SB216 SJR6

Marilyn Miller von Foerster MA, PT, Salem Oregon
www.marilynvonfoerster.com

I appreciate the opportunity to address this epidemic affecting our children.

<u>Problem</u>
Back pain, strain, postural distortion, long term effects of school backpack use.

<u>Solution from a clinical perspective</u>
1) Teach the body skills of good posture, good body mechanics with everyday activity.
2) Load body with good posture, using an axial loading system that does not distort posture with increased loading.

<u>This Legislation</u>
I applaud this issue being before you. Since the 1970's children have been using backpacks to carry their school books and have suffered the consequences. Since backpacks are off-axis loads, posture immediately has to adjust, and if the load is increased, postural distortion is increased. This combination of loading in increasingly poor posture for prolonged periods everyday, is the recipe for pain and injury. If backpacks continue to be used for school, it is crucial to reduce the weight a child should carry in his/her backpack. This is important to reduce the problem, but is not a solution.

The strategies of addressing this problem over these 40+ years have been largely ineffective, because they only address the weight carried and the manner in which the bag is worn and adjusted. This bill again addresses predominantly the weight of the load carried, not the posture associated with the design of the bag itself.

If the load is transferred to a loading system that aligns with the body's vertical axis, postural tone is enhanced and pain is relieved or greatly reduced with the same load.

<u>Other Related Public Health Issues</u>
There are two other significant public health issues directly related to this discussion: osteoporosis, and deaths from opioite misuse.

<u>Osteoporosis</u> is a pediatric disease that usually manifests itself later. Prevention of the disease can only happen during the growth period when weight-bearing activity

is crucial for bone density for a lifetime. Carrying weight is important and beneficial, not harmful, as long as it is done moderately and axially, with good posture.

The Opioite Epidemic, is predominantly the result of misuse of pain medication, most often prescribed for back pain. Back pain often begins in childhood, usually related to backpack use, which causes postural distortion and poor movement habits, with heavy weight added on. Students that move their load from their backpack to a bilateral axially-loading system, are relieved of their pain and experience improved posture, the foundation of spinal health.

This Legislation can be a gold mine for addressing all of these problems, if worded thoroughly for effectiveness.

Textbooks when carried in methods described, would then increase their value in education from not only their academic subject but also Physical Education for the most important lifelong movement skills of all, good posture and healthy movement in everyday activity, while increasing postural strength—the basis of healthy bones, pain-free bodies, and positive outlook throughout life.

CONCLUSION

Knowledge is available to effectively solve this problem. I would like to be a resource for you and the Department of Education in creative ways to implement the knowledge effectively and simply.

Please make the following addition to SR216 and SJR6:

School bags must load the body with good posture, using an axial loading system that does not distort posture with increased loading.

Submitted herewith:

What is an Ergonomic Backpack? Marilyn Miller von Foerster MA, PT

Load distribution and postural changes in young adults when wearing a traditional backpack versus the BackTpack. Kimberly D. Dahl, He Wang, Jennifer K. Popp, D. Clark Dickin. Gait & Posture 2016;45:90-96, http://dx.doi.org/10.1016/j.gaitpost.2016.01.012

WHAT IS AN "ERGONOMIC BACKPACK"?

By Marilyn Miller von Foerster, M.A., P.T.

The incidence of backpack-related pain and injury continues to rise and has reached epidemic proportions. Additionally, what we see is probably just the tip of this iceberg, as kids underreport pain, and many parents discount the pain reports they do get, because "they are young" and they see no alternative.

Conventional backpacks used as schoolbags adversely affect the health, safety and productivity of developing schoolchildren, in clear opposition to the goals of ergonomics. They are off-axis, posterior-loading systems, causing the body to compensate with postural distortion. It is postural distortion which is chiefly responsible for chronic musculoskeletal pain. Any load applied off-axis is unhealthy for this reason. The postural distortion will continue unless the load is aligned with the body's axis, in obedience to the laws of physics and physiology.

As backpack use for school has become widespread, numerous articles and programs have offered instruction and guidelines in "backpack safety" and many manufacturers claim to offer "ergonomic backpacks." These guidelines, and even legislation, focus on limiting the weight put in a conventional backpack, an important consideration if this system continues to be used. It will reduce some symptoms, but the chief problem of postural distortion is not addressed effectively.

The term orthopaedic literally means "straight child". It is only during the growth period that one can affect alignment of bones with mechanical means other than surgery, and it is only during the growth period that bones can naturally build density, a lifetime investment.

> The International Ergonomics Association defines Ergonomics or Human Factors as follows:
>
> *<u>Ergonomics</u> (or Human Factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.*
>
> *Human Factors and Ergonomics is employed to fulfill the goals of health and safety, and productivity.*

Therefore, unloading the body is not necessarily a healthy alternative for developing bones. Bones require daily muscle/bone resistance during the growth period in order to build density. Our young people are getting less and less activity and no posture training. Carrying books may be their only opportunity for adequate exercise to increase bone density and prevent osteoporosis, the leading cause of fractures in adults, and increasingly seen in children. The load can be their friend and train good posture, when carried in healthy alignment.

Switching to a rolling backpack is a short-term remedy for discomfort, not a posture-training or bone density solution. A rolling backpack is actually heavier and more awkward when carrying is required (busses, stairs, irregular surfaces).

The safety and health hazards inherent in school use of the conventional backpack — originally intended for mountain recreation, not as a school bag or everyday bag — compelled me to design a healthy alternative for school or everyday use: the BackTpack.

