SJR6

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I have been a practicing physical therapist for 47 years, including research and teaching, with a focus on back health and injury prevention, which are based on habits of healthy posture and movement.

Back health in the school environment has been a focus of mine for over 15 years. I have been a member of Healthy Kids Learn Better Coalition starting in 2005. I have advised school districts on school chair purchases for back health of students and have done extensive research on the backpack problem.

I appreciate the opportunity to address this epidemic affecting our children. My goal is to provide our legislators with information to reach effective solutions to this problem.

Problem

Back pain, strain, postural distortion, long term effects of school backpack use, including the increased risk of back disability in adulthood

This Legislation

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, because the center of gravity has changed. If the off-axis load is increased, postural distortion is increased. This combination of loading in increasingly poor posture for prolonged periods every day 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 main strategies that have addressed the problem for over 40 years, weight carried and method of wearing the backpack, have been largely ineffective. Statistics of pain and injury from backpack use have increased. According to the Journal of the American Medical Association Pediatrics, low back pain among school-aged children is also increasing. This affects school attendance, general physical activity, and creates an increased risk for low back pain in adulthood, the greatest medical cost to industry and workforce productivity, let alone quality of life.

The strategies have been ineffective because they only address the weight carried in backpacks and the manner in which the bag is worn and adjusted. This bill again addresses predominantly the weight of the load carried, not the postural distortion caused by the design of the bag itself. It does however encourage use of "ergonomic backpacks", which begins to address effective solutions. However, 'ergonomic' is not well understood or defined in reference to backpacks, which in themselves do not display ergonomics.

It is misleading to address weight carried as the chief culprit in this problem. That would lead the public to believe that our children should carry no weight at all, when in fact weight is crucial during the growth period for building bone density for a lifetime.

The chief culprit is postural distortion caused by a carrying system that loads the body behind its vertical axis, the common backpack, which also requires frequent unhealthy movement patterns in order to handle the load. These two factors—poor posture, and poor handling movements—are injurious, especially with heavy loads. Therefore we should not load typical school backpacks heavily. If the moderate 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.

Looking to effective solutions, we need to examine the bag itself, provide carrying systems that load the body with good posture, and allow the user access to contents in a healthy way. There are bags available that do just that. It is also possible to create one's own system when the principles are clearly understood.

We are in fact training **something** with everything we carry on a daily basis. We can make the choice to train good strong posture and awareness of healthy movement habits in our children with such everyday activities, rather than train patterns of pain and disability.

Solution

1) Thoroughly analyze the cause of the problems being addressed. Is the weight the culprit? or is weight an essential element for healthy bone development? Should any weight be carried with poor posture?

2) Educate the public about the physics and developmental physiology related to how the body is meant to carry loads and why it is important for lifelong health.

3) Apply knowledge of physics related to reducing the force of the load upon the spine. The further the load from the axis, the more the force is multiplied on the spine. Eliminate the torque by loading on the vertical axis.

4) Teach body skills of good posture, good body mechanics with everyday activity, and especially when lifting and carrying loads.

5) Always load the body with good posture, using an axial loading system for carrying school supplies that does not distort posture with increased loading.

Other Related Public Health Issues

There are two other significant public health issues directly related to this discussion: osteoporosis, and deaths from opioite misuse.

Osteoporosis is a pediatric disease that usually manifests itself later in life. Prevention of the disease can only happen during the growth period, the 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. They also have access to items without bending and twisting with the load.

This Legislation can be the key for unlocking the solution to 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. Back health demands that loads be carried with good posture and handled with good body mechanics.

Please make the following addition to SJR6 *in italics* to read:
Page 2, line 12 (b) Schools should encourage the use of ergonomic backpacks with individualized compartments to properly distribute the weight of books and equipment, and *which load the body on the vertical spinal axis with no postural distortion.*

Submitted herewith:

Our Kids, Backpacks, and the Back Epidemic. M von Foerster, Orthopeadic Practice Vol. 15:3:03

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

Influence of Physical Activity on Bone Strength in Children and Adolescents: A Systematic Review and Narrative Synthesis. Abstract: Vina PS Tan et al. Journal of Bone and Mineral Research, Vol29, No. 10, October 2014

