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Research Article

Immediate Responses to Increased Backpack Load on Vestibular Function, Balance and Gait Parameters in Young Adults

Genç Yetişkinlerde Artan Sırt Çantası Yükünün Vestibüler Fonksiyon, Denge ve Yürüme Parametreleri Üzerindeki Anlık Etkileri

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ABSTRACT

Purpose: The effect of carrying a heavy backpack on body biomechanics have gained interest of the researchers in recent years. However, research regarding effects of backpack weight on vestibular function are limited. The aim of this study was to investigate immediate responses to increased backpack load on vestibular function, balance and gait parameters in young adults. **Material and Methods:** This was a prospective study including a total of 25 participants. The participants were evaluated with the stepping test for vestibular function, Y balance test for dynamic balance and an instrumented treadmill for the gait parameters with backpack 0%; 15% and 30% of body weight. **Results:** Regarding vestibular function, it was observed that test results were better with the increasing backpack load (p<0.05). In dynamic balance, there were significant differences in posteromedial and posterolateral directions (p<0.05). In terms of gait parameters, cycle time, cadence, gait velocity, ambulation index and bilateral step lengths were decreased as the load increased (p<0.05). **Discussion:** The results can be interpreted that the changes may be a part of compensatory mechanisms to protect and maintain the body biomechanics against the backpack weight. By putting extra weight, one can be challenged during vestibular training.

Anahtar Kelimeler: Backpack loads; Proprioception; Balance; Gait; Vestibular function.

ÖZ

Amaç: Ağır sırt çantası taşımanın vücut biyomekaniğine etkisi son yıllarda araştırmacıların ilgisini çekmektedir. Bununla birlikte, sırt çantası ağırlığının vestibüler fonksiyon üzerindeki etkileri ile ilgili araştırmalar sınırlıdır. Bu çalışmanın amacı, genç erişkinlerde artan sırt çantası yükünün vestibüler fonksiyon, denge ve yürüme parametreleri üzerindeki akut yanıtlarını araştırmaktı. **Gereç ve Yöntem:** Prospektif olarak dizayn edilen çalışmaya toplam 25 katılımcı dahil edilmiştir. Katılımcılar, vestibüler fonksiyon için adım testi, dinamik denge için Y denge testi ve yürüyüş parametreleri için enstrümental koşu bandı kullanılarak %0; %15 ve %30 vücut ağırlığındaki sırt çantalarıyla değerlendirildi. **Sonuçlar:** Vestibüler fonksiyon ile ilgili olarak, artan sırt çantası yükü ile test sonuçlarının daha iyi olduğu görüldü(p<0,05). Dinamik dengede posteromedial ve posterolateral yönlerde önemli farklılıklar vardı(p<0,05). Yürüme parametreleri açısından, yük arttıkça döngü süresi, kadans, yürüme hızı, ambulasyon indeksi ve bilateral adım uzunlukları azaldı (p<0,05). **Tartışma:** Sonuçlar, sırt çantası ağırlığına karşı görülen değişikliklerin vücut biyomekaniğini korumak ve sürdürmek için kompansatuar mekanizmaların bir parçası olabileceği şeklinde yorumlanabilir. Ekstra ağırlık koyarak, vestibüler eğitim sırasında kişi zorlanabilir.

Anahtar Kelimeler: Sırt çantası ağırlığı; Propriyosepsiyon; Denge; Yürüyüş; Vestibüler.

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Backpacks are commonly used by different populations, particularly young adults who constitute military personnel, hikers or college students (Birrell, Hooper and Haslam, 2007; Heller et al., 2009; Rodrigues et al., 2018; Simpson, Munro, and Steele, 2011; Wang, Pascoe and Weimar, 2001). However, the load of the backpack leads to various problems including alteration of balance and gait parameters (Chow, Kwok, Cheng et al., 2006; Heller et al., 2009; May et al., 2009; Rodrigues et al., 2018; Wang, Pascoe and Weimar, 2001). Chow et al. demonstrated that increasing backpack load cause alteration of balance mainly in anteroposterior direction but also mediolateral direction in schoolgirls without any musculoskeletal disorders (Chow, et al., 2006). May et al. showed that carrying a backpack containing a load of 30% of body weight degrades balance control in young adults (May, et al., 2009). Carrying a heavy backpack load leads to changes in balance components including increased postural sway, reduced postural stability and degraded upright standing posture (Chow, et al., 2006; Heller, et al., 2009; Li, Chan, Ng et al., 2019; Sahli, et al., 2013). Besides changes of balance, alteration of gait parameters with increasing backpack load has already been demonstrated in various studies (Ahmad and Barbosa, 2019; Chow, Kwok, Au-Yang et al., 2005; Hong and Cheung, 2003; Rodrigues, et al., 2018; Wang, Pascoe and Weimar, 2001). One of these studies which was conducted by Wang, Pascoe and Weimar denoted that a backpack load of 15% cause reduced walking speed and single support time but increased double support time in college students (Wang, Pascoe and Weimar, 2001). Rodrigues et al showed that a backpack that is 20% of body weight significantly resulted in decreased gait stability and regularity at preferred walking speed on a treadmill for four minutes in young adults under various positions including back bilaterally, back unilaterally and frontally (Rodrigues, et al., 2018).

