, 70% of the variance in PL NL was explained by phase angle as measured by the InBody 770 BIA. For the regression analysis of the criterion variable PL LL, height was the only significant variable, $F(1,13) = 6.18$, $p = 0.027$. The multiple correlation coefficient was -0.57 with an adjusted R^2 of 0.32 indicating that conservatively, 32% of the variance in PL LL was explained by height. Similarly, the multiple regression analysis of PL LH yielded body mass as the only significant variable, $F(1,13) = 15.32$, $p =$

Table 3.
Bivariate correlations between path length, anthropometric and body composition variables.

	Path Length (cm) (NL)	***Path Length (cm) (LL)***	***Path Length (cm) (LH)***	***Height (cm)***	***Age (yrs)***	***Mass (kg)***	***Phase Angle***	***% Body Fat***
Path Length (cm) (NL)	1.00							
Path Length (cm) (LL)	0.57*	1.00						
Path Length (cm) (LH)	0.77**	0.68**	1.00					
Height (cm)	-0.77**	-0.57*	-0.73**	1.00				
Age (yrs)	-0.23	-0.40	-0.37	0.17	1.00			
Mass (kg)	-0.64**	-0.55*	-0.74**	0.74**	0.22	1.00		
Phase Angle	-0.84**	-0.54*	-0.65**	0.67**	0.31	0.71**	1.00	
% Body Fat	0.27	0.01	0.00	-0.36	-0.03	0.19	-0.21	1.00

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

0.002. The multiple correlation coefficient was -0.74 with an adjusted R^2 of 0.54 indicating that 54% of the variance in the PL LH was explained by the subject's mass. These significant variables (phase angle – PL NL; height – PL LL; and mass – PL LH) had correlations above 0.5 and are indicative of moderate to strong correlations. Scatterplots of these variables are shown in Figure 2.

a

b

c

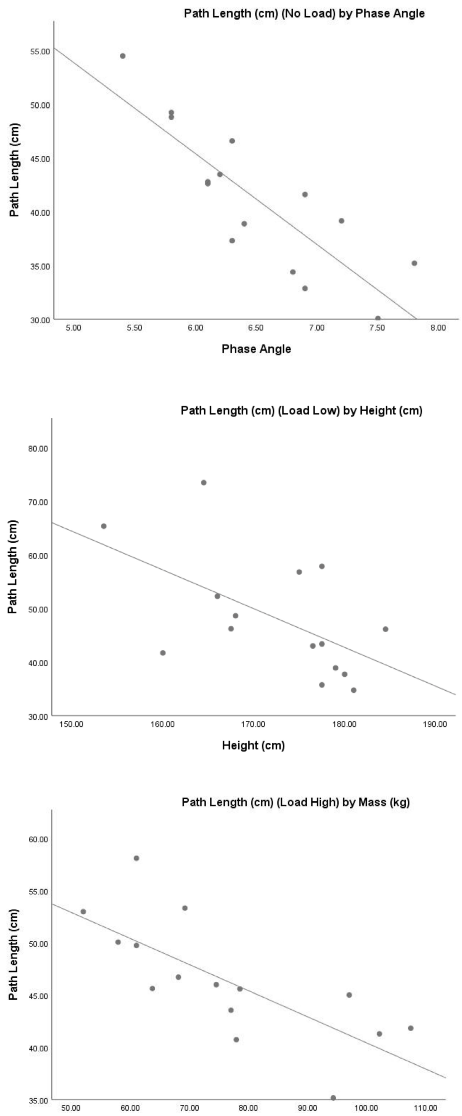

Figure 2. *Correlations between a) PL NL with phase angle, y=96.22-8.57(phase angle); b) PL LL with height, y=1.73E2-0.72(height); and c) PL LH with mass, y=65.44-0.25(mass).*

Discussion

Prior research has shown that backpack loads regardless of load location (high or low) increases postural sway metrics.[1] This could increase the potential for falls and instability in older as well as younger individuals.[9, 11] We confirmed that load (regardless of location in backpack) increased postural sway while reducing ML SampEn. SampEn, is a measure of movement structure and periodicity[17-20] and the observed decrease represents a greater amount of rhythmicity and structure of sway in the mediolateral direction with load. The reduction of SampEn may be associated with increased attentional demands to greater load bearing.[21-23] Our results contrast with those of Baudendistel *et al*.[24] who found that bimanual load carrying of 0%, 5%, and 10% of body mass resulted in greater AP SampEN with load but no change in ML SampEn. A different study examining bimanual load carrying of 0, 14, and 30 kg[23] found a reduction in both AP SampEn and ML SampEn particularly with the heaviest load. Despite the location of load in these two studies (bimanual)[23, 24] compared to our backpack study, collectively, greater loading appears to disrupt both the quantity and periodicity of sway.