Load Distribution and Postural Changes in Young Adults When Wearing a Traditional Backpack Versus the BackTpack. Kimberly D. Dahl, et al. Gait & Posture 2016;45:90-96, http://dx.doi.org/10.1016/j.gaitpost.2016.01.012

Our Kids, Backpacks, and the Back Epidemic

Marilyn Miller von Foerster, PT, MA

INTRODUCTION

In my 34 years of teaching back health and rehabilitation I have observed that lifelong habits of poor posture are a main contributing factor to back pain and disability. That is why I am committed to address these habits as early in life as possible. Poor posture includes such things as forward head, forward trunk lean, and associated short stride length which we see as tendencies in aging. There are numerous references in the literature linking backpack use not only to back pain and injury but to these posture and gait problems.[1-9] What alarms me now is how many children I see with posture and gait that we associate with 80 year olds and certainly with the majority of patients with back pain.

Since my son introduced me to the world of children 13 years ago, I have spent a good deal of time volunteering in schools. I have seen so many factors in the life of our school children which contribute to back disability that as a physical therapist I am appalled. I will share with you the problems I see and what I feel needs to be done to correct them.

FROM THE CENTER OUT

In my clinical approach I have always started at the center and worked out, while evaluating the individual as a whole. I am applying this same approach to our kids, backpacks, and the back pain epidemic.

School Chairs

Our children spend nearly 6 hours of their school day sitting in bucket seats that have been designed for ease of stacking rather than for the humans sitting in them (Figure 1). In order to sit relaxed in seats like these, one must assume a posterior pelvic tilt and spinal kyphosis with forward head. If children plan to read or write at their desks, they must exaggerate these postural distortions even further (Figure 2). Teachers usually require students to sit back in their chairs for reasons of orderliness and safety—understandable priorities in our crowded classrooms—but in the typical school chairs the only way to sit with proper spinal position is to sit on the front edge of the chair so that your pelvis is free to rotate anteriorly on the femur to assume a neutral position. Most children instinctively try to reach this position (if there molding process is not too advanced already).

Figure 1.

Figure 2.

Aside from the postural distortion created by these child-molding chairs, the hamstrings are put in a shortened position while seated at a desk, as are the hip flexors. The length of these two major muscle groups is crucial to proper spinal/pelvic posture and mechanics. When the children are allowed to elongate in stance, it is only for enough time to hurriedly don their backpack and rush to the next class or have a quick trip to the locker if they are lucky enough to have one. There is certainly no time for a thorough stretch of these shortened muscle groups. And, there is certainly no time and attention spent on getting one's head back on top of the spine in a vertical orientation!

Forward Heads

Heads are forward from hours in the chair, leaning over desks, hovering over computers (Figure 3) (while seated in

Figure 3.

other bucket seats or chairs that require a backward lean, as recommended by "ergonomists"), lounging in soft sofas at home watching TV, playing with Legos on the floor, etc. Children, and our entire society in general, spend so much time with a forward head that our brains adopt this as a new "normal" position. How many times have we heard from our patients when we correct their head position that "it feels unnatural, like I'm leaning backward."

Backpacks on Top of it All

Upon these flexed spines, children don the backpack, which has for some reason become a standard school supply item. The horizontal forces of weight behind and straps in front over shoulders, dictate a forward lean and facilitate rounded shoulders and forward head (Figure 4). Now that we have our developing loved-one sufficiently slumped for a sufficient period of time throughout each day, we add a 20-pound load to the whole gravity challenge. This is imposed upon a rapidly developing skeleton that

Figure 4.

will be shaped for a lifetime within these few years. All our children are victims of this disabling requirement. What are we as a society and a profession doing, tolerating this pattern?

WHY ARE OUR CHILDREN SO ATTACHED TO BACKPACKS?

