

UNIVERSITY OF MIAMI

POSTURAL COMPENSATIONS AND SUBJECTIVE COMPLAINTS
DUE TO BACKPACK LOADS AND WEAR TIME IN SCHOOLCHILDREN
AGED 8 TO 11

By

Frances Elizabeth Kistner

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

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Frances Elizabeth Kistner

Approved:

Ira M. Fiebert, Ph.D., P.T.
Associate Professor
Department of Physical Therapy

Terri A. Scandura, Ph.D.
Dean of the Graduate School

Kathryn E. Roach, Ph.D., P.T.
Associate Professor
Department of Physical Therapy

James G. Moore, Ph.D., P.T.
Assistant Professor
Department of Physical Therapy

Penny G. Kroll, Ph.D., P.T.
Chair and Professor
Department of Physical Therapy
Marshall University

KISTNER, FRANCES ELIZABETH
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Backpacks are used by more than 90% of schoolchildren worldwide and over 40 million students in the United States on a regular basis. The carriage of loaded backpacks is associated with kinematic and physiological changes, as well as complaints of neck and back pain. Since a history of backpain in childhood is the strongest predictor of having musculoskeletal discomfort and back pain as an adult, development of back pain due to backpack use is of prognostic concern. The purpose of this dissertation was to examine the effects of backpack weights (up to 20% body weight (BW)) on children's posture, subjective complaints of pain and perceived exertion, and walking endurance. A secondary goal was to examine the data to identify and recommend a weight limit for backpacks carried by elementary school children based on the results.

In Chapter 2, we performed a preliminary study designed to examine the effects of loaded backpacks on forward head posture in school children. The results of this study found that forward head posture increased with both backpack weight and condition. The greatest differences were noted at the 15% and 20%BW backpack loads with initial loading, but after 6 minutes of walking the forward head posture was similar for all backpack loads.

In Chapter 3, we conducted a study to evaluate multiple postural angles and the subjective complaints of pain and perceived exertion/fatigue in children to determine the effects of both the weight and time spent carrying loaded backpacks up to 20%BW. Subjects showed significant changes in all measures including the Six Minute Walk Test (6MWT), OMNI Walk/Run Scale of perceived exertion/fatigue and subjective complaints of pain, as well as the postural angles of Craniovertebral Angle, Forward Trunk Lean, and Pelvic Tilt. Subjects demonstrated immediate and significant changes in forward head posture, forward trunk lean, and pelvic tilt while wearing backpacks weighing 10%, 15% and 20%BW, but the 10%BW backpack resulted in the least amount of change. This study also found that these postural angles changed additionally after walking 6 minutes while carrying the loaded backpacks. Subjects also demonstrated decreased 6MWT distances and increased reports of perceived exertion and pain after carrying backpacks weighing 10%, 15% and 20%BW.

In Chapter 4, we discussed the clinical implications of this research. It was determined that backpack loads weighing 10%, 15% and 20%BW of a child's body weight result in immediate changes in posture, which continue to increase after walking six minutes with the loaded backpack. The backpack loads significantly impacted the children's walking endurance as well as their reports of perceived exertion/fatigue and regional pain. This study found that of the loads tested, the 10%BW resulted in the least amount of change in all outcome measures. However, the 10%BW load was not innocuous, as it still created significant changes in posture and subjective complaints. Backpack weight limit guidelines need to be written to protect children from carrying backpacks weighing more than 10% body weight.

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LIST OF ABBREVIATIONS

Unloaded	Testing condition at baseline, prior to donning the loaded backpack.
Initial Load	Testing condition immediately after donning the loaded backpack
Post Walk	Testing condition after walking six minutes with the loaded backpack
6MWT	Six minute Walk Test
AAOS	American Association of Orthopaedic Surgeons
ACA	American Chiropractic Association
ALICE	All-Purpose Lightweight Individual Carrying Equipment
AOTA	America Occupational Therapy Association
APTA	America Physical Therapy Association
BMI	Body Mass Index
BORG	Scale to measure ratings of perceived exertion on a scale of 6 to 20
BORG 10	The BORG scale constructed as a category (C) ratio (R) scale of 1 to 10
BOS	Base of Support
BW	Body Weight
COM	Center of Mass
CVA	Cranivertebral Angle
FHP	Forward Head Position
FTL	Forward Trunk Lean
ICF	The International Classification of Functioning, Disability and Health
MOLLE	MOdular Lightweight Load-carrying Equipment
MSD	Musculoskeletal Disorder
NIOSH	National Institute of Occupational Safety and Health
OMNI	Rating of Perceived Exertion scale using pictorial descriptors
RPE	Rating of Perceived Exertion
SAPAC	Self-Administered Physical Activity Checklist
TILT	Pelvic Tilt Angle
VAS	Visual Analog Scale
WHO	World Health Organization

Chapter 1: Introduction

Backpacks are commonly used by students of all ages with more than 90% of schoolchildren carrying backpacks worldwide¹ and roughly 40 million students in the United States using them on a regular basis.^{2,3} Backpacks are also frequently used by soldiers and hikers to carry a variety of loads. Over the last 40 years, researchers examining various aspects of backpack usage have discovered evidence, such as pain, cardiorespiratory changes and posture changes, which has lead to an increased concern about the effects of heavy backpack load carriage on children.^{4,5,6,7,8,9,10,11}

Decreased availability of school lockers as a result of vandalism and security concerns,^{4,9} increased homework,⁴ larger textbooks,⁴ and other objects being carried to school⁶ has prompted the increase use of backpacks by school children which in turn, has lead to both an increase in weight and duration of backpack carriage.⁹

Children are introduced to the concept of carrying a backpack as early as 2 years of age when daycare attendees carry a change of clothing, lunch, toys and more in their own backpack. While toddlers may think they are being “big girls and boys”, they are just beginning a cycle of load carriage that may continue well into adulthood. The carrying of backpacks is associated with kinematic and physiological changes, as well as complaints of neck and back pain. Since a history of backpain in childhood is a strong predictor of having musculoskeletal discomfort and back pain as an adult, development of back pain due to backpack use is of prognostic concern.^{12,13,14}

Structure and Function of the Skeleton

Backpacks, which are commonly used by adults and children for carrying objects for school, work and recreation produce an external influence upon the human body, and

potentially affect multiple body systems and positioning of body structures. A review of the lower extremity joint complexes will be of benefit to understanding the effect of carrying a backpack on the human body and therefore is carried out below.

Functional weight bearing activities, such as standing or walking involve ankle complex motion with either the leg moving on the foot, or the foot moving on the leg. Active control and coordination of this complex are essential for normal gait, stance, and postural control and enables stability and mobility through an interaction of multiple articulations. The primary movers controlling the ankle complex in the sagittal plane are the dorsiflexor and the plantarflexor muscles. The dorsiflexors contract concentrically to bring the tibia (and body) forward over the foot and the plantarflexors contract eccentrically to control that degree of anterior movement. Conversely, concentric contraction of the plantarflexors brings the tibia (and body) backwards over the foot and eccentric contraction of the dorsiflexors controls the degree of posterior movement. Control and coordination of these structures is essential for stance, gait, and postural control. There are other muscles involved in controlled actions within the foot, but they will not be discussed here.

The knee joint consists of the tibia, the femur and the patella. The primary motion available at the knee is flexion and extension, however, movement in the frontal and transverse plane are also present. As with the ankle, discussion of knee motion is described from the closed chain perspective, with a foot fixed on the ground. The primary movers in the sagittal plane at the knee include the quadriceps femoris which concentrically extends the knee and eccentrically controls flexion, and the hamstrings which concentrically flex the knee and eccentrically control knee extension.

Additionally, the hamstrings assist with hip extension, and the quadriceps assist with hip flexion as these muscles also cross the hip joint. During lifting, the quadriceps are the primary knee extensor, but the hip extensors provide significant strength for extension of the hip.¹⁵ During bending, the flexion moment at the hip is controlled by eccentric activity of the hamstrings.¹⁵ Weakness of the hamstrings and/or quadriceps may affect control of the hip and knee when bending and lifting.¹⁵

The hip joint consists of the femur and the innominate bone of the pelvis. The sacrum completes the pelvis, and will be discussed with the vertebral column. The hip demonstrates motion in all three planes, but discussion here is limited to the sagittal plane, again in closed chain, in weight bearing with the foot fixed on the floor. The pelvis tilting anteriorly on a fixed femur produces hip flexion and a posteriorly tilting pelvis extends the hip. True hip flexion must be distinguished from apparent hip motion coming from the lumbar spine. In closed chain hip flexion, at the end ROM, the pelvis begins to rotate anteriorly on the femoral heads. In turn, this flattens the lumbar spine. Together, this provides an apparent hip flexion range of motion (ROM) measure that is greater than the pure hip flexion of pelvis on femur. Conversely, hip extension may lead to a posteriorly tilted pelvis to create a greater apparent hip extension or hyperextension. The primary hip flexors are the psoas major and the iliacus, together known as the iliopsoas muscle. While the primary action of the iliopsoas is flexion of the hip, there are additional actions which are relevant to this discussion. Due to the origination of the psoas on the transverse processes and lateral vertebral bodies of T12 to L5, and the origination of the iliacus from the iliac fossa, the sacrum and the ligaments of the lumbosacral and sacroiliac joints, these muscles also have an effect on the low back. The

alignment of the psoas major also applies compressive forces to the lumbar spine and also pulls on the intervertebral discs resulting in increased low back pain with hip flexion movements.¹⁵ Additionally, tightness of the psoas and the iliacus limits hip extension, resulting in an increased anterior pelvic tilt and excessive lumbar lordosis as the lumbar vertebrae are pulled anteriorly. Compensatory lumbar extension is then required to maintain an upright posture with horizontal gaze.¹⁵ Without the compensatory lordosis, tightness of the iliopsoas may result in a forward lean and a decreased lordotic curve.¹⁵

Hip extension occurs through activation of the gluteus maximus as well as the hamstrings and adductor magnus. The extensors stabilize the pelvis and contribute to the control of upright posture when the COM of the trunk moves forward. The hip extensors also contract eccentrically to control the movement of the pelvis during forward bending of the trunk, and concentrically to bring the trunk back to an upright position. Tightness of the gluteus maximus and the hamstrings restrict hip flexion when bending or lifting and may produce increased trunk flexion during activities. This increase in lumbar spine motion may contribute to low back pain.¹⁵

The pelvis is comprised of the two innominate bones and the sacrum. The sacrum is formed from the fusion of the five sacral vertebral segments and resembles an inverted triangle. The base of the sacrum is the superior surface of the first sacral vertebra, which articulates with the fifth lumbar vertebra. The base of the sacrum is tilted forward roughly 30° and is generally greater in females. This angle, the sacral inclination, relates directly to lumbar lordosis, as an increase in the sacral inclination produces an increase in the lumbar lordosis.^{15,16} The articulation of the sacrum and L5 is known as the lumbosacral junction and is the point of the greatest stress of the entire spine due to the

compressive and shear stresses of the body's weight pressing down through L5 to the sacrum.¹⁵

The spinal column above the sacrum consists of 24 vertebrae and is able to support the head while providing a base for upper extremity movement and provides the flexibility for the wide range of spinal movements required for daily living. From a sagittal view, the spine demonstrates three major curves, the posteriorly concave cervical and lumbar lordosis and the anteriorly concave thoracic kyphosis. The spine is supported by a complex system of ligaments and muscles. The primary extensor muscles of the thoracolumbar spine in the sagittal plane are the erector spinae (including the longissimus, iliocostalis and spinalis groups). The rectus abdominus and other muscles of the abdominal wall (external oblique, internal oblique and transverse abdominus) are involved in trunk flexion and stabilize the spinal column during lifting. Cervical spine muscles flex and extend the cervical spine, as well as flex and extend the head on the neck at the atlanto-occipital (AO) joint.¹⁵ The prime movers for extension in the cervical spine are the semispinalis capitis, the semispinalis cervicis, the splenius capitis and cervicis, levator scapulae, longissimus captitus and the upper fibers of the trapezius. The combined actions of the deep suboccipital muscles fine tune the extension of the head on the upper cervical spine.¹⁵ The cervical flexors include the sternocleidomastoid, the longus colli, the longus capitis, the scalene and the anterior rectus capitis. In an upright position, the center of mass (COM) of the head is slightly anterior of the AO joint, creating an external flexion moment. In response, the neck extensors contract to maintain an upright head with a horizontal gaze. Changes in any aspect of postural alignment, from the feet to the head, require compensations throughout the body.¹⁵

Normal Upright Posture

To examine upright posture and subsequent compensatory responses, an examination of the kinematics of posture is required. Ideal postural alignment, according to Kendall, involves “a minimal amount of stress and strain and is conducive to maximal efficiency of the body.”^{15,17} Ideal posture is described using a theoretical plumb line (or vertical posture line) that passes through the auditory meatus, just anterior to the acromion, just anterior to the greater trochanter, slightly anterior to the knee joint and just anterior to the ankle joint.^{15,17,18} This alignment enables relative silence in the postural muscles except for the plantarflexors which remain lightly active to maintain static equilibrium.

Kinetics of Normal Posture

Gravity and ground reaction forces apply external moments to the hip, knee and spine as the vertical posture line passes each respective region. These external moments are countered by the body’s internal moments supplied by muscle or connective tissues at the knees and hips. The pelvis is in neutral when the anterior superior iliac spines and the posterior superior iliac spines are relatively in the same plane. With a neutral pelvis, the vertebral column demonstrates a lordosis of the lumbar spine. The vertebral column curves both anteriorly and posteriorly through the lumbar, thoracic and cervical regions in normal alignment, with the theoretical plumb line passing through the bodies of the lumbar vertebrae and anterior of the thoracic curve.¹⁷ In ideal alignment, COM of the head is just anterior of the AO joint,¹⁵ the neck displays a cervical lordosis and the head balances with the least amount of muscular effort while maintaining horizontal gaze.¹⁸ Analysis of the forces reveal that the maintaining an upright head position requires

extensor force of roughly one half the weight of the head at the AO joint, and almost twice the weight of the head is required at the C7-T1 joint to maintain the position of the head.¹⁵ Deviations in posture may occur at any point in the body, from the feet, to the knees, hips, spine or head, which will result in compensations and decreased muscular efficiency as the body attempts to maintain upright with a horizontal gaze.