Knowing the load of backpack's influence on balance and gait parameters, studies focused on determining the optimal backpack load up to now (Chow, et al., 2005; Chow, et al., 2006; Rodrigues, et al., 2018; Sahli, et al., 2013). According to our knowledge, there was no study which investigated the mechanisms behind altered balance and gait parameters with increased backpack load. It is already known that one significant component which influence balance and is affected by postural stability, upright posture and gait, is the vestibular system (Day and Fitzpatrick, 2005; Tascioglu, 2005). Despite studies investigating backpack's effect on stability, balance and upright posture, there was no study which examined the influence of different backpack loads on vestibular system which has a greater possibility to effect stability, balance, upright posture and gait. Vestibular system also has a role on cognitive function (Hanes and McCollum, 2006). May et al. demonstrated that additional carriage load deteriorates specific aspects of cognitive function (May, et al., 2009). However, all these studies indirectly indicate alteration of vestibular function and according to our knowledge there was no study which investigate vestibular function directly. This study was aimed to investigate immediate responses to increased backpack load on vestibular function, balance and gait parameters in young adults.

MATERIAL AND METHODS

Participants

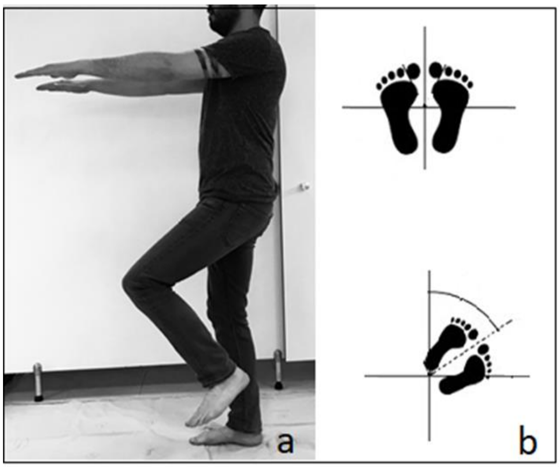
Twenty-five healthy individuals (14 males, 11 females) were included in the study. Inclusion criteria were; a) being young adults aged between 18-25 years old (Dahl, et al.,2016); b) capable of walking on treadmill independently; c) have not any orthopedic or neurologic disorders; d) have not any history of surgery; e) volunteer to participate in the study. Individuals with chronic respiratory diseases, neurologic injuries to the head, shoulder or trunk, or a recent injury (within the previous two years) were excluded from the study. Informed consent was obtained from all participants in the study.

Measurement of vestibular function: The Stepping Test (ST) was used to evaluate vestibular function. The stepping test, developed by Utenberger in 1938 and later modified by Fukuda, is a clinical test used to assess vestibular function The participants were asked to take fifty steps with their eyes closed and hands forward, and the distance between the first position and the last position (distance of displacement) was measured in centimeters and recorded. Besides, the angular values of the last position to the first position (angle of rotation) also recorded with a goniometer (Figure 1).

To assist concentration, the participants counted out loud. The examiners remained close by in silence in order to protect the participants from falling. The testing room was quiet and dimly lit, preventing the participants from guiding through sound or light. Prior to assessment, the examiners demonstrated the task to the participants. The findings were considered abnormal if the participant fell, deviated by more than

45 degrees, or had a lateral shift of more than 1 meter. Both deviations and lateral shifts were noted (Fukuda, 1959). Test–retest reliability of ST was shown an intraclass correlation coefficients range (ICC) in healthy individuals (ICC: 0.69 for distance of displacement; ICC: 0.66 for angle of rotation) (Bonanni and Newton, 1998).

Figure 1. *The Fukuda-Stepping Test (a), angle of rotation (b)*



Measurement of dynamic balance: To evaluate dynamic balance, Y-balance Test which is a frequently used test in the clinic was applied. One of the lower extremities was positioned at the center of the test material and the other one is required to extend towards anterior, posterolateral and posteromedial directions. After four familiarization trials, the average value was obtained from three trials and normalized data according to the lower extremity length from anterior superior iliac spine to the medial malleolus Interrater test–retest reliability of the average reach of 3 trails was found an intraclass correlation coefficients range of 0.85 to 0.93 (Shaffer, Teyhen, Lorenson et al., 2013).