If we really want to solve this backpack problem we must first analyze its cause, just as we do with our patients. I would like to first acknowledge the fine study of two Pacific University doctoral students of physical therapy, Jessica Johnson and Cathleen King, who analyzed many factors involved in backpack use in adolescence and especially the importance of studying specific age groups in order to best analyze and solve this problem.[10]

General observations I have made with my own child and his classmates as to why they use and misuse the backpack to the detriment of their bodies, despite all the advice from knowledgeable teachers and parents, has suggested the following reasons:

Convenience

- —They don't want to be caught without something important to have along so they keep much more than they need in the backpack. Therefore the weight of the pack increases beyond healthy limits.
- —It is awkward and time consuming to take it on and off so why not just keep it on therefore increasing the length of time carrying the load.
- —"Out of sight out of mind." Hand and arms are free for other activities and the backpack becomes in effect unconsciously grafted to the body, forcing our neuromusculoskeletal systems to make the necessary mechanical and physiological adaptations in order to continue to function with gravity.

Fashion

- —Coolness. Gotta wear the sag bag!
- —No student in their right mind would be caught without a backpack in school!
- —The kindergarteners want to be big and look like a real student.
- —Media and marketing make it cooler by the minute and by the dollar. Marketing sophistication is way beyond the influence of parents and certainly beyond their pocketbooks.

Required Equipment

- —Many schools include backpacks in their school supply list.

SO WHAT CAN WE DO ABOUT IT? "Form Follows Function"

We all know that the human body is designed to stand vertically. Physical therapists know what good spinal position is (though amazingly controversial these days!), and that its most efficient loading is as close to vertical, or spinal elongation, as possible. We need no elaborate research efforts to convince us that the best way to carry a load is close to the spine, the best way to use our legs properly in gait is with vertical posture, the best way to reinforce and train a movement is to give it resistance and repetition in the direction as similar to the desired movement and function as possible. As we train people to reach their highest functional levels we guide them to experience this relationship of their body with gravity. Our children all have this relationship in its purest form when they begin walking, balancing their heavy heads. I have included a diagram illustrating the horizontal and vertical components of forces associated with backpack carrying (Figure 5). The sketch illustrates why the forward pull of the shoulders is necessary to balance the downward pull of the backpack load.

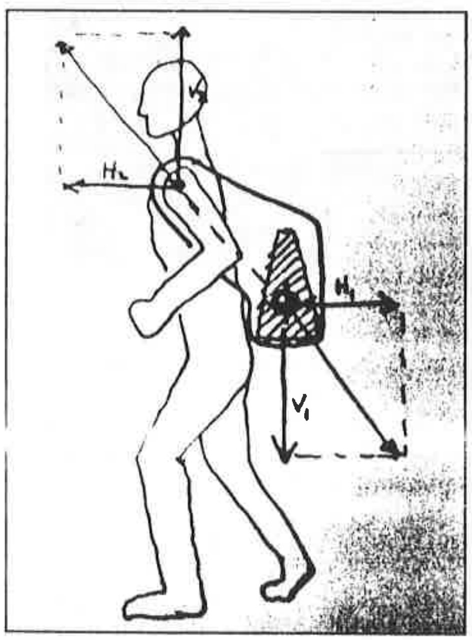

Figure 5.

Load Axially

The human body is its own load, ie, mass and gravity. How is it made to work with its weight? It is made to work vertically in partnership with gravity. So shouldn't we complement this already perfect design by keeping the load vertical and not messing it up! We should look at our toddlers and our wise native brothers and sisters and use our heads to balance our axial loads, as they have done for centuries.

Are we victims of fashion too? Our first reaction when someone in our culture places something on their head — laughter! We think they are being silly. Well it's time to get serious. And don't underestimate our children's wisdom. When given the facts about themselves, their bodies, and peoples of this earth, kids will want to make the right choices, especially if they are part of the creative solution process—and know that they are helping their own loved ones by their example and their ideas.

Horizontal versus vertical

Look at our classrooms, our daily lives, our chairs, our loads. Do they complement this vertical effort or do they change the direction of our human movement and posture toward the horizontal activities of our lives—driving, computer work, watching TV? In my experience the only effective way to train good posture is to do proprioceptive neuromuscular facilitation for axial extension. This can be done with any head carrying exercise or device that is of minimal but sufficient weight to proprioceptively facilitate, once the individual assumes full axial extension and optimal spinal posture, which can be measured by CV angle measurements.[11] This often requires extensive retraining to overcome decades of poor postural habits.

People of the World

Why don't we join the rest of the world and carry loads as they have been doing for centuries, from the head and/or with balanced axial loading over the shoulders? They must use their bodies properly for survival. They cannot rely on technology to do the body's work, and they have no worker's compensation for back disability.