Development of Normal Posture

The spines of children and adolescents are different from the spinal structures of adults¹² as the development of the human spine is not complete until the third decade. Children reach full spinal growth by 24 years of age,¹⁹ and experience several growth periods, especially during their school-age years, from 5 to 18 years.²⁰ Prior to birth, a fetus is curled in utero with a flexed, kyphotic vertebral column. The cervical lordosis develops after birth, with maturation as a baby begins to lift its head against gravity in observation of its surroundings. This is followed by the development of the lumbar lordosis develops as the infant begins extending its arms and lifting its chest off the surface. The infant begins to moves its pelvis and legs against gravity while laying prone, and the lumbar lordosis further develops as the infant starts creeping and then walking. In early walking, the hip flexors pull the pelvis anteriorly, which additionally, pulls the lumbar spine into a more lordotic curve.²¹ Normal anterior pelvic tilt for children 3 to 5 years ranges from 10° to 20°²² and reaches adult angles by 8 to 10 years.²² Young children, whose balance has not fully matured, may present with slight forward trunk flexion with a wider BOS. Up to age 10, a protruding abdomen may be seen. It has been observed that children at approximately 9 years of age may demonstrate an

increased lordosis which decreases with age.¹⁷ Proper postural development depends on several influences including; nutrition (vitamin D), the environment (backpacks, desks & chairs), presence of pathological conditions (club foot, cerebral palsy), and developmental (handedness) factors. The observation of a habit which may lead to the development of a postural fault should be followed by the appropriate corrective measures,¹⁷ i.e., using the correct desk and chair in proportion to a child's size, or carrying a backpack with the correct size and weight in relation to a child's size.

Posture and Postural Control of Standing Balance

In quiet stance, the human body is not perfectly static. There are small oscillations of movement as the body sways anteriorly, posteriorly and side to side. Normal standing posture, with the inclusion of sway, is described as an inverted pendulum or a cone, where the pendulum (the body) sways over the fixed BOS (the feet). The limits of stability describes the maximum movement of the COG over the BOS without loss of balance.²³ The anterior-posterior limits of stability are roughly 12 degrees from posterior to anterior, and 16 degrees from side to side.²³ Adults and children older than 7 years use approximately 70% of their BOS to support the limits of stability.²⁴ Children younger than 7 years use 44-53% of their BOS which results in a smaller limit of stability.²⁴ The ability to remain upright with the COM over the BOS is the essence of balance, or postural stability.²⁵

If the COM moves outside of the BOS, the person becomes unbalanced and must respond appropriately, or fall.²⁶ The control of balance is complex and involves interactions from both the musculoskeletal and nervous systems.²⁵ Postural control

requires the integration of information coming from the visual, vestibular, and somatosensory systems for detecting balance changes²⁷ and the ability to produce the appropriate musculoskeletal response²⁸ through feedback and feedforward control.²⁵ Feedback control refers to the response to an external disturbance, such as a misstep requiring a stepping response, the orienting of a child's head to vertical when tilted or a change in a child's posture due to the donning of a loaded backpack.²⁵ Feedback control has been noted in children as young as 15-31 months of age producing postural responses comparable to 7 to 10 year olds and adults in response to perturbations.²⁸ Feedforward control refers to anticipatory postural adjustments, balance responses in anticipation of a disruption.^{25,28} These skills develop later, emerging between 6 and 10 years of age.²⁸

Postural Control Inputs

Postural control requires the receipt, integration and interpretation of input from the visual, vestibular, and somatosensory systems for detecting changes in the COM²⁷ due to an internal or external perturbation. Each of these sensory systems contributes to postural control by providing specific information to the central nervous system about the position and movement of the body in respect to the surrounding environment. The central nervous system then interprets the sensory information and directs the musculoskeletal system how to move so that the COM remains over the BOS and the body maintains postural stability. The visual system provides information about the position of the head and eyes in relation to the surroundings, as well as data about motion of the head through forward and peripheral visual input.^{23,25} While visual input is important, it may provide sensory information that conflicts with that of the other

systems, or may be absent.²⁵ This doesn't necessarily lead to a loss of balance.²⁵ The somatosensory system (muscle, joint receptors and mechanoreceptors), provides proprioceptive data about the body's position in space as well as in relation to the support surface.^{23,25} The vestibular system provides information about the head's position and movement in space with respect to gravity and inertial forces.^{23,25} A conflict in or absence of sensory input requires suppression of the inaccurate information and reweighting of input from the other sensory systems. Together these three senses contribute and influence postural control.²⁵ The information from these systems is centrally processed by the central nervous system which then selects and responds with the appropriate muscle strategies to maintain balance.

Postural Control Outputs

It is suggested that multiple factors interact to achieve balance. Balance and postural control relies on the sensory information coming into the central nervous system, the reception and integration of this information, the selection of the correct motor response, and the integrity of the musculoskeletal system to produce the desired movement. Four balance strategies have been identified to maintain equilibrium for adults. The ankle strategy is used when small adjustments are made to control sway movements or in response to minor perturbations. Bilateral ankle musculature activates to manage and modify small movement of the COM without any postural adjustments above the ankle. The ankle strategy response to a lateral balance perturbation involves direction-dependent asymmetries of the ankle muscles to maintain balance.²⁹ The hip strategy is elicited where larger adjustments are made to keep the COM within the BOS.

This strategy is observed when the perturbation moves the COM to the edge of one's limit of stability and the ankle strategy is insufficient to prevent a loss of balance. Flexion or extension of the hip brings the upper body over the BOS, essentially moving the head in the opposite direction of the hips, thus preserving balance over the BOS.

The stepping strategy is elicited when the perturbation is too great for either the ankle or hip strategies to maintain postural control. At this point, a step is required to bring the BOS under a COM that has moved outside of the original BOS due to the perturbation to prevent a fall.²⁵

The last strategy is the suspensory strategy, where hip, knee, and ankle flexion occur to lower the COM towards the BOS.²⁷ The goal of each of these strategies is to maintain the equilibrium of balance, and keep the COM located above the BOS. A mechanical or external perturbation that perturbs the body, such as a backpack load; or a postural perturbation, such as visual conflict may lead to disequilibrium, requiring a response to prevent a loss of balance.

Development of Postural Control

Studies examining age relationships to postural control demonstrate that infants develop postural strategies through experience and postural skill development.^{27,30} Postural responses are more than simple reflexive responses to a perturbation. Responses are also shaped by expectations, goals, experience and environmental context.³¹

In early development of postural control the visual system is dominant²⁵ as infants and young children rely heavily on visual input to maintain their balance.²³ Between the ages of 3 and 6 years, they demonstrate an increased reliance of somatosensory information,³⁰ with maturation of somatosensory function by 6 years of age.³² By

approximately 7 years, children develop the ability to resolve sensory conflicts and reweight sensory input.²³ Postural control strategies mature as children age, although there is great variability in both strategy and degree of postural control response in children younger than 7 years of age.²⁷ Both children and adults demonstrate a distal response (ankle muscles) to a perturbation first, followed by a proximal response (hip muscles), though the children's responses demonstrate immature characteristics compared to the adult's responses.²⁷ Examination of balance strategies in children 10 months to 10 years found that young walkers, with less than 6 months of walking experience, primarily demonstrated a passive hip strategy following a perturbation, as opposed to an active hip strategy in older children (aged 7 to 10) who were able to withstand larger perturbations.³³ By 7 to 10 years of age²⁷ children demonstrate mature postural control responses comparable to adults for resolution of sensory conflict.³⁴ By 11 to 13 years of age children demonstrate adult-like abilities to select varying balance strategies in challenging static & dynamic conditions.²⁸

Back Pain in Adults

Low Back Pain (LBP), a musculoskeletal disorder, is a leading cause of disability in adults under 45 years of age³⁵ and is one of the most common health problems in the United States.^{35,36} Low back pain is usually classified as either specific or non-specific. Specific LBP is pain that is associated with an identifiable pathology and can be identified and treated appropriately.³⁷ Non-specific LBP accounts for ~90% of back pain cases as they don't have an easily identified cause. This pain may be acute, and resolve within three months, or chronic, with repeated episodes of pain flare-ups. Back pain studies report a one-year prevalence of 50%, a lifetime prevalence of LBP in adults of 70-

80%,^{38,39,40} and a report of recurrence of LBP within 12 months of an acute injury by 62-73% of patients.^{37,41} The mechanics of LBP are related to posture and may be due to an imbalance or a strain either in the back or in a related structure. Faulty mechanics of the feet, legs or pelvis may lead to LBP. Weakness or tightness in muscles of the legs, pelvis and trunk may alter the support or mobility of the spine.¹⁷ Spinal postures such as increased or decreased lumbar lordosis and increased or decreased spinal inclination are reportedly associated with low back pain.⁴²

Risk Factors for Back Pain in Adults

Low back pain may result from many possible etiologies. Risk factors include occupational factors such as job satisfaction, physical strain, repetitive motions and materials handling due to occupational demands,³⁷ individual factors such as gender, age, genetics, height and weight; lifestyle habits such as smoking, alcohol, fitness and general health;^{37,43} and psychosocial factors such as stress, pain behavior and cognitive functioning.³⁷ While low back pain does not have a linear relationship with age, as multiple factors may be involved, there is growing evidence of low back pain present in children and young adults.^{37,44,45,46} Furthermore, the strongest predictor of having musculoskeletal discomfort and back pain as an adult is a prior history of these symptoms in childhood.^{45,46,47} In the workplace, the incidence of LBP may be reduced by minimizing exposure to physical risk factors.⁴⁸ Recently, an examination of physical exposure in relation to risk of LBP found a linear relationship between duration of lift and duration of carrying (of a load) to risk of spine impairment, indicating cumulative loading as a risk factor for LBP.⁴⁸

Back Pain in Children

Studies indicate increased complaints of back pain, shoulder pain, and muscle soreness in older, high school students compared to elementary school children^{11,49} with a lifetime prevalence of low back pain, ranging from 12% in 12 year olds to as high as 74% in 17 year old students.^{11,44,49,50,51,52} Low back pain in adolescence is described as “non-specific”⁴⁴ and is discussed mostly in terms of incidence and prevalence, and association with gender, age, trunk or hip muscle weakness, decreased thigh muscle flexibility, and smoking as opposed to describing the mechanics of low back pain in relation to spinal structures.^{44,53,54,55}

Risk Factors for Back Pain in Children

Potential risk factors for the development of back, neck and shoulder pain in children include; age (12-15 year olds had the highest reports of pain), growth rate, decreased lower body & thigh muscle flexibility, thoracic kyphosis, hyperlordosis, weak abdominals, depression, stress and even smoking.^{49,53,54} Studies by Grimmer and Williams found girls were more likely to report back pain compared to boys.^{19,49} Other risk factors include physical activity levels, trunk strength, psychological profile, time spent sitting, or watching television, and family history of back pain.⁶ A larger body mass index (BMI) score is also associated with back pain.¹¹ Additionally, backpacks and load carriage have been linked to low back problems and pain in youth^{2,19,49,56} with the identification of both weight and duration of backpack carriage as a risk factor for nonspecific back pain in youth.^{8,11,19} Negrini et al’s examination of Italian youth found 46.1% of the 6th graders studied reported back pain caused by their school backpacks.⁸ The severity of back pain has caused roughly 16-23% of children to miss school activities

or seek medical attention.^{9,44,57,58} Additionally, Korovessis's study of spinal curvature with backpack loads found that taller children reported less pain than shorter children carrying the same load.⁵⁹

Neck Pain and Forward Head Posture

It has been reported that approximately one third of adults will experience neck pain within a 12 month time period.⁶⁰ Neck pain is a common complaint, with one year prevalence over 37% for adults, and women reporting neck pain more frequently than men in 23 of 30 studies examined by Fejer.⁶¹ Neck pain in youth has a cumulative annual incidence of 28.4% among adolescents 12 to 16 years of age,⁴⁹ with 50% of children 12 to 18 years old reporting occasional symptoms of neck and upper limb pain.^{17,21} Regardless of age, there is a greater report of neck pain in females versus males.^{17,21,61} Croft et al report a link between past neck injuries and present complaints, indicating that a prior history of recurrent (rather than acute) neck injury is a risk factor for neck pain.⁶⁰

The abnormal postural alignment of one's head being held forward of their trunk, or forward head posture, has been observed in both men and women of all ages during natural sitting and standing.^{62,63,64} Changes in the posture alter the moments at the head and neck. Protraction of the head is a forward translation of the head in the sagittal plane forward of the vertical gravity line of ideal posture.²¹ This produces extension in the upper cervical spine and flexion within the lower cervical spine.²¹ The forward head position (FHP) changes the alignment of the muscles within the anterior and posterior neck. A habitual FHP may result in the stretch weakness of the anterior neck muscles,¹⁷ but also shortens the sternocleidomastoid.²¹ The posterior aspects of the cervical vertebra

are compressed, and the neck extensors shorten, but the semispinalis capitis and levator scapula are under increased stress as they work up to four times harder to maintain a level gaze.^{15,17,21} According to Kapandji, while the normal apparent head weight is about 10 pounds, another 10 pounds of apparent head weight is added for every inch the COM of the head is anterior of the normal vertical gravity line⁶⁵ that the posterior cervical muscles must isometrically counter to maintain a horizontal gaze. Additionally, suboccipital muscles are also working harder to extend the AO joint for the level gaze.^{15,21} Together, all of this increased muscular activity can lead to muscle spasms in the posterior neck.²¹ These muscle spasms are associated with both occipital and tension headaches.^{17,21} The FHP has been associated with neck pain, headaches and disability in adults,^{17,62,66,67,68} radiating pain into the head and TMJ,^{17,21} and changes in respiratory accessory muscle activity and the resting positions of the tongue and mandible.⁶⁹

History of Backpack Use

The terms “Haversack”, “Knapsack”, “Rucksack” and “Backpack” are used interchangeably to refer to a utilitarian bag with two shoulder straps for carrying objects on one’s back. The Oxford English Dictionary identifies the term “knapzak”, the Dutch origin of knapsack, as being first recorded in the 16th century. Another entry in 1749 documents the use of a haversack, a bag in which a soldier carries his rations, worn with a strap over his shoulder.⁷⁰ In 1886, John Merriam copied early American Indians to create an external frame backpack and filed the first backpack patent recorded in the United States.⁷¹ Since the 1880’s, the design of the backpack has evolved from sticks and animal skins to metal frames and various fabric materials.