HEALTH AND SAFETY CONCERNS with use of a conventional backpack:

1) **POSTURE DISTORTION:** commonly seen forward head, kyphosis (rounded spine), rounded shoulders, anteriorly tilted pelvis, hyper-extended knees. Poor foot alignment
2) **PAIN AND INJURY:** to back, neck, shoulders from poor posture, poor body mechanics: twisting and forward bending. Need for frequent removal, or must sit with poor posture and load on spine.
3) **INJURY TO OTHERS:** user is unaware of posterior bulk of backpack; can easily knock others down when turning quickly. Trip hazard when left on floor.
4) **POOR SECURITY:** accessible to those behind you, not to you. Must remove to access items or to sit down; difficulty in running with it on
5) **BIKING INSTABILITY, POOR POSTURE, AWKWARD OR NO ACCESS:** top-heavy, must remove for access; encourages kyphosis, cervical hyper-extension causing neck pain
6) **INCREASED WEIGHT OF LOAD INCREASES POSTURAL DISTORTION** and associated pain
7) **EMERGENCY EVACUATION CONCERNS:** classroom floor obstacles, speed, access, uphill running difficulty (Tsunami evacuation), danger to others in crowd when turning, etc.
8) **BALANCE DISTURBANCE RELATED TO POSTERIOR LOADING**

It is a neuromuscular training fact that when resistance is applied against a given direction of movement, that movement is strengthened and trained. This means that resistance applied consistently over time to the front of the shoulders, as by the straps of a loaded backpack, will train a forward head and forward lean with rounded shoulders. To train upright posture, we must load the body on its vertical axis, i.e., the book on the head, or a balanced bilateral load.

It is possible to correct the habitual postural distortion trained by a posterior loading system by applying the load in alignment with the vertical axis instead of on the back. If we apply these clinically sound principles to the everyday loading system of students, we will train their lifelong postural habits for musculoskeletal health.

SOLUTIONS FOR HEALTH AND SAFETY that the BackTpack offers:

1) **POSTURE DISTORTION IS ELIMINATED**. Spine is loaded axially. No leaning; response to load is vertical posture.
2) **REDUCED PAIN AND INJURY**: Reduced or eliminated with postural training system of axial loading and the ability to sit with BackTpack on with load transferred off spine and shoulders onto "LAP-STRAP." Since compartments are always accessible, and the wearer can sit unloaded with bag on, there is no need to frequently take the bag off.
3) **NO INJURY TO OTHERS** from user being unaware of posterior projection: BackTpack wearer is always aware of personal space related to bag he/she is wearing and can accommodate space so as not to impose it on others' safety.
4) **PERSONAL SECURITY, CONTROL OVER BELONGINGS:** The wearer's items are accessible only to the wearer. The bag does not need to be removed for access or when sitting.
5) **BIKING STABILITY, POSTURE, ACCESS:** BackTpack provides a lower center of gravity, is a balanced load, and compartments are easily accessed. When in the forward lean position, the load is applied to the body in posterior-to-anterior direction against the spine (not from shoulders), promoting a neutral spinal alignment of thoracic spine and neck.
6) **WEIGHT OF LOAD DOES NOT AFFECT POSTURE:** Since the BackTpack loads axially, there is no postural distortion with increased load. Loading this way trains upright posture. The limit of the load increase is a matter of comfort to the wearer. Some or all of the load can be transferred to the hips via the optional hip loading system provided in the design.
7) **EMERGENCY EVACUATION:** BackTpack remedies all of the safety issues mentioned. BackTpacks do not need to be removed for sitting — no trip hazard — and can even remain on the chair when the wearer gets up. The wearer has balance and mobility for rapid evacuation. Turning does not pose a hazard to others.
8) **NO BALANCE DISTURBANCE FROM LOAD:** Balance is reinforced with axial, bilateral loading.

Based on over 30 years of evidence, backpacks continue to cause postural distortion, pain and injury when used as a daily school bag in spite of "backpack safety" programs and guidelines, and claims of "ergonomic" design. Using BackTpack as a school bag effectively addresses the issues contributing to such problems. BackTpack is truly ergonomic.

If students insist on using their backpacks for school, they and their parents must be made aware of the long–term physiological effects and how best to mitigate them with appropriate exercises, training in posture and body mechanics, and to be informed of healthy alternatives for carrying their supplies. Medical professionals can do their part in combating this epidemic by informing the public about these safety issues and about what makes a healthy choice when investing in a child's school bag.

Gait & Posture 45 (2016) 90–96

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Load distribution and postural changes in young adults when wearing a traditional backpack versus the BackTpack

Kimberly D. Dahl [a,b], He Wang [a,b], Jennifer K. Popp [b], D. Clark Dickin [a,b,*]

[a] Biomechanics Laboratory, Ball State University, 2000 W. University Ave, Muncie, IN 47306, USA
[b] School of Kinesiology, Ball State University, 2000 W. University Ave, Muncie, IN 47306, USA

ARTICLE INFO

Article history:
Received 16 July 2015
Received in revised form 30 December 2015
Accepted 12 January 2016

Keywords:
Load carriage
Trunk posture
Gait
Head angle

ABSTRACT

Backpacks lead to poor posture due to the posterior placement of the load, which overtime may contribute to low back pain and musculoskeletal complications. This study examined postural and load distribution differences between a traditional backpack (BP) and a nontraditional backpack (BTP) in a young adult population. Using a 3D motion analysis system, 24 healthy young adults (22.5 ± 2.5 years, 12 male) completed both static stance and walking trials on a treadmill with No Load and with 15% and 25% of their body weight using the two different backpacks. There was a significant difference in trunk angle, head angle, and lower extremity joint mechanics between the backpack and load conditions during walking ($p < .05$). Notably, relative to the No Load condition, trunk angle decreased approximately 14° while head angle increased approximately 13° for the BP 25% state on average. In contrast, average trunk and head angle differences for the BTP 25% state were approximately 7.5° and 7°, respectively. There was also a significant difference in head angle from pre- to post-walk ($p < .05$) across backpacks, loads, and time. Taken together, the results indicate that the BTP more closely resembled the participants' natural stance and gait patterns as determined by the No Load condition. The more upright posture supported by the BTP may help reduce characteristics of poor posture and, ideally, help to reduce low back pain while carrying loads.