In plains regions such as in Africa, many natives apply a twisted rag in a donut shape as a base for carrying objects directly on the head. In mountainous regions requiring constant travel on inclines, people use a tumpline (head strap) system with a basket on the back (see Figure 6). In 1983 when visiting Nepal with our beloved colleague, the late Sarah Semens, I personally experienced the Nepalese carrying system for 2 weeks by employing it myself. I also met with an orthopaedic surgeon in Kathmandu who expressed amazement that the Nepalese people who carry very heavy loads in this manner for days at a time, do not have the back problems so common in our society. Needless to say,

Figure 6.

they begin postural training by necessity at a very early age.

When speaking in classrooms, I bring slides of people around the world to demonstrate how we are all part of the human family and how we have much to learn from those less "privileged" than we. This has been an enormous breaker of the fashion and vanity consciousness that especially influences adolescents. It gets them excited and expands their awareness of design possibilities.

ACTIONS I HAVE TAKEN

My crusade began when my son was in the fourth grade. The class was studying comparative skeletal anatomy, and when they got to the human, the teacher asked if I would cover that area. I took the opportunity to teach about why we were designed as we are and how to respect and care for that design, posture first. I provided small travel cushions for the children's chairs so they could experience correct and incorrect sitting posture. They used them for the rest of the year and experienced how much better their backs felt. I notified our local newspaper about the project. The editor did a very informative and fun article using photographs of the children. She was happy to have me do most of the writing so the information would be correct. These cushions by the way are a simple remedy for the bucket seats, short of replacing them. I have arranged for all the classrooms I have been involved in to purchase these cushions at a discounted rate.

I discovered several years later that the fourth-grade was an ideal time to start the posture and back health awareness education. Fourth-graders are open to ideas and less affected by the many physiological and social concerns of adolescence that limit attitudes about their bodies.

I continued working with each of my son's classes, now approaching the eighth-grade. Our local newspapers and television stations have been interested in each class project.This has been a real validator with the kids and the community, as well as just exciting and fun. It has also been useful as carry over information for the students from year to year.

In one fifth-grade class, I involved the students in evaluating several chair samples to advise the principal in what chairs he should order when chairs were to be replaced. I also photographed the children in sitting posture at their desks, before and after training. This posture awareness project with all 60 fifth-graders of the Nestucca Valley School District was shown on big-time Portland network news, a huge thrill for the students of our small rural community on the Oregon Coast.

At the end of the project, I gave them copies of the photos so that they and their families could visualize the subject and practice at home. Photos are especially valuable as teaching tools because there is so little time and attention available in the classroom for outside people such as us.

I also involved the students in book bag design brainstorming. Here they could apply to a real-life situation what they learned about the basics of how the body works, with respect for the spine as the center of healthy movement and posture. They came up with "right on" suggestions. One of these is also my recommendation: bilateral shoulder bags joined like a vest with an optional head strap.

Currently I am working on an attachment to the present backpacks that will decrease the horizontal vector and include the head for some of the load, which facilitates axial extension and optimal posture. If any of you are interested in my backpack attachment you can contact me. Maybe some researchers among you would like to use it in a study.

I have included "Guidelines for Backpack Use" in Appendix 1; a handout I put together for students, parents, local doctors' offices, etc. I made it available to parents, students and teachers in local schools during the registration and orientation periods and throughout the year.

When Sharon Kitzhaber, a physical therapist, was First Lady of Oregon, I wrote to her for her input regarding my concerns about the spinal health of our school children related to poor postural habits. She recommended I speak with the Physical Education Specialist of the Oregon State Board of Education, Margaret Bates. After an afternoon of interesting exchange of ideas and information, she suggested I write an article for the professional journal of Oregon physical educators. See Appendix 2.