Military Use of Backpacks

Backpacks designed for the military have been under examination since 1858.⁷² Combat load carriage systems like the All-Purpose Lightweight Individual Carrying Equipment (ALICE) system were developed to enable soldiers to carry multiple items without being dependent on a supply vehicle.⁷³ According to the 1990 US Army Field Manual, soldiers are recommended to carry a maximum combat load of 22kg (48.4lb) which is 32% of the body weight (BW) of a 150lb male.⁷⁴ However, in training exercises they have carried marching loads (while marching in formation, carrying all necessary equipment) of 40-44kg (88-97lbs)⁷⁵ and combat loads (loads carrying only essential gear necessary for combat) of 68 kg (150lb).^{72,76} Marching loads include full body armor, weaponry & ammunition, water canteens, meals, and hygiene & first aid kits.⁷⁵ Since 1973, the standard military backpack utilized by the Army was the ALICE backpack. In the 1990's a prototype combo chest-and-back-pack was been examined to improve distribution of the load and enable a more upright walking posture, however it placed a bulky pack on the chest. More recent military backpacks place the bulk of the load on the back and utilizes a chest vest with a modular belt and pouch attachments to further distribute the soldier's load. Soldiers train with the backpacks on to improve their ability to complete a march and be able to execute mission-related tasks at the end of the march.⁷⁶ Research is ongoing to improve the military load carriage systems to be lighter and more versatile.⁷⁷

Workplace and Recreational Use of Backpacks

Adults use backpacks for employment, as a method for transporting laptop computers, papers or books, or during recreational hiking. Workforce backpacks are

minimally addressed in the literature. Workforce transport of laptops frequently involve messenger-bag-type, soft-sided briefcases for laptops. Some backpacks are designed for laptops, but mainly resemble youth backpacks. Professional observation indicates that adults use similar backpacks as children, and also do not use chest or pelvic straps to disperse the weight. Adults users generally have more control regarding the contents of their backpacks and can adjust the contents as needed.

Hiking backpacks are loaded with a focus on utility and weight and function. “High Performance” backpacks are used by hikers for “backpacking”, “tramping”, “trekking”, or bushwalking”. Hikers generally carry all necessary food, gear and supplies in their pack for a hiking trip on foot. These trips may last for days or weeks, so the weight of the backpack and all contents is of great importance. These backpacks tend to be very expensive compared a typical student’s school backpack. Like the military packs, hiking backpacks are designed with framing (internal or external), padding, and pelvis and chest straps to disperse the backpack weight through the pelvis & hips and control lateral movement of the backpack during use.

Youth Use of Backpacks

Backpacks are an essential and regular component of school life for most children and are used by more than 90% of schoolchildren worldwide.¹ Typical student backpacks are basically fabric bags with straps⁷⁸ that weigh between 1 and 2.5 pounds when empty and have a capacity of 1600-2200 cubic inches (29-35 liters). Standard backpacks frequently display thin or poorly padded shoulder straps which may cut into the neck and shoulder musculature. While some standard student backpacks may have

some lumbar or back padding, it is frequently partial or minimal, thus allowing the books to apply pressure directly on the child's spine during carriage. The absence of a hip belt forces the child to bear the full weight of the backpack on the shoulders. Unfortunately, improved backpack designs are associated with an increased cost to the user (or in this case, the parents). As children can easily demolish a backpack within a few months of use, the purchasing of multiple backpacks can easily become cost prohibitive. Most children wear a backpack that is too big for their body frame and it is frequently overloaded with oversized textbooks, folders, lunchboxes and electronics. Many children do not wear the backpack upon their mid-back, but lengthen both shoulder straps to enable the bag to hang down low and even ride across their sacral spine⁴. Increased shoulder strain has been shown to result from this position.^{4,79}

Poor design and usage of backpacks in children may ultimately result in an increased financial impact to the United States economy, as well as increased personal costs to our children and their quality of life if they begin adulthood with the existing dysfunction of back pain. In the adult working population, there were almost 650,000 back injuries reported in 2009.⁸⁰ At an estimated \$23,800 average cost per claim,⁸¹ the current economic cost of back injuries in the United States is substantial. Back pain in children who have yet to enter the adult workforce are likely to increase these numbers as it is known that the complaint of back pain in children is a predictor of back pain in adulthood.⁶

Influence of Skill/Experience

Comparison of changes in the spinal curve (in the sagittal plane) between novice and experienced hikers found that experienced hikers demonstrated decreased

movements of spinal segments compared to novice backpack users.⁸² The study suggested that the decrease in sagittal movements was due to the experienced hiker's ability to control their posture, thus maintaining the position of the spine. Additionally, all subjects demonstrated a forward trunk lean while wearing the backpack, with the maximum angular changes between the thoracic and lumbar spinal levels.⁸²

Examination of the effect of a moderate backpack load on shoulder strap forces in experienced and novice hikers was measured through the use of force transducers placed on both the anterior and posterior parts of the shoulder straps. As subjects walked on a treadmill at a 5% grade, the weight of backpack was increased from 2.5 kg (5.5lb) to 10, 15, and 20 kg (22, 33 and 44 lb). This study noted differences of the strap forces for experienced hikers versus non-hikers, suggesting that expert hikers were able to adjust their postures to the load.⁸³

Physical training with progressively increased backpack loads decreases energy cost, improves aerobic fitness, and increased walking speed for both soldiers and civilian women, similar to a training program with involving running and resistance training.⁷³

Influence of Position of Backpack Load on the Trunk

The level of backpack load placement on the trunk has direct consequences on the postural alignment of the body. Chansirinukor found adolescents were unable to maintain an upright standing posture when carrying more than 15% of body weight due to the imposed load.¹² Grimmer examined adolescents carrying backpacks containing 3%, 5% & 10%BW positioned high, low and centered on the back, compared to unloaded standing.⁸⁴ Backpack loads placed higher on the back produced greater anterior postural

shifts at all weights, compared to the loads placed on the center or low back.⁸⁴ Holewijn examined the pressures placed on the shoulders by backpacks on varying weights. The pressures on the scapula and top of shoulder significantly increased during carriage of a backpack which was supported mainly by the shoulders as compared to a backpack which was designed to support weight on the hips through use of a wide waist belt.⁸⁵ The placement of a backpack load higher on the trunk has an effect on postural stability. The load is less stable, and tends to sway more during walking due to the higher combined COM compared to the combined COM of a load placed lower on the trunk.^{73,79} Greater activation in the erector spinae and trapezius muscles is also present with loads placed higher on the back.⁷⁹

Influence of Gender

Gender does not have a consistent relationship with pain complaints in children who carry backpacks; although female gender has been more frequently reported to have a positive relationship with pain in children who carry backpacks.^{3,9,11,59,86,87,88,89} Grimmer's examination of gender differences and backpack related pain found an increased report of pain for girls at 12 years, followed by an increase in pain complaints in boys 2 years later.¹⁹ In contrast, Negrini did not find a statistical relationship of gender and pain in schoolchildren in Italy.⁸

Prevalence of Backpack Use

According to the Bureau of Labor Statistics, there were more than 2.4 million people serving in the Armed Forces of the United States in 2009.⁹⁰ Of those, more than

1.4 million were on active duty, having trained with backpacks and possess them as part of their daily gear.⁹⁰ According to a survey conducted by the National Sporting Goods Association indicated that in 2009, 50.9 million people over 7 years of age went camping (usually requiring backpacks to carry their gear) and 34.0 million people went hiking in the US alone.⁹¹ Regular camping and hiking outings are an integral part of the Boy Scouts of America program. As of December 2010, there were almost 4 million registered Boy Scouts and adult Scout leaders.⁹²

Disease Level – Backpack Weights Currently Carried

A schoolbag weighing more than 15% to 20% of a child's body weight is associated with back pain, and improper use of the backpack can result in changes of posture and gait.⁶ Children who experience back pain are at increased risk of having back pain as adults.^{6,12,13,93} As a result of the increased concern of backpack loads and their associated responses, maximum weight limits for children's backpacks have been suggested at 10% of body weight.^{94,95,96} However, examination of backpack loads indicates a great variety in the amount of weight carried by children of all ages around the world.

An early study examining the physiological effect (as measured by changes in metabolic cost) of schoolbag carriage in children by Malhotra & Sen Gupta in 1965 resulted in the recommended carrying weight of 10%BW.⁹⁴ Studies among American, European, South African and Australian school children reveal that backpacks contain loads greater than 10%BW.^{2,11,86,97,98} Backpack weights have been reported at 17%BW⁷ and 20%BW in the US⁴ with a maximum of 41%BW¹¹ in the United States. Children in

France reportedly carry an average of 19.25%BW with a maximum of 38%BW. Almost one half of these children carried backpacks weighing more than 20%BW.⁵⁷ In Italy, the daily load carried by school children averaged 22%BW with a maximum of 46.2%BW.⁹⁷ One third of these children carried backpack weights that exceeded 30%BW.⁹⁷ Children have also been reported to carry backpack loads of 20%BW in Hong Kong.^{95,96,99}

Backpack-Related Injuries in Children

According to The Bone and Joint Decade, a global, multi-disciplinary initiative involving 58 countries dedicated towards research and education for diagnosis and treatment of musculoskeletal conditions, more than 2 million children aged 5 to 14 years are treated each year for musculoskeletal conditions, at a cost of over \$7 billion.¹⁰⁰ Backpack related injuries constitute a portion of these injuries. There were more than 21,000 backpack-related injuries treated at hospital emergency rooms, doctors' offices and clinics in 2003 according to the U.S. Consumer Product Safety Commission up from more than 13,260 backpack related injuries in 2000.^{101,102} Approximately half of those injuries affected children 18 years and under. The injuries reported included tripping and falling over or being hit by a backpack, as well as complaints of strains to the shoulder, neck and back due to the carrying of a backpack.¹⁰¹ In a review of emergency room visits by children for backpack related injuries in 1999-2000, the most common site of backpack-related injuries was the head/face, followed respectively by the hand, the wrist, shoulder, ankle and back.¹⁰³ Carrying a backpack was associated with 59% of the injuries to the back.¹⁰³

Impact of Backpack Load on the Developing Human Body

Researchers suggest that the adolescent spine may be vulnerable to developing low back pain from carrying heavy backpacks during the most critical period of spinal development from 12-14 years,¹⁹ as the spinal ligaments and muscles are not fully developed until after 16 years of age.¹⁰ The tissues of the human body are sensitive and responsive to tension, compression, shear and torsion of the loads that are applied to them.¹⁰⁴ Heavy loading of the spine during growth is known to induce vertebral stress, resulting in problems such as scoliosis, kyphosis and lordosis in children.¹⁰ External forces, such as heavy backpack loads, may affect the development of normal skeletal alignment,¹² resulting in musculoskeletal complaints, vertebral abnormalities¹⁰⁵ and compensatory strategies that alter postures and structures.⁴

Hong et al suggests the altered biomechanics required by children to carry increased loads on a daily basis “might be harmful and influence their normal musculoskeletal developmental growth.” and suggests that a backpack load of 10% body weight is recommended “since it causes the least disturbance of metabolic processes.”⁹⁵

Impact of an External Load on the Human Body

Biomechanically, the goal of the human system is to achieve a balanced state. Without the influence of an external force, quiet stance uses passive muscle tension, the ground reaction force vector and light eccentric activity of the plantarflexor and cervical extensors to remain in equilibrium. A backpack weighting 10%, 20% or more of one’s body weight challenges that biomechanical equilibrium and the postural control of the system. The backpack load on the trunk has direct consequences on postural alignment and various responses of the body. Adolescents are unable to maintain a standing posture

when carrying more than 15% of body weight due to the imposition of the load.¹² A backpack load changes the upright posture and alters the internal and external forces exerted upon the body. Spinal responses, biomechanical responses and postural control responses are elicited as the body regains postural stability.

Effect of Spinal Loading

Spinal loading during manual materials handling tasks has been studied extensively in adults¹⁰⁶ with imaging, biomechanical modeling, cadaveric studies¹⁰⁷ and determinations of intradiscal pressures in various postures and during tasks via fine needle sensors.¹⁰⁸ Studies examining the effect of vertical load carriage on the spinal column have indicated changes including disc degeneration, spinal creep (intervertebral disc compression) and histological changes.^{51,109} Spinal degeneration is associated with back pain.¹⁰⁷ Histological signs of disc degeneration initially include alterations of disc endplates in 8-13 year-olds, and later include changes in vessels, cells, tissue structure, and even changes within the nucleus pulposus, annulus fibrosus and endplates.⁵¹ MRI studies have revealed disc degeneration in 26-38% of 15 year-olds examined.⁵¹ The human lumbar spine is subjected to large compressive loads on a daily basis. Repetitive or prolonged lifting of large or small loads may lead to cumulative loading of the spinal structures. Biomechanical modeling of the lifting of a load that weighs 25% of body weight will produce a compressive force on L2 of four times body weight assuming the lifted load is close to the body.²¹ The shape of the spine and the change in shape affects spinal compression and spinal shear, as the internal moment arm and connective tissue tension change with alignment. An increased lordosis will increase the sacral inclination. The addition of a load will then increase the shear stresses at the lumbosacral junction.