1. Introduction

Load carriage can be the most convenient way to transport items (e.g. military, students, athletes). Previous reports indicated over 40 million students in the United States used backpacks on a regular basis [1]. Improper backpack use (unilateral or excessive posterior loading) has led to alignment issues such as forward head posture (FHP), rounded shoulders, kyphosis, low back pain, and an asymmetrical axial skeleton [2–5].

Posture is the amalgamation of the position of multiple joints, bones, and muscles along the longitudinal axis of the body [6]. A neutral posture aligns these components in equilibrium. However, continuous poor postural compensations can lead to musculoskeletal imbalances and pain. Forward head posture occurs when the head is held anterior to its neutral, balanced position and stresses the cervical vertebrae and posterior neck muscles [7,8]. Low back pain may be caused by forward flexion of the trunk, which stresses the ligaments and intervertebral discs of the lumbar region [9,10].

Researchers have investigated the weight of backpacks, duration of wear, and postural and gait changes during load carriage. Postural compensations have been reported in conjunction with loads above approximately 20% body weight [11,12]. These compensations were reported in static trials where increased weight was correlated with an increase in FHP, trunk flexion, spinal asymmetry, and tensile forces in the intervertebral discs [4,5,13]. Similarly, postural changes with backpack use are seen during gait, including FHP, rounded shoulders, and forward trunk lean [14–16]. Backpack loads can also impact gait by increasing horizontal braking forces [14], ankle dorsiflexion, and hip and knee flexion [16].

By maintaining a neutral posture through load displacement around the body's vertical axis, nontraditional backpacks seek to reduce, and perhaps avoid, postural compensations seen in traditional backpacks. Alterations in load distribution have been assessed using a double-pack design, which distributed the load both in front and behind the participant and demonstrated decreased trunk lean and smaller center of mass displacement compared to traditional backpacks [17]. Alternatively, front-packs,

* Corresponding author at: Biomechanics Laboratory, Ball State University, Room HP 311, Muncie, IN 47306, USA. Tel.: +1 765 285 5178; fax: +1 765 285 8762.
E-mail address: dcdickin@bsu.edu (D.C. Dickin).

http://dx.doi.org/10.1016/j.gaitpost.2016.01.012
0966-6362/

which place the load anterior to the wearer, produce less FHP and hip flexion than traditional backpacks resulting in greater upright posture [18]. However, front-packs have also created an increase in thoracic kyphosis [19].

The principal purpose of this study was to assess postural changes at the spine between a traditional backpack and a nontraditional backpack (load placed bilaterally on the wearer). Additionally, the effects of load distribution on hip and knee joint mechanics during static stance and heel strike during walking were evaluated. It was hypothesized that the nontraditional backpack would result in more upright posture showing less forward trunk inclination and FHP. It was also hypothesized that the nontraditional backpack would result in smaller joint moments in the sagittal plane than the traditional backpack.

2. Methods

2.1. Participants and sampling procedures

Twenty-four healthy young adults (22.5 ± 2.5 years, 12 males) participated in this study. Participants were free from lower extremity and back injury and any other musculoskeletal or neurological condition inhibiting their ability to carry a backpack at 15% and 25% of their body weight. Participants carried a traditional backpack on a regular basis (3+ days/week) and completed a university-approved consent form and health questionnaire prior to participation.

2.2. Measurements

Posture and gait mechanics were captured using a 14-camera Vicon infrared motion capture system (VICON Inc., Denver, CO, USA) and an AMTI force instrumented treadmill (AMTI Inc., Watertown, MA, USA) collecting at 120 and 2400 Hz, respectively. A traditional backpack (U.S. Polo Assn Sport Backpack, Colfax, LA, USA) and a BackTpack (BackTpack LLC, Salem, OR, USA) were used to manipulate load carriage (Fig. 1). Load was added to the backpacks in increments of 1, 5, and 10 pounds to equal 15% and 25% of the wearer's body weight, representing loads below and above those recommended in the literature [11,15,20,21]. This load was evenly distributed in the backpacks, placing the heaviest weight closest to the spine for the traditional backpack (BP) and balancing the weights between the two pockets for the BackTpack (BTP). The shoulder straps were adjusted for each participant's height to place the BP above the hips at the low back and the BTP level with the hips. Neither a sternum strap nor hip-loading belt was utilized for the BP as not all traditional backpacks have these features. Per design requirements, a sternum strap and non-load-carrying lap strap were utilized and individually fitted for the BTP.

2.3. Procedures

Anthropometric measurements, height, and weight were recorded, and a Vicon (Vicon Motion Systems Ltd., Denver, CO, USA) Plug-In Gait marker set (legs, trunk, head) was used with standard retro-reflective markers and modified four-marker thigh and shank clusters on each leg. Lateral thigh clusters were placed anteriorly to compensate for the BTP's lateral bags. Body weight measurements were used to determine backpack loads of 15% and 25% body weight.

Participants completed 15 collection conditions which included: static upright posture recordings pre and post walking with no backpack/load ('No Load') and while wearing each of the BTP and BP loaded with 15% and 25% body weight (total 10 static posture conditions); and walking recordings were collected under the same No Load, and 15% and 25% conditions (total 5 walking conditions). Participants were instructed to "walk naturally with your head facing forward." Following the No Load state, backpack and load conditions were randomized. Participants walked at a constant speed of 1.4 m/s for 6 min to help desensitize them to the backpack during which, but not earlier than 1 min, data was extracted over a 7-s period corresponding to optimal conditions