FURTHER ACTIONS WE CAN ALL TAKE IN OUR COMMUNITIES

- Collaborate with your local Pediatric Orthopedist to expose these problems to your community from a broad medical perspective.
- Go into the classrooms, volunteer to help. While you are there, notice all the other factors in addition to backpacks that contribute to the back pain epidemic.
- Offer to do a posture class in the classroom or instruct teachers in the basics to share with their class and incorporate into daily classroom good habits.
- Meet with physical education and classroom teachers. At first I had thought that PE was the class in which to teach posture and body mechanics, but then I realized that the instructors only have a very short time with each student, and maybe only two classes a week. Since it is really daily habits that we need to address, I now think back health habits are best brought into the classroom. Present them in a way that benefits teachers as well. Everyone needs to stretch throughout the day and the students and teachers will work better, and with a more positive attitude if their bodies are not being abused at the same time.
- Find out how the chairs are ordered, what catalogues, who orders, the criteria they use, etc. and offer to educate and help with the selection of chairs.
- Contact vendors and school chair designers, schools of industrial design, etc. Educate them in the importance of fostering good posture with design.
- Coordinate PTs and OTs in your school district to demonstrate our professional commitment as a team to address issues that affect lifelong spinal health.
- Contact your legislators. Legislation is proposed in California regarding backpacks. Lead that process in your state. Los Angeles County schools employ physical therapists to oversee the ordering of furniture and to properly adjust it to the students.
- Best of all, teach children what to be aware of at school and at home. Teach

them to feel and learn healthy posture through their neuromotor system, and how to properly stretch the muscles that are shortening while just being a student. Teach them the mechanics of backpack use and have them design a better system for carrying books. They love learning and creating solutions to their own problems. Most of them will have an emotional involvement with the problem since the majority of families have someone who has suffered a lot with back pain, has been crabby, unable to work, and unable to play with them due to back pain.

- Get the media involved.
- Write the Surgeon General.
- If all else fails...use the legal system!!!!

But once again, let's remember to go to the CENTER first. You can't correct all of these problems fast enough anyway, so take a deep breath and start with one. If you are a parent you can do something about the health of your own child now. I sometimes spend too much time with the big problems of our society instead of addressing the problem right in my own household.

Here is what we work on at home to keep our child orthopaedically healthy:

ACTIONS ON THE HOME FRONT

- Practice good posture: when sitting, standing, sleeping, reading, playing Legos, eating at the table, etc. Use occasional posture checks such as standing against the wall to learn how it feels to be vertical or lying flat on the floor, so the head can learn proper alignment with the spine.
- Our son especially loves sports so we demonstrate how these posture principles improve all athletic performance. Build on your child's personal interests.
- Eliminate leaning onto elbows whenever possible, especially while eating.
- Encourage frequent change of positions and know what positions to get into that "undo" the position he may have been in for a long time, eg, with Legos on the floor or computer activity.
- A written Home Exercise Program!! of appropriate stretches (hamstrings, hip flexors, thoracic spinal extension), and strengthening exercises (situps, pull-ups, handstands, leg strengthening, etc).
- Head-carrying activities whenever possible.
- Experiment with carrying systems other than a backpack.
- Solicit his suggestions of how we all can improve our postural habits and encourage ideas from him of other stretches and strengthening exercises to do.
- Play games like keeping a balloon off the ground or batting it back and forth, volleyball, head carrying relays, pull-up contests, etc.
- Share clinical examples of disabilities from postural disorders, and comments from patients, such as "if only someone had told me this 40 years ago."
- Learn about carrying methods of people around the world who must use their bodies correctly for survival.
- And most important of all, BE AN EXAMPLE. We imitate one another.

SUMMARY

GET RID OF BACKPACKS for school use. They were originally designed for mountain climbers, whose hands are occupied and who are bent forward to climb an incline. Somehow the market spread to children for school supplies, and now backpacks are fashion statements. (Check out fashion and posture since the 70s, the post-Backpack Era vs. pre-70s, the pre-Backpack Era, in films, cartoons, magazines, commercials, etc.)

LOAD AXIALLY. If we need school bags at all (which is certainly questionable for kindergarteners and first graders), they should allow the weight to be evenly distributed on both sides and as close to the spine as possible to facilitate axial extension. Learn from native populations around the world who depend on their bodies for survival, instead of the conveniences our prosperity provides. They are the authorities in body mechanics. They use their heads and balance their loads. Teaching habits of healthy aging, beginning with our children, is the professional challenge of our day.