Conversely, biomechanical modeling of a flattened lordosis will reveal a decrease in the sacral inclination with an increase in the predicted compression force on the L5-S1 disc.^{21,110} An examination of axial loading with 0, 8 or 16 kg (0, 17.6 or 35lb) loads on adults found that subjects with a larger lordotic curve at rest exhibited an increased curvature under load. The lordotic curvature flattened under load in those subjects who had demonstrated a lesser lumbar lordosis at rest.¹¹⁰ Kanlayanaphotporn et al examined spinal creep, or the loss of spinal height as an indicator of vertical deformation of the intervertebral discs during loading, in seated adolescent and adult males in response to a 15%BW load carried on the subject's shoulders. Both age groups demonstrated significant differences in vertical spinal creep over time, but the skeletally immature spines of the adolescent subjects demonstrated a significantly greater magnitude of vertical spinal creep.¹⁰⁹

However, a backpack load is a posterior load versus an anterior load. A study to examine lumbar intervertebral disk height change due to 10%, 20%, and 30%BW backpack loads in 11 year old children revealed significant changes in the height and symmetry of the disks as well as an increase in Cobb angles indicating an increase in lumbar curve asymmetry.¹¹¹ The children's spines demonstrated a linear correlation of the backpack loads to compression of the intervertebral discs at each spinal level from T12-L1 to L5-S1 with double the compression of the L5-S1 disc versus T12-L1 disc. The children reported higher back pain levels with increased loads.¹¹¹ Chow used motion analysis and a specialized backpack to examine spinal changes at 10%, 15% and 20%BW loads. A decrease in lumbar lordosis, increase in trunk inclination and increase in head on trunk extension was noted with increased loads.¹¹² The relative orientation of adjacent

vertebrae and the stress distribution within apophyseal joints and discs may all be affected due to changes in posture. Altered stress concentrations due to incorrect postures may lead to spinal pain.¹⁰⁷ Adams suggests that the “precise manner in which a person sits, stands and moves could affect the pain perception from innervated tissues...” This pain mechanism is referred to as a “functional pathology.”¹⁰⁷

Orloff & Rapp examined changes in spinal curvatures due to fatigue and load carriage of a backpack, and found significant increases in the thoracic & lumbar spinal curvatures as the subjects fatigued while carrying a weighted backpack.⁵⁶ These changes in curvature may alter the stresses on the intervertebral discs, muscles, and ligaments of the back.⁵⁶

Biomechanical Response to Backpack Loads - Overall

Upon donning a loaded backpack, the individual must respond and shift anteriorly to bring the new, combined COM (of the body and backpack load) over the BOS (the feet) to compensate for the initial posterior shift in COM. A backpack carried with double straps and supported by both shoulders will result in an anterior/posterior shift rather than a mediolateral shift to the left or right. This shift is achieved by either leaning forward at the head, trunk, hips or ankles, thus increasing the activation of the responding postural muscles.⁵⁶ If the load is carried by a single strap on one shoulder, the subsequent compensation involves a lateral trunk shift to achieve a stable position.⁷ Both responses may lead to pain as well as injury by stressing the ligaments or muscles in the back, or by changing the forces applied to intervertebral discs.⁷ The lateral trunk shift response also leads to a malalignment of the spine by promoting elevation of the carrying shoulder and

deviation of the spine away from the backpack. Although temporary, these alterations in the spinal curvature due to improper posture may be medically classified as functional scoliosis.⁷

Biomechanical Response to Backpack Loads – Forward Head Position

The carrying of a backpack alters upright posture and results in postural responses that require a complex interaction of trunk and limb adjustments to accommodate to the new stressor and maintain upright equilibrium.²⁵ One specific associated postural compensation is an increased forward head position. According to Kendall & McCreary, the forward head position is one with cervical spine hyperextension, with shortened cervical extensors and lengthened cervical flexors.¹⁷ There is protraction of the head forward of the line of gravity of neutral upright standing posture which changes the alignment of the muscles within the anterior and posterior neck. This position creates an increase in forward tension, fatigue and compressive forces on the posterior cervical region.⁶⁹ The forward head position can be measured by the craniocervbral angle (CVA), which is formed by a line from the tragus of the ear to the spinous process of C7 and the horizontal, intersecting at C7. A decreased CVA measurement indicates an increased forward head position. A larger CVA measure indicates a more upright, erect head and neck posture.¹²

Studies have identified significant changes in CVA that are associated with headaches and neck pain. In adults, women with cervicogenic headaches demonstrated significant mean difference in CVA of 4.8° compared to women without headaches.¹¹³

The CVA in adults with neck pain was about 5° less than the CVA in those without neck pain.⁶⁸

Grimmer et al found significant associations between heavy backpack weights and complaints of spinal pain in adolescents as well as a significant relationship between backpack weight and forward head posture as measured by CVA, with the greatest difference in younger children.¹¹⁴ Children with neck pain demonstrated significant changes in CVA with a 10%BW backpack load of 5.23° , as opposed to children without neck pain who demonstrate a 5.03° significant difference in CVA at a 15%BW back pack load.¹¹⁵

Chansirinukor examined the effects of backpacks on students cervical and shoulder postures as influenced by backpack weight, position on the trunk and amount of time spent carrying the loaded backpacks.¹² The craniovertebral angle (CVA) decreased while carrying a backpack, indicating a significant increase in forward head posture with a backpack containing 15% bodyweight.¹² Carrying a two-strap backpack versus a one-strap backpack had the smallest effect on the neck and trunk angles. Significant differences in CVA were noted at the 15%BW load, suggesting that postural responses in adolescents are sensitive to loads of 15%BW,¹² supporting Pascoe et al who reported significant forward head positions with a load of 17%BW.⁷ In addition to the change in forward head position due to a load, Chansirinukor et al also found a significant decrease in the CVA after a 5 minute walk with the student carrying their own backpack.¹² Lai found that cervical and shoulder postures were influenced by both amount of weight in a backpack and amount of time spent carrying a backpack, suggesting that potential problems may occur from backpack weights greater than 10%.¹⁰ Carrying a 15%BW

load caused significant increases in the forward head posture of 10 year old children while standing, and also after walking 1000 meters.¹¹⁶ The results of these studies indicate that duration of load carriage (or exposure to the load) as well as the weight of load influences forward head posture.

Biomechanical Response to Backpack Loads – Forward Trunk Lean

The kinematic response to standing or walking with a heavy backpack load is evident through the changes in postural alignment, postural stability and gait. A highly evident change of carrying a heavy backpack load is forward trunk lean, or flexion. As discussed above, to counter the posterior moment and the weight of the backpack load, an individual must move their COM forward within their BOS or risk falling backwards. The resulting forward trunk lean creates a flexion moment at the trunk, hips and ankles, while continuing the extensor moment at the knees, leading to a posture which is no longer upright. Hong et al's examination of children's gait under varying backpack loads showed a 20% body weight pack resulted in significantly increased forward trunk lean during gait.⁹⁶ Chansirinukor found that backpacks weighing greater than 15% body weight prevented adolescents from maintaining an upright standing posture.¹² A 15%BW backpack caused significant increases in the forward trunk lean of 10 year old children both while standing and after walking 1000 meters.¹¹⁶ Carrying a 17%BW load in one-strap backpack and a two-strap backpack increased forward trunk lean and forward head positions in 11 to 13 year old children.⁷

A review of physical responses to backpack loads in soldiers found that a backpack load placed lower on the back resulted in greater forward lean, but a load

placed higher on the back produced increased postural sway during standing.⁷³

Similarly, Lamar found a direct relationship between backpack weight and forward trunk lean in children at backpack loads of 15% and 25% bodyweight during walking.¹¹⁷

Biomechanical modeling of the lumbosacral forces from 15%BW and 30%BW backpack loads compared to unloaded in young adult men found that the peak lumbosacral forces increased with both backpack loads.¹¹⁸ The peak lumbosacral force increased by 26.7% from unloaded. The mean lumbosacral force in the unloaded condition was 1.5 times body weight. This increased to 1.9 times body weight with the 15%BW load, an increase of 26.7% from unloaded. The peak lumbosacral force increased to 2.46 times body weight with the 30%BW load, an increase of 64% from unloaded.¹¹⁸ Trunk flexion also increased with both loads for all subjects, with a change from unloaded to loaded of 7.81° while walking with a 15%BW load and a change from unloaded to loaded of 12.64° while walking with a 30%BW load.¹¹⁸ The degree of forward trunk flexion in 12 to 13 year old children may be sensitive to lighter backpack loads, exhibiting a statistically significant difference to upright, unloaded postures at 5%BW loads. This may have an impact on the subjective pain complaints in children.¹¹⁹ Forward trunk flexion increased in 9 year old children during standing and during gait with backpacks of 10%, 15% and 20%BW with greater trunk lean during gait compared to stance for all load conditions.¹²⁰

Biomechanical Response to Backpack Loads – Changes in Gait

The kinematic response to a heavy backpack load is evident through the changes in gait. Stride cadence increased while stride length decreased during gait while carrying 17%BW in a two-strap backpack.⁷ Hong et al examination of children's gait under varying backpack loads revealed that a 20%BW pack resulted in significant increases in

forward trunk lean, stance duration and double limb support as well as decreased single leg support time and decreased trunk angular motion during gait.⁹⁶ Backpack loads of 20%BW carried by 9 year olds resulted in decreased gait velocity and cadence, and increased double support time.¹²⁰ Double support time increased for 12 to 13 year olds while carrying a 15%BW backpack load over both shoulders.¹²¹

Significant changes in forward head posture at 15%BW loads and forward trunk lean at 10%, 15% and 20%BW loads have been reported after walking 5 and 6 minutes.^{12,120} This indicates that not only does a heavy backpack influence a child's posture, but the exposure to the load over time is also a factor in the overall changes in posture.

Postural Control (Balance) Response to Backpack Loads

Carrying a backpack alters upright posture and results in postural responses that require a complex interaction of trunk and limb adjustments to maintain upright equilibrium²⁵ and accommodate to the new combined COM of the individual and the backpack. Little is known about the influence of backpack loading on postural control; however it is important to be able to maintain balance while carrying a backpack. This is especially important with military and firefighting personnel who carry loads up to 68kg (150lb).^{72,76,122} Palumbo examined the influence of backpack loads on dynamic balance by testing body excursion and control of college student's ability of move their COM to predetermined targets while carrying a backpack. The results showed slower movement velocity in all directions and decreased anterior-posterior directional control, but increased right-left directional control.¹²³ Talbott found that the COM moved forward when subjects carried a 20%BW load, moving towards the anterior limit of the BOS, and

resulting in greater sway, indicating decreased postural stability.^{124,125} Further analysis of COM movement over the BOS revealed a linear increase of postural sway with heavier backpack loads.¹²⁶ This was supported by Heller et al who found an increase in sway both anterior-posteriorly and mediolaterally in young women carrying a 28%BW backpack load.¹²⁷ This increase in sway movement is known to correlate with an increased fall risk in the elderly.¹²⁷ Loads positioned higher on the trunk are also associated with increased sway as the challenge to stability increases.¹²²

Placing a load higher versus lower on the back also has an effect on the postural stability. Lee and Lee, testing young adults holding a 12kg (26.5lb) load at varying heights, examined the effects of the COM's of the different load heights on center of pressure (COP) and limits of stability.¹²⁸ Results indicate decreased limits of stability, and COP excursions with a load placed higher on the back with a hip strategy utilized to maintain balance.¹²⁸ Loads placed lower on the back increased the limits of stability, and triggered the utilization of ankle strategies for balance control.¹²⁸ These results support the findings of Bobet (1984) who found increased sway with higher loads due to increased angular acceleration, due to a larger moment of inertia and a larger distance from the center of rotation of the subject.⁷⁹

The ankles are an essential component of postural control, not just for receiving information but for producing appropriate musculoskeletal responses for postural stability. The ankle musculature must be able to produce enough force to maintain stability during a desired activity or in response to an external load such backpack load. Fatigue on the muscular components affects proprioceptive information and may delay motor response.^{129,130} Increased postural sway has been observed with induced fatigue of

the plantarflexor muscles,¹³⁰ with significantly larger amounts of sway when subjects carried a 20%BW load carried in a weighted vest.¹³⁰ Additionally, lumbar extensor fatigue also increased postural sway.¹³¹

Physiological Response to Backpack Loads

Studies of children and adolescents indicate a clear association between backpack load and measurable kinematic responses including modification of gait, posture, balance as well as physiological responses including cardiovascular, pulmonary, metabolic and nerve function changes and changes in lung volume.