Procedure: Three different backpack applications were used to assess vestibular function, dynamic balance and gait parameters of the participants: without loads %0 of BW (Application 1), weighted backpack at 15% of BW (Application 2) and weighted backpack at 30% of BW (Application 3). The standardized backpack type with double strap was used for loads at waist level for each of the subjects.

Data analyses

To determine sample sizes, a power analysis was performed using G*power (Heinrich Heine University, Düsseldorf, Germany) version 3.1.9.2. As the primary outcome measure, the step length was determined with a mean and standard deviation of two points with difference between two dependent means (matched pairs) test in agreement with the study by Lehnen et al (%0 BW: 62.6± 5.9; %20 BW: 63.7 ± 5.4) with a total of 25 patients providing a power of 80% and α = 0.05 (2 tailed) (Lehnen, Magnani, Sá e Souza et al., 2017). SPSS version 22.0 program (IBM Inc., Chicago, IL, USA) was used for statistical analysis and the statistical significance was set at $p < 0.05$. After performing histogram and normality tests (Kolmogorov–Smirnov, and Shapiro–Wilk) normality tests, to compare the effect of backpack weight (%0, %15 and %30 of BW) on gait parameters, dynamic balance, and vestibular function. The Friedman Test was carried out for nonparametric variables and Repeated Measures ANOVA for parametric variables. If significant differences were found, between-group differences were analysed using Wilcoxon test for non-parametric variables or paired sample t test for parametric variables. Bonferroni post-hoc test was performed to determine the differences among the applications.

RESULTS

A total of 25 subjects (14 males and 11 females) participated in this study. The mean age of the participants was 22±1.4 years (range 20–25 years), and their mean BMI was 21.7±2.3 kg/m2. Demographic characteristics of the participants are shown in Table 1 as means and standard deviations.

Table 1. Demographic characteristics of the subjects.

(n= 25)	Mean ± SD	Min	Max
Age (years)	22±1.4	20	25
Height (cm)	168±9	150	188
Body Mass (kg)	61±9	42	84
BMI (kg/m^2)	21.7±2.3	15.62	26.22

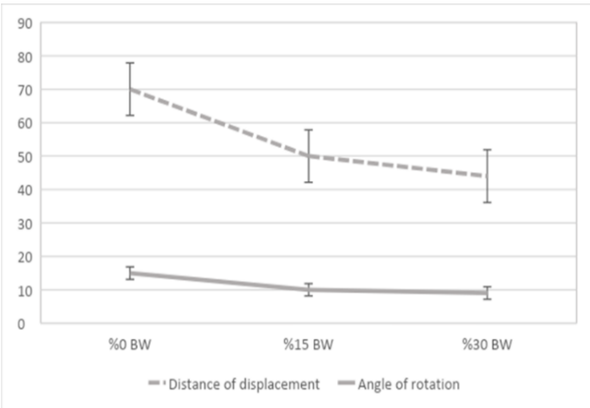
In analyzing the distance of displacement of the applications, statistically significant differences emerged in the comparison of all three cases regarding proprioception, as well as in the comparisons of the first and third applications (p = 0.018 and p = 0.006, respectively) (Table 2) (Figure 2).

Table 2. Comparison among applications in terms of vestibular function.

n=25	Application 1 (%0)	Application 2 (%15)	Application 3 (%30)	Between applications			
				3[a]	1-2	1-3	2-3
Distance of displacement (cm)	70 (58-96)	50(29-71)	44(19-83)	0.018*	0.135	0.006*	0.366
Angle of rotation (degree)	15(2-32)	10(0-23)	9(0-21)	0.241	0.032	0.408	0.446

[a]*Friedman Test, Wilcoxon test: *p<0,005*

Figure 2. Changes in distance of displacement and angle of rotation of all three applications



Regarding the dynamic balance, statistically significant differences were observed in the comparison in all three applications (p = 0.000), in the comparisons between the first and third applications for posteromedial balance (p = 0.001), in the comparison between the first and third applications, and between the second and third applications for posterolateral balance (p = 0.001, and p <0.001, respectively) (Table 3). Statistically significant differences were observed in the comparisons regarding gait parameters (step length, cycle time, gait velocity, cadence, ambulation index) in all three conditions (p<0.05) (Table 4).