LET'S BE AN EXAMPLE. We must be able to show what we know if we want to teach it. I am proud that Physical Therapy is taking a leadership role in educating the public so all people can be as healthy as they were created to be. This must continue to be our focus.

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WHAT IS AN ERGONOMIC BACKPACK?

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

The International Ergonomics Association defines Ergonomics or Human Factors as follows:[2]

> Ergonomics (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.

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." Nevertheless, 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.

Backpacks are off-axis, posterior loading systems, causing the body to compensate with postural distortion. The postural distortion will continue unless the load is aligned with the body's axis, in obedience to the laws of physics and physiology. It is this postural distortion as well as the posterior protrusion of the backpack, not the magnitude of the imposed load, which are chiefly responsible for the pain and injuries.

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 build density, a lifetime investment.

Since postural distortion, not the magnitude of the load, is a chief disabling factor of backpack use, switching to a rolling backpack is a short-term remedy, but not a solution. A rolling backpack provides no postural training — the mechanism is actually heavier and more awkward when carrying is required (busses, stairs, irregular surfaces), and 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. Carrying their 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.

Backpacks worn on the back, or on one shoulder only, clearly do not fulfill the goals of health and safety, and productivity. The safety hazards inherent in the design of the 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, SAFETY AND PRODUCTIVITY 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
4) **POOR SECURITY:** accessible to those behind you, not to you: must remove to access items or to sit down; difficult to run with on
5) **BIKING INSTABILITY, POOR POSTURE, AWKWARD OR NO ACCESS:** top heavy, must remove for access; encourages kyphosis, cervical hyperextension 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.

- to train a high stepping gait, we weight the ankles
- to encourage hip flexion in gait we provide resistance to anterior pelvis
- to train a forward head and forward lean with rounded shoulders, we apply resistance anteriorly to shoulders, i.e., a loaded backpack (posterior load) with shoulder straps
- to train upright posture ,we load the body on its vertical axis, i.e., the book on the head, or a balanced bilateral load

The only way to correct the habitual postural distortion trained by a posterior loading system is to apply the load on the axis instead of 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, SAFETY AND PRODUCTIVITY that the BackTpack offers:

1) **POSTURE DISTORTION:** Eliminated. Spine is loaded axially. No leaning, reaction to load is vertical posture.
2) **PAIN AND INJURY** from poor posture and poor body mechanics: Reduced or eliminated with postural training system of axial loading and the ability to sit with BackTpack on, load transferred off spine and shoulders onto strap over thighs. 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) **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) **SECURITY:** The wearer's items are accessible only to the wearer. The bag does not need to be removed 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) **INCREASED WEIGHT OF LOAD INCREASES POSTURAL DISTORTION:** Since the BackTpack is a postural training system, loading axially, there is no postural distortion with increased load. 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, and if removed, can be draped on the chair instead of the floor. The wearer has balance and mobility for rapid evacuation.
8) **BALANCE DISTURBANCE FROM POSTERIOR LOAD:** No balance disturbance with axial, bilateral loading. Balance is reinforced.

Based on 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 their child's school bag.

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Influence of Physical Activity on Bone Strength in Children and Adolescents: A Systematic Review and Narrative Synthesis

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ABSTRACT

A preponderance of evidence from systematic reviews supports the effectiveness of weight-bearing exercises on *bone mass* accrual, especially during the growing years. However, only one systematic review (limited to randomized controlled trials) examined the role of physical activity (PA) on *bone strength*. Thus, our systematic review extended the scope of the previous review by including all PA intervention and observational studies, including organized sports participation studies, with child or adolescent bone strength as the main outcome. We also sought to discern the skeletal elements (eg, mass, structure, density) that accompanied significant bone strength changes. Our electronic-database, forward, and reference searches yielded 14 intervention and 23 observational studies that met our inclusion criteria. We used the Effective Public Health Practice Project (EPHPP) tool to assess the quality of studies. Due to heterogeneity across studies, we adopted a narrative synthesis for our analysis and found that bone strength adaptations to PA were related to maturity level, sex, and study quality. Three (of five) weight-bearing PA intervention studies with a strong rating reported significantly greater gains in bone strength for the intervention group (3% to 4%) compared with only three significant (of nine) moderate intervention studies. Changes in bone structure (eg, bone cross-sectional area, cortical thickness, alone or in combination) rather than bone mass most often accompanied significant bone strength outcomes. Prepuberty and peripuberty may be the most opportune time for boys and girls to enhance bone strength through PA, although this finding is tempered by the few available studies in more mature groups. Despite the central role that muscle plays in bones' response to loading, few studies discerned the specific contribution of muscle function (or surrogates) to bone strength. Although not the focus of the current review, this seems an important consideration for future studies. © 2014 American Society for Bone and Mineral Research.