Cardiovascular Response to Backpack Loads

Cardiovascular changes due to backpack use include responses in heart rate,^{85,96,132} blood pressure,⁸⁵ and metabolic rate,^{85,96} as well as brachial artery flow.¹³³ Hong examined heart rate, blood pressure and energy expenditure in children carrying backpacks weighing 10, 15, and 20%BW compared to not wearing a backpack, and found increased heart rates across all loads, which returned to normal after a brief recovery period.⁹⁶ Blood pressure also increased, but demonstrated a significant difference between 0 and 20%BW loads, requiring longer time to return to baseline for subjects carrying 15 and 20%BW.⁹⁶ Upon examining physiological responses to various weights of shoulder supported loads and waist supported loads, Holewijn found that heart rate increased while standing with a backpack, regardless of weight or support. Heart rate and oxygen uptake were both influenced by the backpack weight during gait.⁸⁵ Sagiv noted increased cardiac output and increased lactic acid concentration in the bloodstream in

trained adult athletes carrying loaded backpacks on an inclined treadmill.¹³² Talbott et al found significantly decreased brachial artery blood flow in school age children carrying a backpack of 20% bodyweight. Brachial artery flow was further decreased when the backpack load was worn high on the back as compared to lower on the back.¹³³

Pulmonary Response to Backpack Loads

Studies of adults have shown that lung function can be affected by carrying heavy loads close to the trunk.¹³⁴ To examine the effect of various backpack loads on lung function in children, Lai examined 9 year old children standing with backpacks containing 10, 20, & 30%BW compared to standing with no load, or with a kyphotic posture; and found significantly compromised lung volumes when children carried the 20 and 30%BW backpacks, or stood with a kyphotic posture.¹⁰ The kyphotic posture produced an equivalent decrease in lung function when compared to the carrying of a backpack weighing at least 10% of body weight. This was described as having a restrictive effect, perhaps similar to restrictive lung disease, or restriction from a body brace.¹⁰ Examination of respiratory changes in 10 year old boys carrying backpacks up to 20%BW found that the 10%BW load did not significantly affect trunk posture or respiration, as opposed to the significant increase when the backpack load reached 20% of body weight.¹³⁵ With increased backpack loads, thoracic volume (activation of thoracic respiratory muscles) also increased. These results suggest that the 10%BW load has the least impact on the respiratory function of children.¹³⁵ Young adult males carried loads of 15kg (33lb) (just under 20%BW) with loose shoulder, chest and hip straps and again with tightened shoulder, chest and hip straps while performing maximally forced

expirations.¹³⁴ Several measures of lung function were reduced with the tight strap condition similar to a restrictive ventilatory change in lung function.¹³⁴

Metabolic Response to Backpack Loads

With the increased and ongoing concern regarding the effects of load carriage of backpacks in children, studies have examined the metabolic cost of carrying loaded backpacks. Results indicate that the position of the backpack load on the child's body has a linear relationship to the energy expenditure while walking with a backpack load.⁶ The study by Malhotra & Sen Gupta found that a load carried in a double strap backpack required less oxygen consumption in children as compared to a load on one shoulder (which required 37% more energy than the backpack) or a load carried in one hand (which required 82% more energy than the backpack)⁹⁴. The backpack weight was not to exceed 10 to 12%BW.⁹⁴ Mean work intensity measurements of oxygen consumption and energy expenditure in children carrying 0%, 10%, 15% and 20%BW loads found the greatest metabolic cost at the 20%BW load condition.⁹⁶

Legg found that carrying a 30%BW load in a rucksack (a backpack) resulted in a 34% higher energy cost than simply carrying a 35%BW load near the trunk.¹³⁶ Lloyd compared the energy expenditure associated with a traditional rucksack (posterior load) versus one with front pockets (anterior and posterior load distribution).¹³⁷ Overall, the traditional rucksack resulted in increased energy expenditure as well as an increased heart rate compared to the front pocket rucksack during gait on level & inclined surfaces.¹³⁷

Increased backpack loads are associated with higher energy costs and work intensities as are subjective complaints. Ratings of Perceived Exertion at 30%BW load

are significantly greater than those at 0% and 15%BW loads in young adults.¹³⁸ Oxygen consumption, heart rate and expired ventilation also increased with the heavier loads over time, resulting in roughly a 5-6% increase in metabolic cost from 0 to 15%BW loads and again from 15% to 30%BW loads in trained young adult men.¹³⁸

Nerve Function Response to Backpack Loads – Rucksack Palsy

Extensive, prolonged carrying of a heavy backpack on the shoulders may lead to a traction injury of the C5 and C6 nerve roots of the upper brachial plexus known as Rucksack Palsy.^{73,139} In some cases, the compression causes an entrapment of the long thoracic nerve.⁷³ Incidence of Rucksack Palsy in the US Army basic training is 1.2/1,000 when carrying a backpack alone and 0.2/1,000 when carrying a backpack with a frame and hip belt.¹⁴⁰ In 1969, 17 Vietnam War soldiers who developed brachial plexus injuries after backpack use carrying weights ranging 40 to 80 lbs.¹⁴¹ Assuming an average weight of 150 lbs, these weights ranged from 26 – 53% of body weight. All but two of the 17 patients demonstrated impairment in muscles innervated by the upper trunk of the brachial plexus.¹⁴¹ Daube noted the predominance of injury to the non-dominant side, suggesting that the non-dominant arm is more susceptible to permanent damage.¹⁴¹ Daube cited earlier studies of brachial plexus injuries including one which described the development of brachial plexus palsy in four Boy Scouts while they were wearing backpacks.¹⁴¹ In 1981, Goodson observed a correlation between a heavy, high backpack and subsequent bilateral numbness in the hands and forearms due to tight backpack strapping.¹⁴² He noted that a tight strap across the lower axilla would compress major nerves emerging from the brachial plexus. The symptoms were noted to improve upon

terminating the use of the backpack for load carriage.¹⁴² Use of a backpack with a frame and a hip belt to defer some of the load may reduce the risk of rucksack palsy.⁷³

Physiological Response to Backpack Loads – Shoulder Pressure

The weight of a backpack is carried on the shoulders, the, and sometimes the hips back of the user. Recently, researchers have begun looking at the effect of backpack weight on the bearer's shoulders. An early study by Holewijn examined the pressure placed on the shoulders by backpacks of 0%, 7.2%BW and 13.8%BW.⁸⁵ The pressures on the skin of the scapula and top of shoulder significantly increased with the use of a standard backpack which was supported mainly by the shoulders as compared to a backpack which had a hip and waist belt.⁸⁵ The pressures under the straps exceeded the threshold for skin irritation with the 7.2%BW load, and were more than three times greater than the threshold for the 13.8%BW load.⁸⁵ Mackie designed a backpack with load sensors and pressure sensors to examine the effects of backpack load weight (either 10% or 15%BW) and the use of a hip-belt on shoulder strap tension forces (the pull on the straps by the backpack) and shoulder interface pressures (between the strap and the shoulder tissues).¹⁴³ The sensors recorded a 50% increase in the overall shoulder strap forces when carrying the 15%BW backpack weight, proportionate with the 50% increase from the 10%BW load. The pressures on the shoulder increased 70% with the 15%BW backpack load.¹⁴³ The effectiveness of the hip belt was evident, as the shoulder pressure increased only 44% (compared to 70% increase without a hip belt) at the 15%BW load (compared to the 10%BW load), supporting the importance of the use of hip belts and encouraging the reduction of backpack loads.¹⁴³ Another study used force transducers

near the base of backpacks of 13.6, 27.2, and 40.8 kg (30, 60, and 90 lb) loads to examine what region of the trunk was involved in truly carrying backpack loads.¹³⁹ This study found that regardless of the load, 30% of the vertical load was supported by the lower back, and the remaining 70% of the backpack load was carried by the shoulders and upper back.¹³⁹

Obesity – Loaded Backpacks as Transient Obesity

In 2008 over 68% of adults were overweight (Body Mass Index (BMI) \geq 85th percentile) and obese (BMI \geq 95th percentile)¹⁴⁴, while 33-34% of children 6-19 years are overweight,¹⁴⁵ and 17% of school-age children and adolescents are obese.¹⁴⁶ The effects of obesity in children include a decrease in bone mineral in the lumbar spine, increased low back pain, and increased prevalence of slipped capital femoral epiphysis. Additionally, excess weight results in gait alterations including increased step width, decreased hip and knee flexion, a slower gait cadence, and an increased cost of energy during locomotion.¹⁴⁷ The excess weight carried by obese children is considered a “long term” load as opposed to the weight carried during backpack use, which is considered “temporary” loading.¹⁴⁸ Due to the necessary biomechanical response to the altered the COM which positions obese individuals closer to the edge of their stability boundaries, their risk for falls increases.¹⁴⁹ A similar response was noted by Talbott upon examining adolescents wearing a 20%BW backpack, creating a risk for falls.¹²⁴ Palumbo, upon testing for directional control of limits of stability (LOS) in young adults while wearing loaded backpacks of ~11%BW, found slower and less accurate movement in the sagittal plane.¹²³ As the prevalence of childhood obesity increases and children continue to carry

heavily loaded backpacks, these children may be at a further increased risk of injury due to the external backpack load in combination with the internal soft tissue load.

Disablement, ICF and Backpacks

In the realm of medicine, it is necessary to have a theoretical framework to describe a pathological process and its impact on the individual. A theoretical framework provides a structure for the gathering of clinical information and influences assessment and intervention. One such framework is the “Guide to Physical Therapist Practice”,¹⁵⁰ which, just as it states, is a guide of patient management and includes examination, evaluation, diagnosis, prognosis and intervention.²⁵ The Guide is structured around the impact of a disease on a person at multiple levels and has adapted the disablement model developed by Nagi to describe the sequelae of an injury or disease process to disability, and the terminology includes pathology, impairments, functional limitations & disability.²⁵ The pathology is the disease at the organ level, such as arthritis, or a stroke. The impairment describes a structural problem as a result of the pathology, such as decreased range of motion due to a contracture. The functional limitations identify problems related to the person’s ability to perform a task, such as walking or climbing stairs. These usually relate to disability which describes tasks or roles that the person is unable to perform. The disability affects the individual in multiple aspects of life, from activities of daily living, to quality of living to the impact on finances and more.

The “Guide to Physical Therapist Practice” uses an “expanded disablement model that provides both the theoretical framework for understanding physical therapist practice and the classification scheme by which physical therapists make diagnoses.¹⁵⁰ There are

four major classifications: musculoskeletal, neuromuscular, cardiovascular/pulmonary, and integumentary.¹⁵⁰ The Guide also lists diagnosis codes that relate to The World Health Organization (WHO) International Classification of Diseases, 9th edition.¹⁵⁰ Continuing within a practice pattern, the guide lists multiple tests and measures that may characterize or quantify various aspects of the human condition.¹⁵⁰ These outcome measures are followed by suggested interventions and goals that focus on the functional loss and disability of the individual, rather than the original pathology. The Guide and the Nagi model are applicable to the issue of backpacks and children, as an evaluation of a child carrying a heavy backpack may reveal deficits in all four classifications, for example, the child presents with impaired posture, muscle weakness, decreased postural control, altered respiratory function and sore shoulders from the backpack pressures.²⁵ There are several diagnosis codes that could be applied to a child with impairments due to backpack use. Several of the outcome measures listed in Pattern 4B “Impaired Posture”, were used in this study.¹⁵⁰ Several others have been used in studies throughout the world to examine the effects of backpacks on children. As a theoretical framework, the disablement model describes the functional limitations and impact of a pathology on an individual, but it doesn’t include the effect of the environment or personal factors that may negatively or positively influence an individual.²⁵

The World Health Organization developed the International Classification of Functioning, Disability and Health¹⁵¹ in 2001 as a revision to an earlier model of classification that was also originally based on the disablement model.²⁵ The ICF developed in recognition that the impact of disease and pathology needed to be described universally in terms of function.¹⁵² The ICF is a framework to classify relationships of

health and provide a coherent biopsychosocial view of health states from a biological, personal, and social perspective.¹⁵³

The ICF recognizes that human health functions as a product of a dynamic interaction between various health conditions, body structures and body functions and activities and participations, which may in turn be influenced by contextual environmental and personal factors.^{152,153} The ICF term health condition is used to represent diseases, disorders, injury, or trauma, aging, and congenital anomaly.¹⁵³ Impairments may be temporary or permanent and are described as “a significant deviation or loss in body structures (such as organs, limbs, and their components) and function (including physiological or psychological functions of body systems.”¹⁵³ Activities are the execution of a task, whereas activity limitations are “difficulties an individual may have in executing activities (or tasks).”¹⁵³ Participation restrictions are “problems an individual may experience in involvement in life situations.”¹⁵³ The ICF provides qualifiers that allow identification of level of impairment or whether an environmental factor is a facilitator or a barrier.¹⁵²

Within the ICF, “Core Sets” have been identified and developed for specific diseases or specific conditions that contain selections of ICF categories as opposed to the original 1,424 ICF categories¹⁵⁴ which are most appropriate to describe the impact of a disease on function.¹⁵² For example, ICF Core Sets for Ankylosing Spondylitis, Osteoporosis, Rheumatoid Arthritis and Low Back Pain have been identified.^{152,155} The ICF Core Set for LBP identified 78 categories from the body structure, body function, activities & participation and environmental components for the Comprehensive ICF core set. The Brief ICF Core Set includes only 35 categories from the same components of

the ICF.¹⁵⁵ Back pain alone is listed as the fifth most common reason for impairment of activities of daily living.^{35,156}

ICF Model: Application to Backpacks and Children

Problems arising from backpack use for both children and adults can be classified using the ICF model. Body function components that can be affected by LBP due to backpacks include: Sleep, pain, balance, exercise tolerance, mobility of bones or joints, stability of bones or joints, muscle power, gait, and proprioceptive function. Structural impairments may include: posture, muscular limitations, structure of trunk, lower extremity, and other structures related to movement. These impairments may lead to activity limitations or participation restrictions including difficulty with: walking, changing body positions, lifting and carrying, employment (in adults) and recreation.¹⁵⁵ The severity of back pain has caused roughly 16-23% of children to miss school activities or seek medical attention.^{9,44,57,58} With the potential for continued back pain into adulthood and the long term effects of back pain, prevention of pain and disability is paramount.