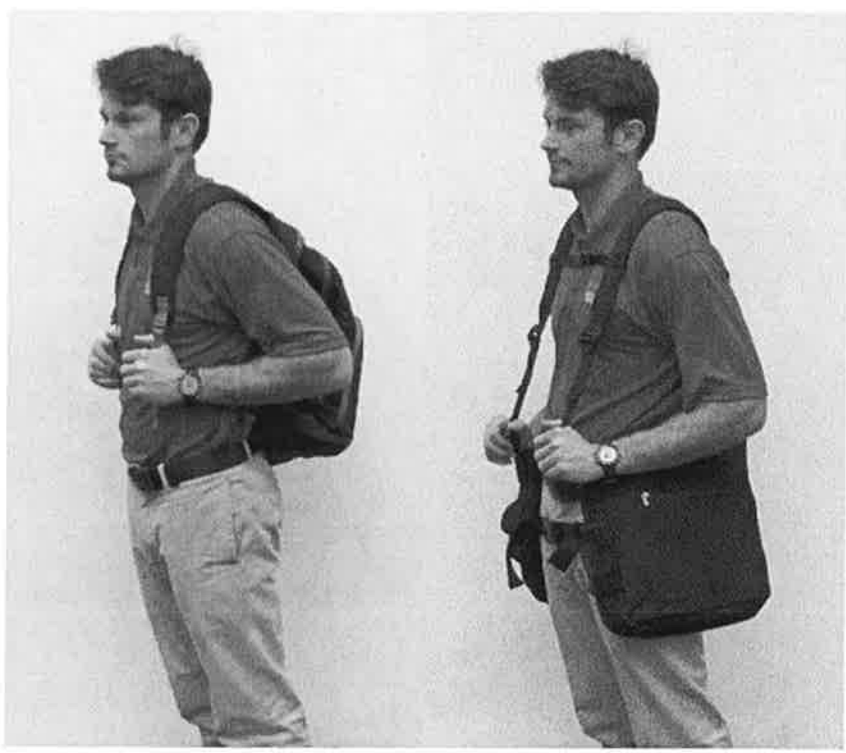

Fig. 1. Traditional backpack (left) and nontraditional BackTpack (right).

Table 1
Mean (SD) of kinetic and kinematic variables during walking trials.

Kinetic variables	No Load	BTP 15%	BTP 25%	BP 15%	BP 25%
Impact peak (BWs)[a,b]	1.20 (.09)	1.37 (.08)	1.49 (.08)	1.35 (.08)	1.47 (.08)
Loading rate (BWs/s)	2.64 (.63)	2.58 (.54)	2.57 (.55)	2.55 (.66)	2.45 (.60)
Sag knee moment[a,b] (Nm/kg)	1.01 (.24)	1.12 (.29)	1.29 (.29)	1.20 (.30)	1.44 (.35)
Frontal knee moment[b] (Nm/kg)	0.67 (.16)	0.77 (.20)	0.79 (.22)	0.74 (.20)	0.82 (.20)
Sag hip moment[a] (Nm/kg)	1.04 (.21)	1.38 (.88)	1.57 (.94)	1.02 (.53)	1.12 (.65)
Frontal hip moment[a] (nm/kg)	1.18 (.23)	1.92 (1.20)	1.71 (.94)	1.26 (.25)	1.52 (.65)
Kinematic variables Head angle[a,b] (°)	−19.12 (10.38)	−12.66 (9.58)	−11.46 (9.79)	−9.02 (9.24)	−6.09 (9.96)
Trunk angle[a,b] (°)	1.75 (3.87)	−2.77 (4.29)	−5.12 (3.68)	−7.94 (4.48)	−12.14 (4.80)
Impact knee angle[a,b] (°)	0.50 (3.46)	1.15 (3.46)	1.31 (3.77)	0.99 (3.65)	3.44 (4.35)
Peak hip angle[a,b] (°)	36.54 (4.88)	38.58 (4.95)	39.48 (5.01)	39.81 (5.44)	42.74 (5.92)

Abbreviations: BackTpack (BTP); Backpack (BP).
Note: Impact peak was measured in body weights (BWs) and loading rate was measured in body weights per second. Impact peak represents the vertical ground reaction force of the loading response peak. All angles were measured in degrees. Moments and angles represent maximum values during the 7-s period corresponding to each participant's optimal collection. Joint moments are in reference to the internal joint moment, and positive values indicate abduction in the frontal plane and extension in the sagittal plane for the knee and hip.
[a] $p < .05$ collapsed across backpacks.
[b] $p < .05$ collapsed across load.

(i.e., participant facing forward, marker visibility, foot–force plate contact).

2.4. Design and analysis

Variables studied included sagittal plane head position and trunk angle as well as sagittal and frontal plane hip and knee moments and joint angles. Marker trajectories were captured and reconstructed using Vicon Nexus (Version 1.8.5 VICON Inc., Denver, CO, USA). Filtered quantitative output of spinal position and joint mechanics were calculated in Visual 3D (Version 5.0, C-Motion, Germantown, MD, USA) using standard kinematic and inverse dynamic calculations [22]. Head angle was calculated relative to the trunk, and trunk angle was calculated relative to the global coordinate system. To assess the effect of load, data were analyzed using separate one-way RM ANOVAs for the 15% and 25% loads contrasting the No Load to the two pack designs. To assess the difference between the BTP and the BP additional 2×2 (backpack $\times$ load percentage) RM ANOVA analyses were performed comparing pack designs and load percentages. Analyses were run separately for the walking and static trials. Follow-up pairwise contrasts were performed to determine the location of significant differences. Where sphericity was violated, Greenhouse–Geisser correction was utilized. All analyses were conducted using SPSS (Version 19, SPSS Inc., Chicago, IL, USA). Bonferroni corrections were used to reduce Type I error and alpha level was set at $p < .05$.

3. Results

A summary of means and standard deviations for variables analyzed during walking is presented in Table 1. Post hoc comparisons defining significant differences for walking trials are presented in Table 2. Summary statistics for significant results during static and walking trials are presented in Table 3.

3.1. Walking – backpack type vs. load kinetics and kinematics

Contrasting the two types of backpacks and the two load conditions resulted in significant differences for both backpack and load on vertical GRF, where the BTP had a higher impact peak than the BP and the 25% load had a larger impact peak than the 15% load (Table 1). Backpack and load had a significant main effect on sagittal knee moment, where the BTP and 15% load had a lower sagittal knee moment than the BP and 25% load, respectively. Frontal knee moment had a significant interaction between backpack and load. Frontal knee moment increased more dramatically between the two loads for the BP than for the BTP. There was a significant main effect of backpack type, but not load, on sagittal and frontal hip moment. The BTP had higher frontal and sagittal plane hip moments than the BP.