Table 3. Comparison among applications in terms of balance

	Application 1 (%0)	Application 2 (%15)	Application 3 (%30)	Between applications			
				3[a]	1-2	1-3	2-3
Anterior balance	74.4±8.5	74.0±7.2	73.1±6.6	0.358	1.000	0.736	0.784
Posteromedial balance	82.3±11.8	79.3±11.8	76.4±12.0	0.000*	0.092	0.001*	0.152
Posterolateral balance	77.6±13.1	75.7±12.2	70.6±11.3	0.000*	0.638	0.001*	0.000*

[a]*Repeated Measures ANOVA, Mauchly's Test, Greenhouse- Geisser corrected, Paired sample t test : *p<0,05*

Table 4. Comparison among applications in terms of gait parameters

	Application 1 (%0)	Application 2 (%15)	Application 3 (%30)	Between applications			
				3[a/b]	1-2	1-3	2-3
Gait velocity	1.01±0.24	0.96±0.24	0.8±0.22	0.000*	0.102	0.000*	0.000*
Cadence	102±11.0	98±11.2	93±12.4	0.000*	0.000*	0.000*	0.004*
Cycle time	0.8(0.7-0.9)	0.8(0.7-0.9)	0.8(0.7-0.8)	0.000*	0.036*	0.009*	0.003*
Step length (L)	67.2±12.4	65.9±11.3	58.5±12.5	0.000*	0.783	0.000*	0.000*
Step length (R)	67.4±12.7	66.1±12.2	59.2±13.0	0.000*	0.839	0.001*	0.002*
CoV (L)	5(4-7)	5(4-6)	6(5-8)	0.009*	2.679	0.144	0.087
CoV (R)	5(4-6)	5(4-6)	6(4-9)	0.059	0.638	0.080	0.114
Stance phase (L)	50(49-50)	50(49-50)	50(49-50)	0.544	0.593	0.564	1.000
Stance phase (R)	50(50-50)	50(50-51)	50(50-51)	0.455	0.334	0.417	1.000
Ambulation index	95(89-96)	92(86-95)	88(85-94)	0.000*	0.012*	0.009*	0.015*

Mean±SD, Median(IQR): [a]*Repeated Measures ANOVA, Mauchly's Test, Greenhouse-Geisser corrected, Paired sample t test:* [b]*Friedman Test, Wilcoxon test: *p<0,005*

DISCUSSION

The aim of the present study was to investigate the immediate responses to increased backpack load on vestibular function, balance and gait parameters in young adults. The findings of the study indicate that decreased cadence and bilateral step lengths, reduced dynamic balance in posteromedial and posterolateral directions and improved distance of displacement occured as the backpack loads increased.

Decreased distance of displacement was noted in this study with increasing backpack load. Distance of displacement depends on integrated sensory information from vestibular and proprioceptive inputs. The standing position (0% BW) is different from the loaded applications as only backpack weight is carried and there will be tactile information from the backpack itself in all applications. Chow et al. showed that spinal curvature and proprioception change with carrying different weights of backpack, and decreasing repositioning consistency was found with increasing backpack load (Chow, Leung and Holmes, 2007). Another study found that during backpack carriage, there were significant increases in repositioning errors of all spinal regions and trunk forward lean (Chow, Hin, Ou et al., 2011). In addition, spinal repositioning ability in static upright stance was adversely affected by load carriage, and lumbopelvic coordination was significantly changed by backpack carriage (Chow, Wang and Pope, 2014). Therefore, the present study was designed to provide some quantitative data to explore the vestibular input during the different load carriage, and the Fukuda– Utenberger stepping test induces supplementary activation of dynamic proprioceptive input and its central integration, known to be distinct from central integration of static proprioceptive input (Onishi, Sugawara, Yamashiro et al., 2013). The changes revealed that there might be a modification of spinal curvature which might provide insight for the association between different load backpack carriage and proprioception. Besides, different load backpack carriage compatible with body weight may be beneficial in increasing vestibular and proprioceptive input. Backpack load can restrict forward and rotational movements because of gravity-related compression. Those restricted movements are thought to be considered as increased vestibular and proprioception performance.