Backpacks as a Risk Factor for Musculoskeletal Disorders

The United States Department of Labor defines a musculoskeletal disorder as “an injury or disorder on the muscles, nerves, tendons, joints, cartilage, or spinal discs.” according to the Bureau of Labor Statistics in 2003.⁸⁰ Consider a 10 pound backpack lifted 5 times in one day; over one school year of 180 days this will result in a cumulative lift of 9000 pounds. Add to this the amount of time the child carries the back, and the exposure to the load is increased. According to Kumar, repeated exposure over a

prolonged period may impede recovery, causing residual strain, an accumulation of which may be facilitory for injury even if the stressor is not large. This progressive reduction in stress tolerance capacity may be due to steadily increasing residual strain.¹⁵⁷ Barr suggests the combined effects of the risk factors are additive, exceeding the tissue tolerance threshold and lead to subsequent injury,¹⁵⁸ which is a “mechanical disruption of tissues resulting in pain...in which the integrity of the tissue in question is violated and its mechanical order perturbed.”¹⁵⁷ While an injury may not involve pre-pathogenesis, it may involve mechanical degradation due to repeated overuse. It is known that following an injury the processes of inflammation and healing occur; however in the case of an injury due to repetitive factors, the tissues may continue to be exposed to the initial stressors. Exposure to a repetitive element is a hazard or a risk factor for musculoskeletal disorders.¹⁵⁷ According to the World Health Organization (WHO) in 1995, there were an estimated 120 million occupational accidental injuries worldwide¹⁵⁹ leading to economic costs as high as 20% of a nation’s Gross National Product.¹⁵⁹

Cost of Back Pain and Musculoskeletal Disorders in the U.S.

In 2003, musculoskeletal disorders (MSD’s) were reported for 33 percent of the injuries and illnesses with days away from work.⁸⁰ Back injuries result in more than 100 million lost work days each year¹⁶⁰ which accounts for 43% of the missed work days due to MSD’s and nearly 50% of the almost 1.3 million work-related MSD’s reported in 2009.⁸⁰ The average total cost per claim for cumulative trauma disorder was \$20,449 in 2005, with low back sprain/strains estimated to be one of the costliest work-related injuries at \$23,820 per claim, contributing to the \$164.7 billion in annual direct &

indirect costs in 2005.⁸¹ In 2004, the economic cost of LBP exceeded \$115 billion and may be potentially estimated at more than \$600 billion per year for indirect, direct costs and all other associated costs.¹⁶¹

When a child becomes disabled to the extent that s/he cannot participate in the workforce as an adult, the indirect cost of lost future income may exceed half a million dollars.¹⁶² Extrapolation of the information above results in the theory that prolonged use of excessively heavy school bags contributes to the development of early musculoskeletal disorders, as well as establishes a vulnerability to developing a MSD later in life. Research performed on animal models examining the histological effect of repetitive motion on both muscles and nerves; repetitive motion, without adequate recovery time leads to damage of these tissue and ultimately decreased function. Barr states: “when considering the development of MSD, loss of function is the hallmark that prompts clinical intervention.”¹⁵⁸ If the extended use of excessively weighted, poorly carried backpacks is a repetitive motion that risks the development of MSD’s in youth, as well as sets the stage for future injuries, we, as health professional, as parents, as participants cannot wait for the loss of function to occur, but must intervene to prevent injury in school children worldwide.

Lifting Limit Guidelines for Adults

Since 1965, researchers have suggested a weight limit for the loads carried by children in schoolbags. As of this writing, there are no official federal or government guidelines to limit how much weight children should carry. However, in 1981 the National Institute of Occupational Safety and Health (NIOSH), recognizing the growing

issue of work related back injuries in adult workers, in order to determine the safety of lifting tasks, developed an weight limit equation which identifies a recommended maximum lift load that nearly all healthy workers should be able move for a specific task without an increased risk of developing lifting-related low back pain.¹⁶³ The weight limit equation calculations include worker height, the task height, the distance of reach, the weight of item to be lifted and other aspects of the lifting task in question. In 1991, NIOSH revised the lift equation, lowering the limit of an acceptable lift weight from 90 pounds (or 40 kg) to 51 pounds (or 23kg) in an workplace setting.¹⁶⁴ Under the Occupational Safety and Health Administration (OSHA) General Duty Clause, Section 5(a)(1), employers are obligated to keep workplaces free from recognized serious hazards, one of which is excessive and hazardous loads.¹⁶⁵ While this revised lifting equation provides a recommended weight limit for a task, it is only a guideline to protect adult workers from manual lifting injuries, not a strict mandate of weight limits.

Conversely, there is no authoritative guideline to protect children who are subjected to excessive, hazardous backpack loads on a daily basis. Assuming ideal lifting conditions and techniques, the recommended weight should not exceed 51 pounds for an adult according to the NIOSH equation.¹⁶³ For an average 150 lb man, that correlates to a 34%BW load. U.S. military standard 1472E for design criteria of military equipment states the total load should not exceed 30% of body weight, and that “One-person back-packed loads over 20 kg (44 lbs) shall be designed, and, if necessary, provided with lifting aids to permit a second person to assist.”¹⁶⁶ That is to say, the U.S. government issued a standard that in order to don a backpack weighing approximately 30% of a 150 pound adult; a second person should assist in its placement.¹⁶⁶ Currently, children do not

have any such a mandate to protect them when lifting and donning a backpack of similar weights. Today's children don't have any authoritative rules or guidelines to protect them from carrying excessively heavy backpack loads that have been documented to weigh up to 46% body weight.

NIOSH has considered the health of youth in the past, gathering a panel of professionals in 2002 to discuss the prevention of musculoskeletal disorders in adolescents and children working in agriculture.¹⁶⁷ In their own documentation, the panel recognized that children/adolescents "are not, in fact, merely small adults".¹⁶⁷ They recognized that while some youth may be of the same stature as adults, they are developmentally different, both physically and psychologically.¹⁶⁷ The panel states that the NIOSH lifting equation, with a maximum of a 50 pounds lift for the majority of adults, would not be valid for youth due to the lack of reliable information on children's physical capabilities are for various ages, genders, statures, and development.¹⁶⁷

The panel also recognized that "it may not be the 15 times that a child or adolescent performed a specific task, but rather the one time they performed the task during a growth spurt or during growth plate formation that caused a musculoskeletal problem."¹⁶⁷ Furthermore, discussion also reflected the acknowledgement that heavy physical demands on children /adolescents may "cause the bones to grow the wrong way or become too stiff, resulting in higher transmissibility of forces to the joint surfaces. These increases in bone density may be precursors or early indicators of chronic musculoskeletal disorders."¹⁶⁷

The risk of musculoskeletal disorders in children is not limited to the agricultural setting. Repetitive carrying of excessively heavy backpacks may very well prove to be a

contributing factor to the development of skeletal dysfunction and pain issues in youth lasting into adulthood.

Current Professional Association Recommendations for Backpack Weight Limits

International concern about the effects of heavy backpacks led to the decision of the Ministry of Education in Austria to set a 10%BW carriage limit in 1996¹⁶⁸ and the National Bureau of Education in France to issue a recommendation that schoolbags weigh less than 10% of a child's body weight in 1995.⁵⁷ This was followed by an international conference in France in 1999 to discuss low backpain in children and youth.^{6,54}

In December of 1999, the American Academy of Orthopaedic Surgeons released a statement to the media regarding the results of an Academy survey of physicians who reported that 58% of 101 physicians had seen school-age patients with complaints of back and shoulder pain due to backpacks.¹⁶⁹ The survey indicated that backpacks weighing more than 20% of a child's body weight could cause clinical problems.¹⁶⁹

Multiple professional associations, including the American Physical Therapy Association, the American Occupational Therapy Association, and the American Chiropractic Association have distributed press releases regarding the prevalence of heavy backpacks and incidence of back, neck, and shoulder pain, as well as risk of brachial plexus injury.^{170,171,172,173} These associations have also suggested guidelines for safer backpack use such as limiting backpack weight to 5-15%BW, using both straps, a hip belt, and even distribution of weight within the pack.^{170,171,172,173} Weir, in the Canadian Medical Association Journal in 2002, advised Canadian physicians and readers about the risks of backpack use.¹⁷⁴

The California Legislature in 2002 acknowledged that elementary school children carry backpacks weighing as much as 40 pounds and approved a bill to adopt maximum weight standards for textbooks in elementary and secondary schools by 2004.¹⁷⁵ An evaluation by the state government found that the combined textbook weight for the four core academic content areas exceeded 15%BW for the majority of students in grades 1 through 12.¹⁷⁵ The state of New Jersey attempted similar legislation to limit textbook weights in 2002.¹⁷⁶ The American Chiropractic Association passed a resolution in 2002 to support textbook publishers to develop electronic copies of textbooks as a way to decrease backpack weights.¹⁷² These legislative motions have focused on the limiting of textbook weights, rather than overall backpack weight limits for children, with varying success.

Statement of Purpose - Specific Aims and Hypotheses

This is a prevention-focused, rather than an intervention or treatment study. Much research and funding are dedicated towards intervention for issues such as backpain or weakness due to an injury. Much less research and funding are dedicated towards preventative research, toward identifying risks and preventing a potential injury before it becomes a real problem. In the adult workplace, there has been gradual recognition of the importance of task, tool, and workplace modification in order to ultimately prevent repetitive injuries in adults. This study was developed from the desire to protect children and limit their early exposure to unnecessary risk of injury from the frequent and regular carrying of heavily loaded backpacks.

Purpose

The purpose of the study was to examine the effects of backpack weights (up to 20%BW) on children's posture, subjective complaints of pain and perceived exertion, and endurance. In addition, a secondary goal was to examine the data to identify and recommend a weight limit for backpacks carried by elementary school children based on the results.

This dissertation includes a preliminary study designed to examine the effects of loaded backpacks on forward head posture in school children (Chapter Two). Chapter Three pertains to the main study evaluating multiple postural angles and the subjective complaints of perceived exertion and pain in children to determine the effects of both the weight and time spent carrying loaded backpacks up to 20%BW. The following hypotheses pertain only to the primary intervention study.

Research Question 1: How do loaded backpacks (of 10, 15, and 20%BW) affect the postures (craniovertebral angle, forward trunk lean and pelvic tilt) of the children who carry them?

Hypothesis 1.1: Is there an immediate difference in postural angles due to backpack weight at initial load?

Hypothesis 1.2: Is there an immediate difference in postural angles among the weights in posture after initial load?

Hypothesis 1.3: Is there a difference in postural angles due to backpack weight after walking 6 minutes with a loaded backpack?

Hypothesis 1.4: Is there a difference in postural angles among the weights after walking 6 minutes with a loaded backpack?

Hypothesis 1.5: Is there a difference in the changes in postural angles across conditions among the weights?

Research Question 2: How do loaded backpacks (of 10, 15, and 20%BW) affect the functional walking endurance (6MWT walking distance) and ratings of perceived exertion/fatigue (OMNI) in children after walking 6 minutes with a loaded backpack?

Hypothesis 2.1: Is there a difference in the distance walked in 6 minutes among the weights?

Hypothesis 2.2: Is there a difference in the OMNI perceived exertion/fatigue scores after walking 6 minutes with load among the weights?

Research Question 3: After walking 6 minutes with a loaded backpack, what is the effect of backpack weight on pain severity as measured by VAS on the neck, shoulders, mid back and low back?

Hypothesis 3.1: Is there a difference among the weight groups in severity of pain at the neck, shoulder, mid back and low back?

Research Question 4: Based on these results, what is the recommended weight limit for backpacks carried by elementary school children ages 8 to 11?

Methods

Study Design

The primary study was a prospective, two-factor repeated measures design, with the subjects serving as their own controls. Institutional Review Board approval was

received in April 2010. The first subjects enrolled in September 2010. The study was completed October 2010.

The study involves the evaluation of the postural and subjective responses of children 8 to 11 years of age before and after walking 6 minutes while wearing a backpack containing one of each of three randomly assigned conditions of 10%, 15% and 20%BW. These backpack weights approximate the load carried by primary school children every day to school. After consent was acquired, baseline demographics and anthropometrics measurements were completed, and subjects completed an unloaded 6 minute walk and distance was measured. This was followed by a rest period during which the subject completed the initial questionnaire with the primary researcher while a second researcher prepared the randomly assigned backpack load.

A photograph was taken of the left side of the subject without a backpack for a baseline posture (unloaded condition). A second photograph was immediately taken upon donning of the weighted backpack (initial load condition). The subjects then walked for 6 minutes at a comfortable self-paced speed while wearing the backpack. At 6 minutes, the subject stopped walking, the distance walked was recorded, and a measure of perceived exertion was obtained. The subject returned to the photograph location and a third picture was taken (post walk condition). The backpack was removed and the subject completed a post-walk pain survey. The subject repeated this process with the remaining backpack loads over the next two weekends. After data collection was complete, the photographs were digitized for angles and measures by an independent researcher. This data was used for statistical analysis.

Subjects and Sample Size

A convenience sample was recruited from children in elementary schools and youth groups local to Boca Raton, Florida. The target sample population consisted of school children between the ages of 8 and 11, to allow inclusion of 3rd through 5th grade students.

The sample size required a minimum of 60 subjects to achieve power of .80 for α , alpha, (two-tailed) = 0.05. 64 subjects were recruited, 63 subjects enrolled and 62 subjects completed 3 weeks of data collection.

Inclusion and Exclusion Criteria

To participate in the study, subjects needed to return to the study location on 3 consecutive weekends. The inclusion criteria included:

1. Male or female
2. Age 8 through 11

Subjects with any of the following conditions were excluded from this study:

1. Clinical presentation suggestive of serious pathology.
2. Systemic illness.
3. Neurological/muscular degenerative disorders.
4. A stated pre-existing condition that prevents load carriage of a backpack using both shoulder straps.
5. History of low back pain complaints limiting backpack use.

Recruitment and Informed Consent

Children were recruited for the study from the surrounding area through use of flyers and word-of-mouth communications. An IRB-approved flyer (Appendix 1) was sent to local elementary schools and youth groups (Cub Scouts, Girl Scouts, Home-school contacts) that summarized the purpose of the study, time requirements and contact information. The parents of the children interested in participating contacted the researcher by telephone to initiate their interest for participation in the study.