Table 2
Post hoc comparisons for 15% and 25% significant main effects.

	Load	Post hoc differences	Post hoc significance
Kinetics			
Impact peak (VGRF)	15 and 25%	BTP ↑ NL	$p < .001$
		BP ↑ NL	$p < .001$
Loading rate	25%	NL ↑ BP	$p = .016$
Sag knee moment	15%	BTP ↑ NL	$p = .027$
		BP ↑ NL	$p < .001$
	25%	BTP ↑ NL	$p < .001$
		BP ↑ NL	$p < .001$
		BP ↑ BTP	**p = .001**
Frontal knee moment	15% and 25%	BTP ↑ NL	$p < .001$
		BP ↑ NL	$p < .001$
Sag hip moment	25%	BTP ↑ NL	$p = .036$
Frontal hip moment	15%	BTP ↑ NL	$p = .024$
		BTP ↑ BP	**p = .044**
	25%	BTP ↑ NL	$p = .040$
Kinematics			
Head angle	15%	NL ↑ BTP	$p < .001$
		NL ↑ BP	$p < .001$
		BTP ↑ BP	**p = .001**
	25%	NL ↑ BTP	$p < .001$
		NL ↑ BP	$p < .001$
		BTP ↑ BP	**p < .001**
Trunk angle	15% and 25%	BTP ↑ NL	$p < .001$
		BP ↑ NL	$p < .001$
		BP ↑ BTP	**p < .001**
Impact knee angle	25%	BP ↑ NL	$p = .001$
		BP ↑ BTP	**p = .001**
Peak hip angle	15%	BTP ↑ NL	$p = .001$
		BP ↑ NL	$p < .001$
	25%	BTP ↑ NL	$p < .001$
		BP ↑ NL	$p < .001$
		BP ↑ BTP	**p = .003**

The pairwise comparisons broken down to show where significant differences occurred for each variable during walking trials. Significant contrasts between pack designs are bolded to highlight the influence of load carriage location. Abbreviations: No Load (NL), BackTpack (BTP), Backpack (BP).

Table 3
Summary statistics corresponding to significant results for walking and static trials.

Walking – *Backpack vs. load* – Kinetics	Factor	F^a	p	Kinematics	Factor	F^a	p	Static – *Backpack vs. load* – Kinematics	Factor	F^a	p
VGRF	Backpack	6.31	.02	Head angle	Backpack	44.48	<.001	Head angle	Backpack	53.10	<.001
	Load	283.11	<.001		Load	10.67	.003		Load	33.28	<.001
Sag knee moment	Backpack	18.37	<.001	Trunk angle	Backpack	164.01	<.001		Time	6.60	.02
	Load	79.95	<.001		Load	123.35	<.001	Trunk angle	Backpack × load	8.36	.008
Front knee moment	Backpack × Load	15.57	0.001		Backpack × Load	15.48	0.001		Backpack × time	5.32	.03
Sag hip moment	Backpack	13.00	.001	Impact knee angle	Backpack	7.73	.01				
Front hip moment	Backpack	6.65	.02		Load	6.98	.02				
					Backpack × Load	7.35	.01				
				Peak hip angle	Backpack	10.66	.003				
					Load	42.20	<.001				
					Backpack × Load	12.38	.002				

Walking – *No Load vs. 15%* – Kinetics	Factor	F^b	p	Kinematics	Factor	F^b	p	Static – *No Load vs. 15%* – Kinematics	Factor	F^b	p
VGRF	Load	143.69	<.001	Head angle	Load	(1.56, 35.86) 58.83	<.001	Head angle	Load	66.08	<.001
Sag knee moment	Load	14.22	<.001	Trunk angle	Load	(1.60, 36.79) 164.96	<.001		Time	10.42[a]	.004
Front knee moment	Load	21.39	<.001	Peak hip angle	Load	18.89	<.001	Trunk angle	Load	199.10	<.001
Front hip moment	Load	(1.05, 24.03) 7.63	.01								

Walking – *No Load vs. 25%* – Kinetics	Factor	F^b	p	Kinematics	Factor	F^b	p	Static – *No Load vs. 25%* – Kinematics	Factor	F	p
VGRF	Load	295.12	<.001	Head angle	Load	78.79	<.001	Head angle	Load	(1.59, 36.51) 130.84	<.001
Loading rate	Load	4.25	.02	Trunk angle	Load	263.28	<.001		Time	7.06[a]	.01
Sag knee moment	Load	54.14	<.001	Impact knee angle	Load	12.55	<.001	Trunk angle	Load	169.19[b]	<.001
Front knee moment	Load	35.75	<.001	Peak hip angle	Load	35.15	<.001				
Sag hip moment	Load	5.48	.01								
Front hip moment	Load	90.73	<.001								

[a] $F(1,23)$.
[b] $F(2,46)$.
Or (df1,df2) as noted.

There was a significant main effect of backpack type on head angle, trunk angle, impact knee angle, and peak hip angle in the sagittal plane (Table 1). When collapsing across load, the BTP elicited significantly more upright head angle than the BP. Load percentage had a significant main effect on head angle, trunk angle, impact knee angle, and peak hip angle. The 15% load had more upright head angle than the 25% load. There was a significant interaction between backpack and load on trunk angle, impact knee angle, and peak hip angle. The BP had a more dramatic increase in trunk flexion than the BTP as load increased. At impact, knee angle for the BTP underwent only marginal amounts of flexion, while the BP produced a much larger difference in knee angle as load increased. A similar pattern was seen for maximum hip angle as load increased.

3.2. Walking—No Load vs. 15% load kinetics and kinematics

Load had a significant main effect on vertical GRF, sagittal knee moment, frontal knee moment, and frontal hip moment. Load also had a significant main effect on head and trunk angle between all three pack conditions. There was a significant main effect of load on peak hip angle. Table 2 presents follow-up pairwise comparisons.