We found that females swayed more than males in both PL and mean velocity of sway with each load condition relative to males. This is generally consistent with the systematic review by Dean *et al*.[6] at least under the condition of no load. We hypothesized that this increase in female sway would be magnified in the high load condition relative to males since loads placed more superior to the whole body center of mass lead to less effective postural control in parameters such as COP mean velocity.[25] However, since there was no load by sex interaction for any postural variable (Table 2) we cannot accept the hypothesis that load located higher in the backpack would create greater sway for females compared with males. Further, our results contrast to those of Rugelj and Sevsek[3] who did not find differences in postural response to the amount and configuration of load between male and female subjects using 12, 21 and 30 kg loads.

Our correlation analysis demonstrated that higher phase angle was significantly related to reduced path length of postural sway for each load condition which confirmed our hypothesis, but percent body fat was not related to sway as we hypothesized. Similar to percent body fat, age was not a related variable to PL of sway but it is noted that our sample consisted of a narrow age range. Height and body mass were also significantly correlated to path length for each load condition and to each other.

Multiple linear regression found that phase angle was a significant correlate of PL of sway in the no load condition. This is consistent with Bertolini and colleagues[9] who found that higher phase angle in the elderly predicted reduced sway area and mediolateral sway velocity. The results from both of these studies might suggest a generalized inverse relationship across ages between phase angle as measured by BIA and postural sway variables making phase angle an attractive and possible alternate method to quickly assess posture control. Phase angle is an indicator of cell membrane integrity, distribution of intra- and extracellular fluids[9], and is associated with muscle quality[26]. Furthermore, phase angle has been demonstrated to increase following resistance training[27] indicating that this type of training may also relate to postural sway[28]. Height was a correlate of path length in the low load condition and body mass correlated path length in the high load condition. Previous research has found a difference in the correlation of postural measures with body factors such as height and weight. In women, postural sway (mean distance and mean velocity) magnified with height and weight.[29] Men however showed no significant change in sway size but significant reduction in sway frequency with height and weight.[29]

There are several limitations and/or ways to improve this study. An a priori calculated sample size estimate could have reduced the risk of an underpowered result or rejecting a null hypothesis that is actually true. We recognize that this limits the statistical power and that true differences between groups may not have been recognized as a result. The narrow age range of the participants precludes us from generalizing the findings to other populations such as middle-age and older adults. We could have used more than two locations for the load conditions as well as more than one magnitude of load to determine if gradations in these factors could have led to a sex by load interaction as we hypothesized. Another consideration would be to have a more dynamic postural task to determine if sex and/ or load in the dynamic situation leads to an interaction between load location and sway pattern. The duration of the postural sway trials might be considered a limitation given that measures of mean velocity for COP do not stabilize until trial duration is longer than 60 seconds[30] even though the premise for the original development of approximate entropy, of which sample entropy is a special case, was so that it could be used with shorter datasets[31]. SampEn was derived from the center of pressure time-series data and may be susceptible to long-range correlations which may mask underlying dynamics of the system.[32] An increment method to remove these long-range correlations has been proposed as a possible solution to these long-range correlations.[32] More variables from the BIA (body composition) might be considered as possible correlative variables in future studies as could other measures of anthropometrics. One potential issue however with this is that having too many variables for example from the BIA might lead to a multicollinearity problem.

Conclusion

Load carriage regardless of load location increased postural sway with the exception of mediolateral SampEn which reduced. Females had greater path length of sway and exhibited greater mean velocity of sway compared to males. Phase angle correlates with postural sway under no load while height correlates with sway while the load is located low in the backpack and body mass correlates with sway in the high load condition. Select anthropometric and body composition variables correlate with postural sway under different load conditions. The results of this investigation indicate that simple laboratory tests of select variables (phase angle, height, mass) could be used to aid in the assessment of postural stability in healthy young adults. This information could be valuable for monitoring and predicting postural performance in young adults who do not have access to a force plate. It may also provide health practitioners an opportunity to promote phase angle improvements to facilitate postural stability through means of resistance training, nutritional support or other lifestyle pursuits.

Abbreviations

ANOVA: Analysis of Variance
ML: Mediolateral
AP: Anteroposterior
PL: Path Length

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