Many researchers stated that students carrying a heavy backpack adopt a bending forward body posture which implies the trunk and neck tendency to bend forward increases since the body center of gravity shifts to the back of the base support. Thus, the anterior muscles of the trunk have to work harder as a part of compensatory reactions of the body. The further distance center of the body shifts backward, the more compensatory muscle activation has to be done. Although the backpack load is mostly related to anteroposterior balance, Chow et al. showed that mediolateral balance has been affected by the backpack load (Chow, et al., 2006). In the present study there were significant differences in posterolateral and posteromedial directions as the backpack weight increased. It might be the result of difficulties in compensating increased backpack weight in posteromedial and posterolateral directions. Besides, to improve posteromedial and posterolateral balance, the trunk and neck of the participant must flex more forward in addition to increased posterior shift of the center of body mass caused by backpack load. Bahiraei et al reported that backpack weight has the greatest effect on posteromedial direction and they also reported statistically different changes in anterior direction while the present study showed no differences in anterior direction (Bahiraei, Jafarian and Mohammad Ali Nasab, 2015). The discrepancy between the two studies in anterior direction may have been due to the age difference of the participants included in the studies. Since the participants in the present study were adults, they most likely had more muscle force to keep them well-balanced. This study had In this study, it was observed that ambulation index and cadence decreased but no change seen in stance phase and gait variability as backpack load increased. In addition, it was shown that a little amount of weight (15% of BW) had no effect on gait speed and stride length, but when the weight was further increased (30% of BW), these parameters also decreased.

This study had similar results with previous studies which demonstrated decreasing in overall gait performance and cadence presumably in order to supply energy, respiratory and cardiovascular load as backpack load increased (Ahmad and Barbosa, 2019; LaFiandra, Holt, Wagenaar et al., 2002; LaFiandra, Wagenaar, Holt et al., 2003; Legg, Ramsey and Knowles, 1992; Lloyd and Cooke, 2000; Obusek, Harman, Frykman et al., 1997). Though reduced gait performance and cadence were found, gait variability and stance phase were not affected by backpack load may be derived from equal loading to lower extremities by backpack and the symmetrically distributed loads around the body’s center of mass (Liu and Lockhart, 2013). No change seen in gait variability which is characterized by the coefficient of variance (CoV) of gait parameters in this study provides contrast results with the findings of Rodrigues, et al. that found gait regularity which indicates enhanced risk of falling for individuals carrying heavy backpack (Rodrigues, et al., 2018). These differences may be stemmed from different methods used in the studies for evaluating gait variability. In addition, increased proprioception may be another reason for preventing gait variability in this study.

In this study, individuals were asked to walk at a self-selected speed. It was shown that individuals choose slower gait speed when they carry heavy backpack (Kinoshita, 1985). According to the results of the present study, there was no significant alteration in gait speed when carrying backpack 15% BW, while gait speed reduce when carrying backpack 30% BW. Decreasing gait speed is a compensatory strategy to provide local dynamic stabilization in order to reduce fall risk. It presumably indicates that individuals have more fear of falling with the heavy loads, which provides consisting findings of Qu. (Qu, 2013). Another decreased important temporal parameter showing the fear of falling is the step cycle as was demonstrated alteration of step cycle with weight also indicates the fear of falling as increased backpack load (Park and Yoo, 2014).

In addition to no change being detected on gait speed, there was also no alteration in stride length when carrying 15% BW backpack load. However, there was reduced gait speed and stride length upon carrying 30% as expected due to decision of individuals gait speed themselves as increased backpack load. This also gives consisted results with the studies of Attwells et al. and Harman et al. that concluded increased backpack load leads to decreased gait speed, stride length and cadence (Attwells, Birrell, Hooper et al., 2006; Harman, Han, Frykman et al., 2000). In addition to this, gait parameters in 30% BW deteriorate more than gait parameters in 15%, indicating that 15% BW is safe for young adults according to our results. This give compatible results with Rodrigues et al who suggested %10 BW backpack load for young adults as more weight would disrupt gait stability and regularity (Rodrigues, et al., 2018).

This study had several limitations. Motivation levels of individuals could not be controlled. Different levels of motivation may have affected the study results. The effect of backpack load could not be investigated according to gender. The backpack used in the study was not individually adjustable. Besides, it was not examined how patients compensate in their body while carrying the backpack. More studies are needed to investigate the effect of backpack weight on the risk of falling or fear of falling.

There were significant changes in vestibular function, balance, gait parameters in the current study. Vestibular input increased, although balance and gait parameter decreased when carrying backpacks with different loads. It may be followed by the deterioration of balance with the increase in backpack load and the change in walking parameters. It seems that the deterioration in balance wasn't affected by the vestibular input, but in this study, it may be associated with the load of the backpacks stimulating tactile sensation and increasing the sensory input. Future studies are required to investigate the effects of the backpack positions and sizes and fear of falling on vestibular function and balance. There is also a need for more studies which assess the effects of vestibular functions and proprioception on gait variability.

Ethical Approval

This study was approved by the Institutional Review Board of Hacettepe University (ID: GO 18/1090).

Authors' Contribution

All authors contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors read and approved the final version of the manuscript.

Conflicts of Interest

The authors stated that no conflict of interest.

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