3.3. Walking—No Load vs. 25% load kinetics and kinematics

For the 25% load, there was a significant main effect on all of the kinetic variables examined: vertical GRF, loading rate, sagittal and frontal knee moments, and sagittal and frontal hip moments (Table 2). All three pack conditions exhibited significant main effects, and follow-up pairwise differences, between each pack condition for head and trunk angle, and peak hip angle. While impact knee angle was larger for BTP than for the other two conditions.

3.4. Static—backpack type and load

There was a significant main effect of time, backpack type, and load on head angle. Head angle became significantly more hyperextended between pre- and post-walk when wearing the BP compared to the BTP and as load increased from 15% to 25% (Fig. 2). There was a significant interaction between time and

backpack and between backpack and load on trunk angle. Collapsed across load, trunk angle had a sharper increase for the BP than the BTP between pre- and post-walk. Going from 15% to 25% with the BP had a larger increase for trunk angle than the BTP when collapsed across time (Fig. 2).

3.5. Static--No Load vs. 15%

Time had a significant main effect on head angle. From pre- to post-walk, head angle became significantly more hyperextended. There was a significant main effect of load on head and trunk angle (Fig. 2). Pairwise comparisons revealed a significantly hyperextended head angle between both backpacks and the No Load condition ($p < .001$). The BP head angle was also significantly more hyperextended than the BTP ($p = .002$) at 15% load. For trunk angle, post hoc analysis revealed significantly more forward trunk flexion with a 15% load between both backpacks and the No Load condition ($p < .001$) and between the BP and BTP ($p < .001$).

3.6. Static--No Load vs. 25%

Time had a significant main effect on head angle, which became significantly more hyperextended from pre- to post-walk. There was a significant main effect of load on head and trunk angle (Fig. 2). Pairwise comparisons revealed that head angle was significantly more hyperextended between both backpacks and

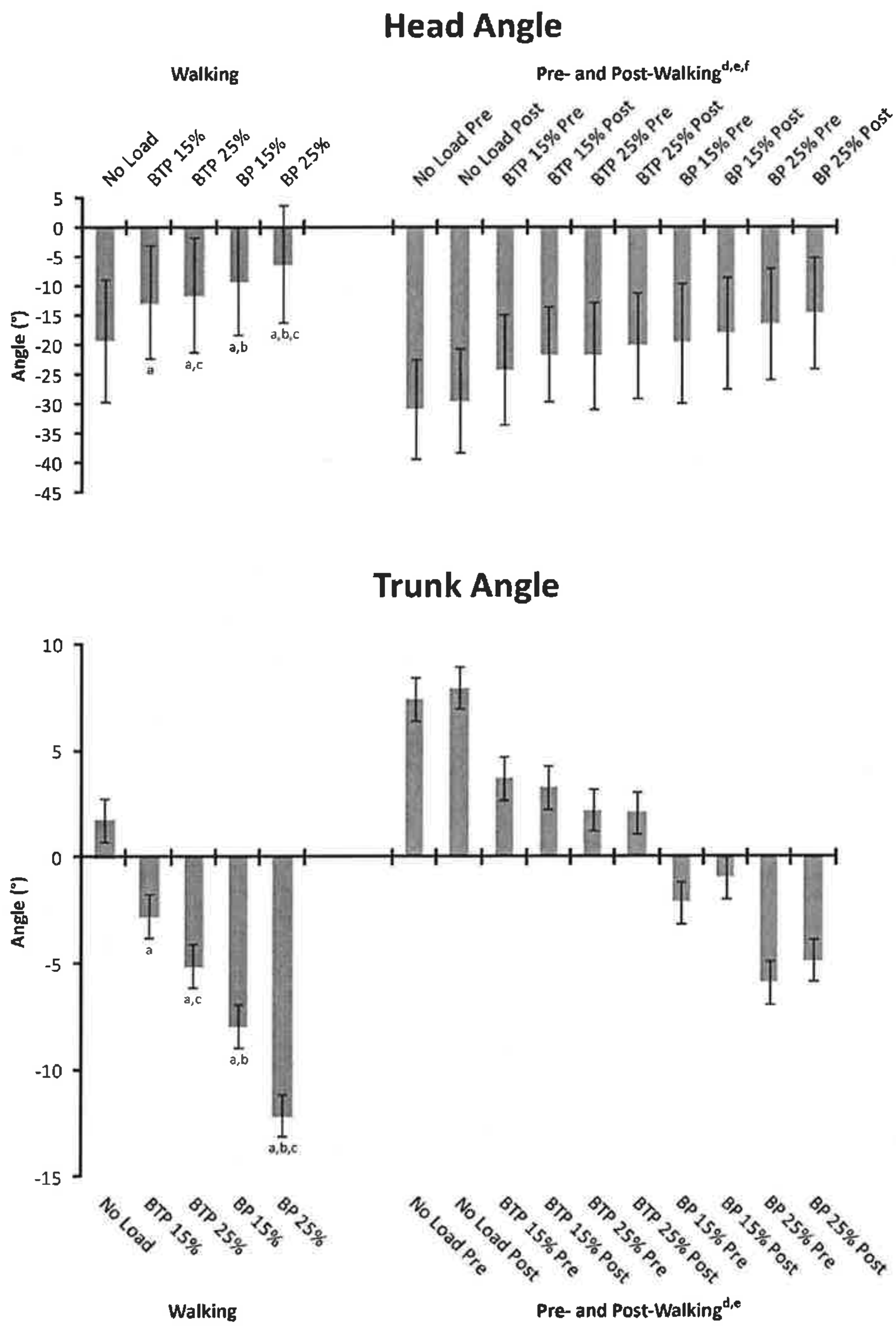

Fig. 2. Head and trunk angles during walking trials and pre- and post-walking static trials for all backpack types and load conditions. Abbreviations: BackTpack (BTP), Backpack (BP). (a) $p \leq .001$ compared to No Load condition; (b) $p \leq .001$ between backpack types of the same load; (c) $p \leq .001$ between load conditions of the same backpack type; (d) $p < .05$ collapsed across backpacks; (e) $p < .05$ collapsed across load; (f) $p < .05$ collapsed across time.

the No Load condition ($p < .001$) and between the BP and BTP ($p < .001$) at 25% load. For trunk angle, post hoc analyses revealed the 25% load produced significantly more forward trunk flexion between both backpacks and the No Load condition ($p < .001$) and between the BP and BTP ($p < .001$).