Upon arriving at the study location, the researcher met with both child and parent and explained the research protocol. The informed consent was provided to the parent, and an assent was provided to the child (Appendix 2 & 3). The researcher was present during the informed consent process to address any questions that the parent and/or child may have had, including risk and compliance issues. The subject and parent were reminded that they could withdraw from the study at anytime. Once the approval was received and the consent and assent were signed, the subject was assigned an identification number and the researchers began the evaluation and measurement aspect of the study.

Blinding and Randomization

Randomization for the weight conditions was established through a Random Integer Generator.¹⁷⁷ Blinding was limited in this study. Subjects were aware of the intent of the study to examine the effects of weighted backpacks. They were not aware of which condition they were being tested on. Only the research assistant who loaded the backpacks with the percentage of weight assigned for each data collection day knew the

weight that the child wore on each day. This research assistant was involved only in the initial demographic data gathering and the loading of the backpacks each day, but not in any other data collection aspects of the study.

Procedure

After consent was given and each subject was enrolled in the study, basic demographic and anthropometric information was collected for each subject on the first day of data collection. This included: age, gender, height, and weight as well as the weight of each subjects' own school backpack. The subject's weight was taken at the beginning of each data collection session to ensure accurate backpack loading as a percentage of the child's weight.

After baseline anthropometrics were measured, the subject walked for 6 minutes at a comfortable self-paced speed without a backpack to provide a baseline comparative 6MWT distance. At the end of the 6 minutes, the distance walked was recorded and an OMNI score of perceived exertion was obtained to document the level of fatigue without a backpack. This was followed by a rest period during which the subject completed the initial questionnaire with the primary researcher.

For the postural angle measurements, the subjects wore tank tops or sleeveless tops and snug bike-type shorts. Bony landmarks were palpated and adhesive reflective markers were placed on the spinous process of C7 and on the left side of the body at the following locations: the tragus of the ear, the acromion-clavicular joint, the greater trochanter, the anterior superior iliac spine, the posterior superior iliac spine, the lateral knee joint line and the lateral malleolus by the primary researcher, an experienced Physical Therapist. If clothing interfered with marker placement on a bony landmark, it

was moved aside and held out of the way with tape. The markers reflected the camera's flash, enabling accurate landmark identification during later analysis.

Subjects stood on a thin pad of paper at an "L" marked with tape on the ground in front of a posture chart. The lateral edge of the left foot was lined up along the longer length of the L, and the toes were placed at the edge of shorter length of the L as viewed in Figure 1. The subject's feet were traced while he/she stood unloaded on the paper, prior to donning a backpack. The subject returned to the same footprints for all photographs to control for foot position across all trials. The paper was marked with the subject's ID number.

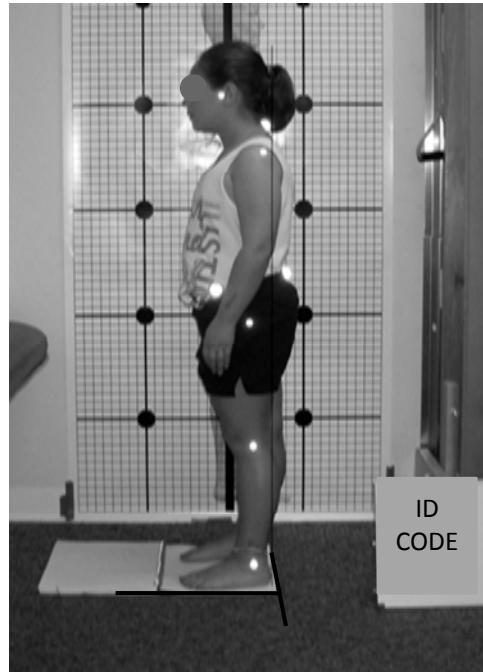


Figure 1.1. The photograph location with traced footprints and "L".

Left-sided profile (sagittal view) photographs were taken according to protocol set forth by Grimmer,⁸⁴ and adapted for this study. Subjects were asked to stand as

“normally” as possible (See Figure 1.1) while viewing a target placed at eye level. An identification tag was placed within photographic range with the subject’s ID and a code to identify the condition being photographed. The 5 megapixel digital camera¹⁷⁸ with a resolution of 1600x1200 was fixed on a tripod 3 meters away from the subject and was set at the height of the subject’s shoulder. A level was used to maintain the camera’s position between sessions.

The backpack load was created through the use of school textbooks of various weights which were placed into the backpack with the largest books closest to the subjects back and secured with strapping to provide a stable, static load. A randomization table was used to determine the order of the backpack loads of 10%, 15% or 20%BW across the three testing sessions.

The first photograph (“unloaded”) was taken of the left side of the subject while he/she stood at the “L” without a backpack. The subject donned the backpack, positioned with the center of the load approximately at the level of T10, and a second photograph (“initial load”) was taken immediately while the subject remained standing on their traced footprints at the “L”. The subject was instructed “walk at a comfortable pace”¹⁷⁹ around a course indicated by red cones.

At 6 minutes, the subject was stopped, the distance walked was recorded and an OMNI score of perceived exertion was obtained. The subject returned to the photograph location, stood on their traced footprints, looked ahead at the target and a third picture (“post-walk”) was taken. The backpack was removed and the subject completed the post-walk pain survey with the primary researcher. The reflective markers were removed and the subject received a token prize after completing each data collection session.

To limit the effects of fatigue during repeated trials in one day, subjects returned during the next two consecutive weeks and were retested with the remaining randomly assigned backpack weigh conditions. After data collection was complete, the digital photographs were analyzed by an independent research assistant, who was blinded to the purpose of the measurements to minimize risk of bias, using Image Tool V.3 by The University of Texas Health Science Center at San Antonio (UTHSCA).¹⁸⁰

Outcome Measures

Quality of Life Outcome Measures

Initial Questionnaire

The subjects completed a two-part initial questionnaire. See Appendix 4. The first part, derived from prior studies^{4,19,181}, inquired about the subject's demographics, backpack usage, subjective complaints, and activity level (including involvement in after-school sports and/or computer & technology usage). The questionnaire included a visual-analog scale (VAS) to assist with identification of region and quantification of discomfort. The second part of the initial questionnaire, the Self-Administered Physical Activity Checklist (SAPAC), a valid measurement tool, was used for the activity component of the questionnaire.¹⁸¹ The SAPAC provides a measure of activity in time and METS for physically active and sedentary activity during the last school day before the data collection day.

Children's OMNI-Walk/Run Scale (OMNI)

The Children's OMNI Scale is a scale of perceived effort that contains both pictorial and verbal descriptors that correspond with a numerical response range of 0 to

10.¹⁸² The OMNI was developed as a perceived exertion rating tool because children younger than 11 cannot consistently assign numbers to words that describe exercise-related feelings and the exercise-related language of some scales are not part of their regular vocabulary.^{182,183} It is a valid measure of perceived exertion of psychophysiological responses representing the exercise-related feelings of fatigue in children and has been correlated with VO₂ max & heart rate in children 6 to 13. Prior studies have utilized BORG and BORG CR10 scores with older subjects, finding increased ratings of perceived exertion with increased backpack loads carried.^{1,184,185,186,187} The OMNI is positively and linearly related to the RPE-BORG for adults.¹⁸⁸ After walking 6 minutes, the Children's OMNI Scale (shown in Figure 2) was used to determine perceived effort immediately after walking with the backpack.

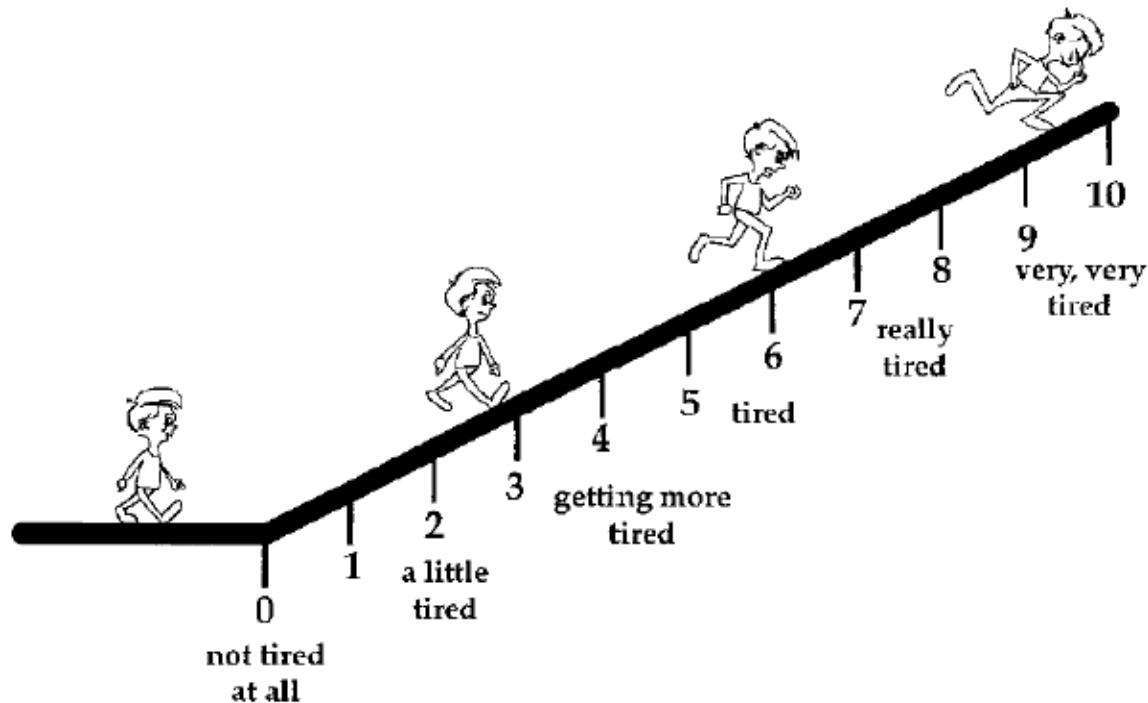


Figure 1.2 The Children's OMNI Walk/Run Scale of Perceived Exertion

Post-Walk Pain Survey with Visual Analog Scale (VAS)

The post-walk survey (Appendix 5) included a visual analog scale (VAS) and a body diagram (modified from Young¹⁸⁹) to measure the subjective complaints of “soreness” or severity of pain in the neck, mid and low back regions after each walking trial. The VAS has been shown to produce reliable information in youth.¹⁹⁰ The VAS is divided into equal increments from 0 to 10, beginning with “no pain (“0”) and ending with “worst pain” (“10”). The body diagram is a sagittal line drawing of the spine with arrows pointing to the neck, mid and low back regions to enable localization of pain. The use of body diagrams and other visual methods for indicating the region of pain have been used in previous studies and are ideal methods for localizing problems.¹⁹¹ After walking for 6 minutes with a randomly assigned backpack weight, the subject was presented with the post-test VAS survey to identify the presence and location of any discomfort or pain. (See Figure 1.3 for an excerpt of full survey shown in Appendix 5).

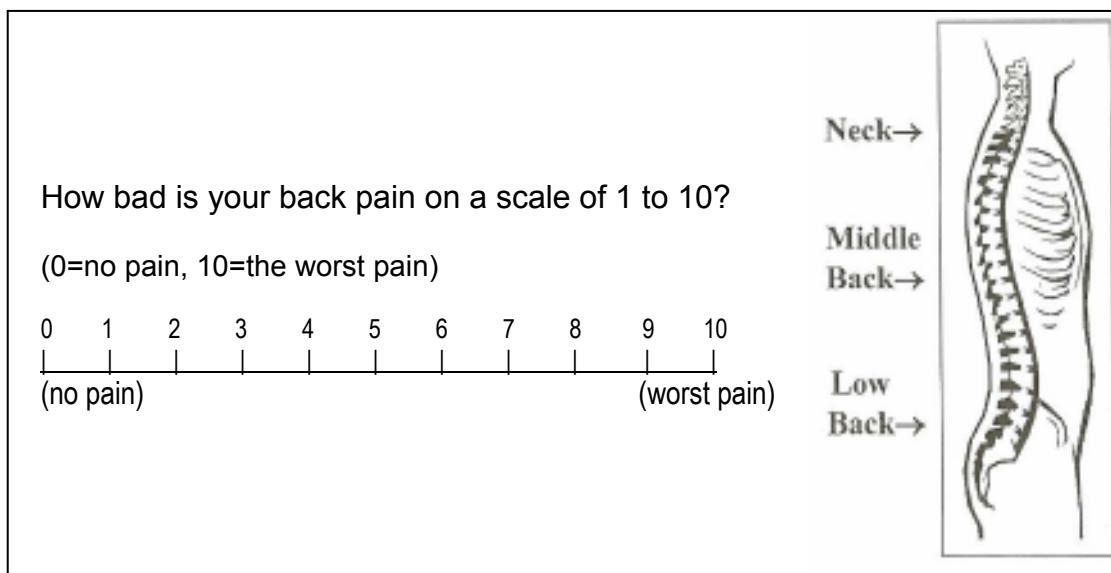


Figure 1.3. Excerpt from the Post-Walk Pain Survey showing the VAS and body diagram. (Body diagram adapted from Young et al)

Activity and Participation Outcome Measures

Six Minute Walk Test (6MWT)

The 6 Minute Walk Test (6MWT) is a measure of functional exercise capacity of an individual.¹⁷⁹ It is able to quantify functional endurance and is sensitive to change.¹⁹² Originally developed for use with patients with pulmonary disease, the 6MWT has been used in epidemiologic research with a variety of patient populations, including adults with heart failure, cystic fibrosis, and liver transplants as well as children with pulmonary hypertension, cystic fibrosis and organ pre-transplant assessment^{179,193} and spinal muscular atrophy.¹⁹² The 6MWT measures the distance that a subject or patient can quickly walk on a flat, hard surface in 6 minutes.¹⁷⁹ The 6MWT is easy to use, low cost and clinically accessible without requiring expensive equipment, and has been established as a reliable and valid functional exercise capacity test for assessing exercise tolerance and endurance in children.¹⁹⁴ Normative values have been established for the 6MWT for children 4-11 years old,¹⁹⁵ 7-16 years old¹⁹⁴ and 3-18 years old.¹⁹⁶ The 6MWT falls under the ICF component of “Changing and maintaining body position (d410-d429)” and “walking (d450).”¹⁵¹ For the current study, the 6MWT provides insight regarding functional walking endurance in children carrying a loaded backpack.