KEY WORDS: BONE STRENGTH; PHYSICAL ACTIVITY; CHILD; ADOLESCENT; SYSTEMATIC REVIEW

Introduction

The antecedents of adult bone health problems develop during the growing years when more than one third of adult bone mass is accrued during two key years around peak adolescent growth.[1] The convergence of this critical period of bone accrual *and* bone loading through weight-bearing, high-impact, and/or muscle-enhancing physical activity (PA) is thought to confer a "window of opportunity" for development of a healthy skeleton.[2] Because osteoporosis and fractures impart a high social, emotional, and financial levy,[3] it is important that children and adolescents adopt physically active behaviors as one potential means to prevent these problems from occurring later in life.

Tempered by genetics, the evidence that weight-bearing PA plays a central role in promoting bone mass accrual, especially during the growing years, is irrefutable.[4] Specifically, over the past two decades many high-quality intervention and longitudinal studies provided strong evidence to support a positive effect of PA on bone mass accrual in boys and girls. Results from these studies are summarized in several excellent reviews.[4–7] Early findings advanced our understanding of how bone accrues in the healthy skeleton and how the skeleton adapts to PA during growth.[8,9]

Ultimate bone strength is comprised of bone's material properties, quantity, dimensions (size and material distribution), quality, and microarchitecture.[10] Although it would be ideal to measure each of these bone parameters, it is not possible to do

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

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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,

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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

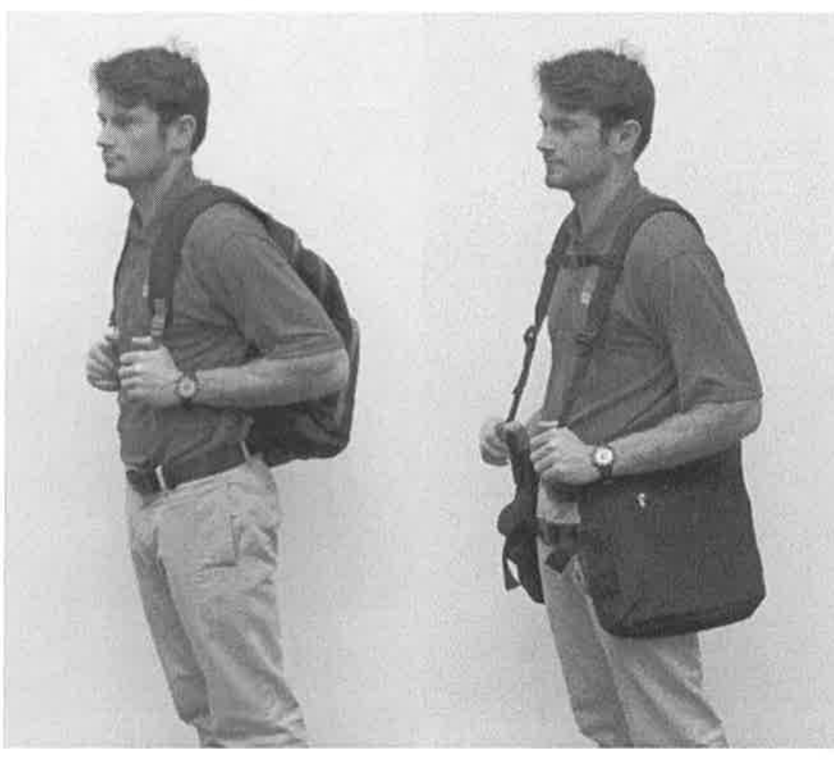

Fig. 1. Traditional backpack (left) and nontraditional BackTpack (right).