4. Discussion

The primary goal of the current study was to determine the impact of load distribution on both gait and posture between two backpack styles in young adults. The hypothesis that the BTP would result in more upright posture than the BP was confirmed for both walking and static trials with less forward trunk lean and FHP for the BTP over the BP. Joint moments at the hip and knee in the sagittal plane were hypothesized to be less for the BTP, which was confirmed for the knee at the 25% load.

4.1. Posture

During walking, postural changes were seen between the two backpacks. At both load percentages, there was more forward trunk lean for the BP than the BTP. This likely resulted from posterior loading with the BP and axial loading with the BTP. Participants leaned forward, placing their COG within the base of support, to compensate for the posterior pull of the load [20,23]. The BTP, however, placed the load in line with the vertical axis, allowing the wearer to maintain a more upright torso position. A more erect stance permits a more natural spine curvature and thus may help reduce the likelihood of low back pain caused by flattening of the lumbar spine with trunk flexion [9]. In this study, head angle reflected trunk angle in that as the trunk flexed, the head hyperextended allowing participants to look straight ahead and not at the ground. Consequently, with the BP resulting in more forward trunk lean, the head position was more hyperextended than the BTP. Hyperextension is involved in FHP, which may result in shoulder and neck pain [12]. Hyperextension also places undue stress on the cervical vertebrae by removing the natural shock-absorbing curve and sends the weight of the head straight to the discs and posterior facets [7].

The significantly more flexed knee angle at impact for the BP at 25% may relate to the larger forward trunk lean. Knee flexion would allow for more absorption of the heavier load and increased mass over the knee caused by trunk flexion. Therefore, knee flexion may help lessen the loading rate and correspondingly reduce joint stress. Peak hip angle may also relate to forward trunk lean by creating a smaller angle between the thigh and the trunk even if the leg itself is not lifted higher. Therefore, significant differences reported for peak hip angle may reflect greater forward trunk lean seen with the BP at the 25% load.

When standing without a pack immediately after walking with one of the packs, differences between the packs were still present. Specifically, head and trunk angle were significantly more hyperextended and flexed, respectively, for the BP than the BTP. Only head angle was affected by time, potentially because at the end of walking participants may have readjusted their head angle to reflect a more upright stance. However, both head and trunk angle continued to be affected by load. Other studies also reported worsening posture with increased load [11,12,24]. Pre- and post-walk differences in head and trunk angle may indicate a residual effect of walking with a backpack.

4.2. Gait

In this study, the ability to carry loads while walking demonstrated an expected increase in vertical GRF regardless of backpack type. Additionally, larger sagittal knee moments for the BP compared to the BTP at 25% may be related to the more flexed trunk angle. Leaning forward at the trunk places more mass over the knee, producing larger knee extensor moments. Interestingly, frontal plane knee moments were larger at the 15% load for the BTP than the BP but switched at the 25% load. Given the risk of developing knee osteoarthritis may increase with excessive frontal knee moments [27], further research is needed to more clearly define the effect of load on knee loading, especially in the frontal plane. At the 15% load there was also a larger frontal hip moment with the BTP than the BP, which may be a result of the location of the weight for the two packs. The lateral location of the BTP pockets may produce more side-to-side movement during walking whereas the BP would produce, or potentially augment, the more typical front-to-back movement seen in gait. An unexpected finding was the higher loading rate for the No Load condition than the BP loaded at 25%. This may be related to the more flexed knee angle at impact for the BP mentioned previously. The straighter leg in the No Load condition would create more of a rigid lever, which may cause the load to be accepted more rapidly and reduce absorption capabilities [25].

While it was determined that there were differences in gait and posture as a function of backpack type, and ultimately the location of the load relative to the axial skeleton, there were some study limitations. Although the order of backpack type and load was randomized and participants were able to rest between pack exchanges, there was no standard rest period. Therefore, the compound effect of wearing a backpack may be a function of limited rest during the exchange between packs and weights. The current study was conducted on a treadmill, which allowed multiple consecutive foot strikes to be analyzed. While not identical to overground walking [26], recent studies have highlighted similarities in terms of kinematic and spatio-temporal parameters between overground and treadmill walking [27,28]. Future studies should examine differences between these backpack types among different populations such as children, older adults, and special populations. Investigations may also consider analyzing muscular activity of both the trunk and lower extremities, the spatio-temporal parameters of gait, and the differences between these backpacks during activities of daily living such as walking at a self-selected pace and stair navigation.

5. Conclusion

In conclusion, while not equal to the No Load condition, load displacement of the BTP allowed the wearer to maintain a more upright posture than the BP—the trunk was more erect and the head was less hyperextended. The more upright stance facilitated by the BTP may reduce the potentially negative effects of poor posture such as neck and shoulder pain, low back pain, and musculoskeletal asymmetries. While not always significantly different from the BP, the BTP more closely resembled the participants' natural gait patterns as determined by the No Load condition.

Acknowledgments

This study was partially funded by Ball State University's ASPiRE Grant. The nontraditional backpacks were provided by BackTpack.

Conflict of interest

There was no conflict of interest regarding this study among any of the authors.

References

[1] Wang Y, Pascoe DD, Weimar W. Evaluation of book backpack load during walking. Ergonomics 2001;44:858–69. http://dx.doi.org/10.1080/00140130118572.