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 × 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	Walking – *Backpack vs. load* – 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	Walking – *No Load vs. 15%* – 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	Walking – *No Load vs. 25%* – 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

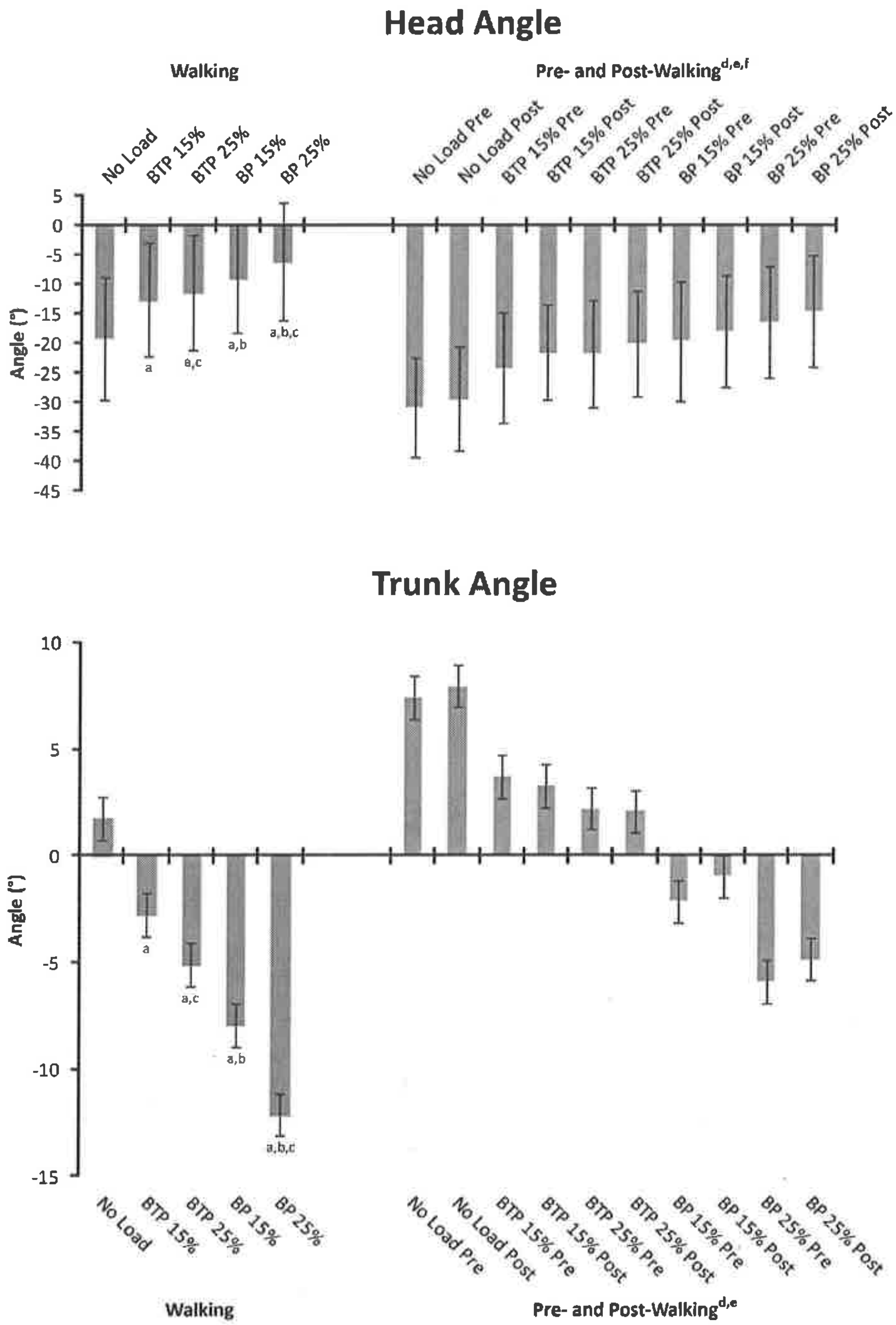

Fig. 2. Head and trunk angles during walking trials and pre- and post-walking static trials for all backpack types and load conditions. Abbreviations: BackTpack (BTP), Backpack (BP). (a) $p \leq .001$ compared to No Load condition; (b) $p \leq .001$ between backpack types of the same load; (c) $p \leq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

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Conflict of interest

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

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