[2] Abrahams S, Ellapen TJ, Van Heerden HJ, Vanker R. The impact of habitual school bag carriage on the health of pubescent scholars. Afr J Phys Health Educ Recreat Dance 2001;17:762–71.

[3] Linders DR, Nuckley DJ. Deduction of spinal loading from vertebral body surface strain measurements. Exp Mech 2007;47:303–10. http://dx.doi.org/10.1007/s11340-006-9008-6.

[4] Orloff HA, Rapp CM. The effects of load carriage on spinal curvature and posture. Spine 2004;29:1325–9. http://dx.doi.org/10.1097/01.BRS.0000127185.74191.B1.

[5] Bettany-Saltikov J, Cole L. The effect of frontpacks, shoulder bags and handheld bags on 3D back shape and posture in young university students: an ISIS2 study. Stud Health Technol Inform 2012;117–21. http://dx.doi.org/10.3233/978-1-61499-067-3-117.

[6] Twomey LT, Taylor JR. In: Twomey LT, Taylor JR, editors. Physical therapy of the low back. 3rd ed., New York: Churchill Livingstone; 2000.

[7] Kapandji IA. The physiology of the joints. 6th ed., English ed. Edinburgh; New York: Churchill Livingstone; 2007.

[8] Kendall FP, McCreary EK, Provance PG, Rogers MM, Romani WA. In: Kendall FP, McCreary EK, Provance PG, Rogers MM, Romani WA, editors. Muscles: testing and function with posture and pain. 5th ed., Baltimore, MD: Lippincott Williams & Wilkins; 2005.

[9] Novak JS. Posture, get it straight!. 1st ed. New York: Perigee Books; 1999.

[10] Oliver J. Back in line. Woburn, MA: Butterworth-Heinemann; 1999.

[11] Al-Khabbaz YSSM, Shimada T, Hasegawa M. The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. Gait Posture 2008;28:297–302. http://dx.doi.org/10.1016/j.gaitpost.2008.01.002.

[12] Kistner F, Fiebert I, Roach K, Moore J. Postural compensations and subjective complaints due to backpack loads and wear time in schoolchildren. Pediatr Phys Ther 2013;25:15–24. http://dx.doi.org/10.1097/PEP.0b013e31827ab2f7.

[13] Rodríguez-Soto AE, Jaworski R, Jensen A, Niederberger B, Hargens AR, Frank LR, et al. Effect of load carriage on lumbar spine kinematics. Spine 2013;38:E783–91. http://dx.doi.org/10.1097/BRS.0b013e3182913e9f.

[14] Attwells RL, Birrell SA, Hooper RH, Mansfield NJ. Influence of carrying heavy loads on soldiers' posture, movements and gait. Ergonomics 2006;49:1527–37. http://dx.doi.org/10.1080/00140130600757237.

[15] Hong Y, Cheung C-K. Gait and posture responses to backpack load during level walking in children. Gait Posture 2003;17:28–33.

[16] Majumdar D, Pal MS, Majumdar D. Effects of military load carriage on kinematics of gait. Ergonomics 2010;53:782–91. http://dx.doi.org/10.1080/00140131003672015.

[17] Lloyd R, Cooke C. Biomechanical differences associated with two different load carriage systems and their relationship to economy. Hum Mov 2011;1:2. http://dx.doi.org/10.2478/v10038-011-0006-x.

[18] Fiolkowski P, Horodyski M, Bishop M, Williams M, Stylianou L. Changes in gait kinematics and posture with the use of a front pack. Ergonomics 2006;49:885–94. http://dx.doi.org/10.1080/00140130600667444.

[19] Wang CXG, Chow DHK, Pope MH. Biomechanical effect of LOAuD carriage on spine curvature and repositioning ability in adolescents. Anaheim, CA: ACTA Press; 2007. p. 161–6.

[20] Kistner F, Fiebert I, Roach K. Effect of backpack load carriage on cervical posture in primary schoolchildren. Work 2012;9:9–108. http://dx.doi.org/10.3233/WOR-2012-1289.

[21] Chow DH, Kwok ML, Au-Yang AC, Holmes AD, Cheng JC, Yao FY, et al. The effect of backpack load on the gait of normal adolescent girls. Ergonomics 2005;48:642–56. http://dx.doi.org/10.1080/00140130500070921.

[22] Winter DA. Biomechanics and motor control of human movement. 4th ed. Hoboken, NJ: John Wiley and Sons Inc.; 2009.

[23] Smith B, Ashton KM, Bohl D, Clark RC, Metheny JB, Klassen S. Influence of carrying a backpack on pelvic tilt, rotation, and obliquity in female college students. Gait Posture 2006;23:263–7. http://dx.doi.org/10.1016/j.gaitpost.2005.02.009.

[24] Chiang H-Y, Jacobs K, Orsmond G. Gender-age environmental associates of middle school students' low back pain. Work 2006;26:197–206.

[25] Seay JF, Fellin RE, Sauer SG, Frykman PN, Bensel CK. Lower extremity biomechanical changes associated with symmetrical torso loading during simulated marching. Mil Med 2014;179:85–91. http://dx.doi.org/10.7205/MILMED-D-13-00090.

[26] Alton F, Baldey L, Caplan S, Morrissey MC. A kinematic comparison of overground and treadmill walking. Clin Biomech (Bristol Avon) 1998;13:434–40. http://dx.doi.org/10.1016/S0268-0033(98)00012-6.

[27] Hollman JH, Watkins MK, Imhoff AC, Braun CE, Akervik KA, Ness DK. A comparison of variability in spatiotemporal gait parameters between treadmill and overground walking conditions. Gait Posture 2015. http://dx.doi.org/10.1016/j.gaitpost.2015.09.024.

[28] Watt JR, Franz JR, Jackson K, Dicharry J, Riley PO, Kerrigan DC. A three-dimensional kinematic and kinetic comparison of overground and treadmill walking in healthy elderly subjects. Clin Biomech 2010;25:444–9. http://dx.doi.org/10.1016/j.clinbiomech.2009.09.002.