Body Structure Impairment Outcome Measure

Postural Angles

Digital photography enables researchers to examine and measure various postural angles in a non-invasive manner. While X-rays are considered the “gold standard” for

imaging due to the visualization of skeletal bone rather than measuring through soft tissues, digital photographs limit radiograph exposure. Various studies have verified the reliability of digital photographs for obtaining clinical measurements of sagittal postural angles.^{197,198} When carrying a loaded backpack, the postural compensations observed can be measured via digital photography and reflective markers. The Craniovertebral Angle (CVA), Forward Trunk Lean (FTL), and Pelvic Tilt (TILT) measures are shown in Figure 4 and were obtained through analysis of the digital photographs.

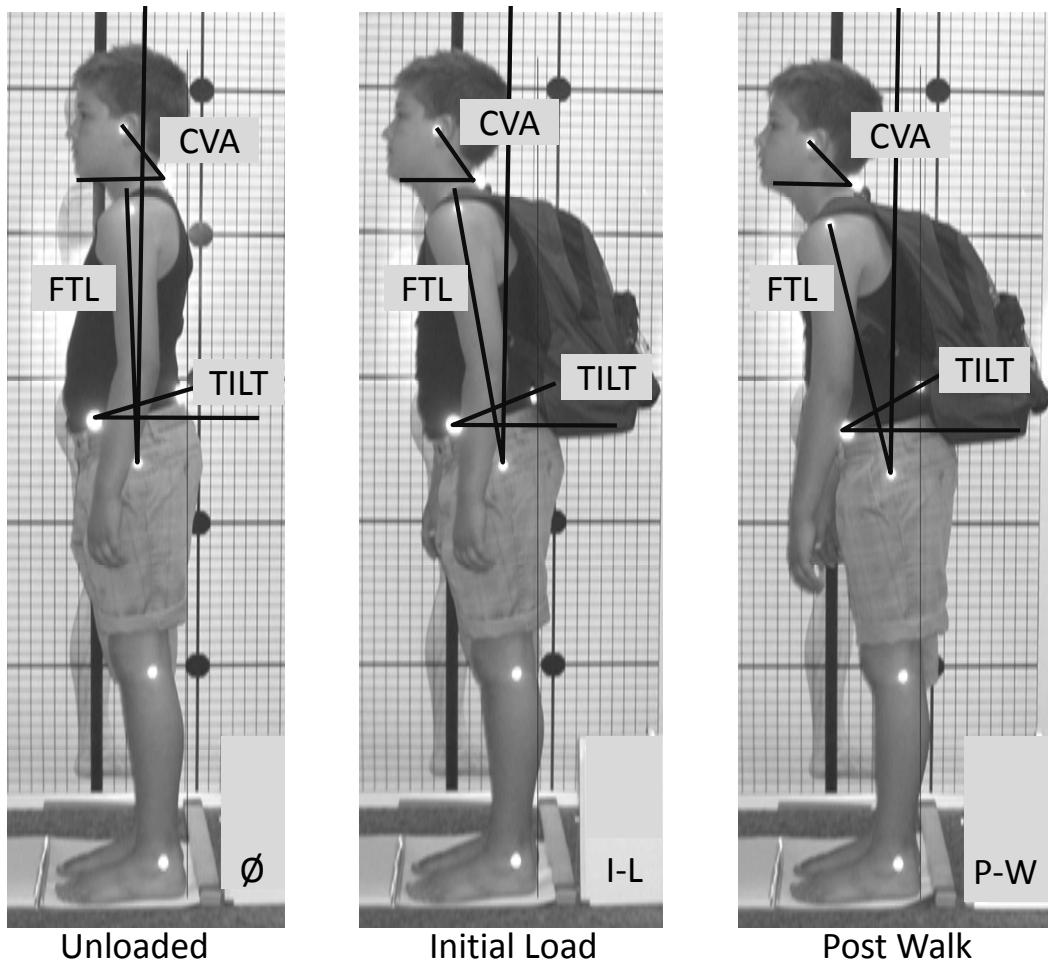


Figure 1.4 Postural Angles at Unloaded, Initial Load and Post Walk

Craniovertebral Angle (CVA)

The craniovertebral angle (CVA) has been used to measure forward head posture (FHP) in relation to headaches, temporal-mandibular joint dysfunction and backpack loads.^{12,62,63,114,115,116,198} The CVA is defined as the angle between a horizontal line through the C7 spinous process and a second line through the spinous process of C7 and the tragus of the ear as shown in Figure 1.5.^{12,84,119,199} A forward head position is represented by a smaller CVA measurement. The CVA is a highly observable response to a backpack^{12,114,115,116,198} and has demonstrated high reliability and very high intrarater and interrater reliability for the measurement of forward head posture.²⁰⁰

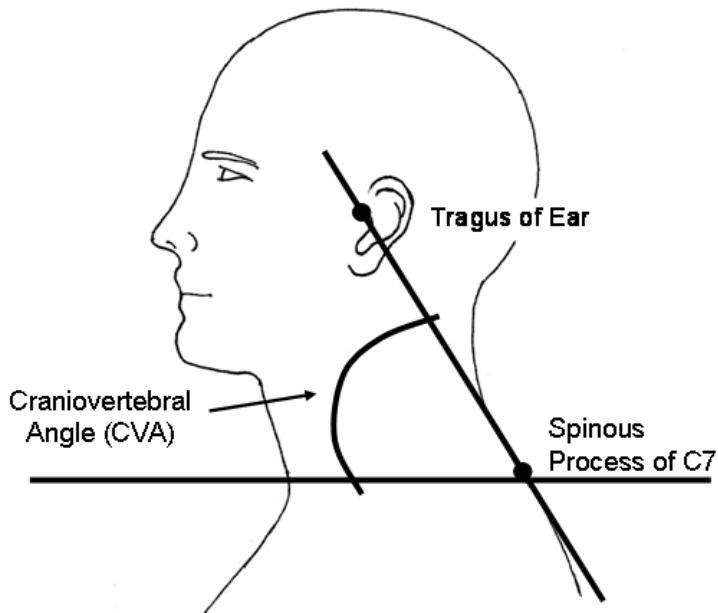


Figure 1.5 The Craniovertebral Angle (adapted from Chansirinukor et al, 2001¹²)

Unloaded CVA measures for children vary, ranging from 46.9 to 48.0° in 8 to 12 year old children.¹¹⁴ Unloaded CVA measures vary, but overall decrease with increasing age in adulthood,¹⁹⁹ with measures ranging from 48.6° to 51.8° in young adults aged 20 to 44 years,^{113,201} 45.1° in adults 50 to 69 years,⁶² 48.8° in women 65 to 74 years, 41.2° in

women 75 to 84, and 35.6° in women over 85 years of age.²⁰⁰ Differences in CVA in older adults due to gender are not significant.²⁰¹ To measure the CVA, reflective markers were placed on the spinous process of C7 and the tragus of the left ear. Using the ImageTool software, the CVA was measured from a line between those markers and a horizontal line. A smaller measurement indicated a more forward head position. A larger measurement indicated a more normal, upright head position.

Forward Trunk Lean (FTL)

The Forward trunk lean (FTL) angle is formed by the intersection of the line from the acromion to the greater trochanter and a vertical reference line as seen in Figure 1.6.^{5,116} With the placement of a posterior load, the biomechanical response to maintain balance brings the new combined COM of the load and the subject forward over the BOS of the feet. One method for maintaining balance is to flex forward at the hips in a forward trunk lean. This measure has shown significant changes associated with increased load carried.^{5,7,119,120,124,135,202,203}

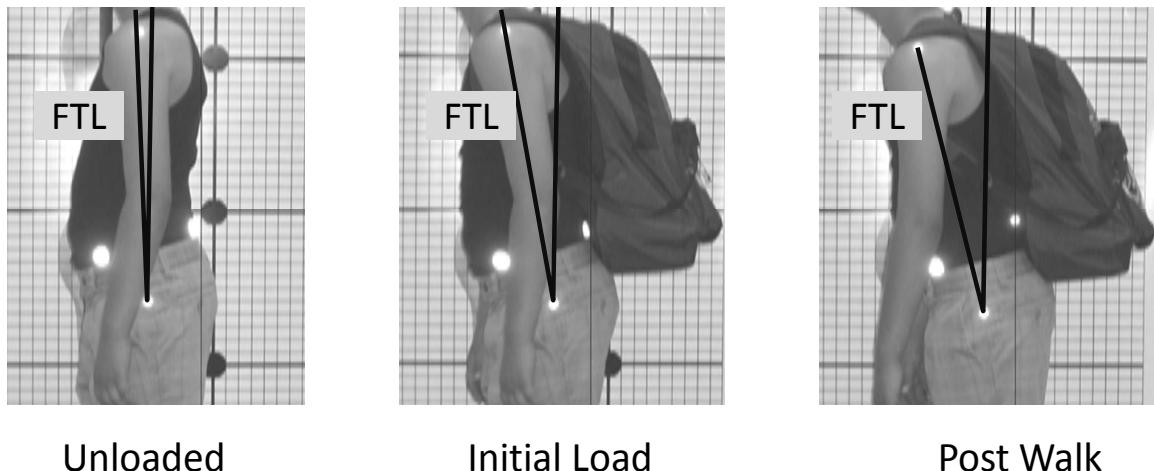


Figure 1.6 Forward Trunk Lean at Unloaded, Initial Load and Post Walk

To measure FTL, reflective markers were placed on the acromion-clavicular joint and the greater trochanter. Using the ImageTool software, the FTL was measured from a line between those markers and a vertical line. A positive number indicated the subject was leaning forward of vertical into trunk flexion. A negative number indicated the subject was leaning backwards, in trunk extension.

Pelvic Tilt (TILT)

According to Kendall & McCreary, a neutral pelvis is one in which the anterior superior iliac spines (ASIS) are in the same horizontal plane as the posterior superior iliac spines (PSIS).¹⁷ A greater angle measured between the ASIS/PSIS plane and the true horizontal plane demonstrates an anteriorly tilted pelvis. Sacral inclination and lumbar lordosis are increased with a greater anterior pelvic tilt.^{17,21} Smith found a significant change in pelvic tilt when wearing a backpack containing 15%BW.²⁰⁴ Additionally, Brackley found increased lordosis angles of 10-year-old children after carrying a 15%BW load.¹¹⁶ While the ASIS/PSIS plane measurement with a caliper and an inclinometer (or level) is a reliable method,^{205,206} it can also be measured in an objective, noninvasive method using photography and markers.²⁰⁷

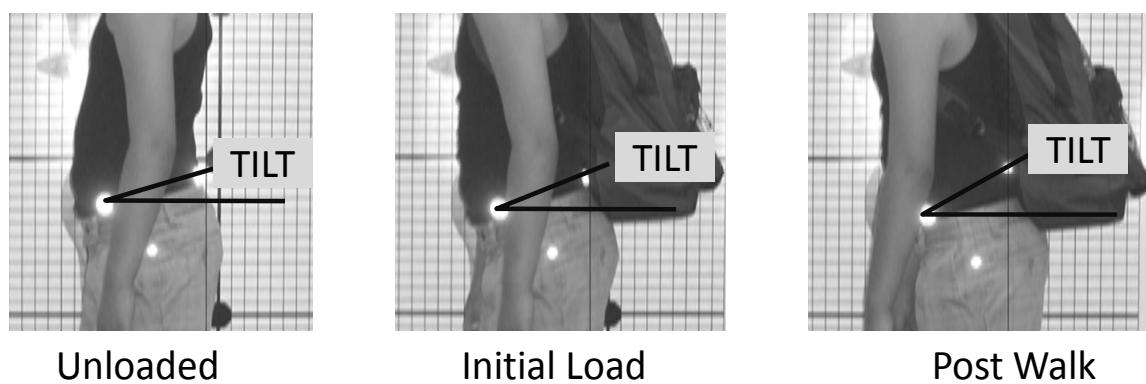


Figure 1.7. Pelvic Tilt at Unloaded, Initial Load and Post Walk

To measure TILT, reflective markers were placed on the left PSIS and ASIS of the subject as shown in Figure 1.7. The angle was measured as a line between the ASIS and PSIS compared to the horizontal through the digitizing software. A larger number indicates an increase in anterior pelvic tilt. A smaller measurement indicates a more posterior pelvic tilt.

Data Analysis

Data analysis was performed using the SAS statistical software PC SAS version 9.²⁰⁸ Descriptive statistics were calculated to characterize the demographic and clinical characteristics of subjects at baseline.

Research Question 1: To answer the question of how loaded backpacks affect children's posture, a two-factor, repeated measures analysis of variance was used to determine if there was a difference among the weights in the change in posture across conditions. A one-factor, repeated measures ANOVA was used to examine differences in postural angles among the weights at initial load, followed by Pairwise comparisons (paired t-test) to examine the effects at each weight. A one-factor, repeated measures ANOVA was used to examine differences in postural angles among the weights after walking 6 minutes, followed by Pairwise comparisons (paired t-test) to examine the effects at each weight.

Research question 2: To answer the question of how loaded backpacks affect the functional walking endurance of the children who carry them, a one factor, repeated measures ANOVA was used to examine differences among the weights in OMNI perceived exertion scores after walking 6 minutes with load, followed by Pairwise

comparisons (paired t-test) to examine the effects at each weight. A one factor, repeated measures ANOVA was used to examine differences among the weights in the 6MWT (or distance walked in 6 minutes) while carrying a loaded backpack, followed by Pairwise comparisons (paired t-test) to examine the effects at each weight.

Research Question 3: To answer the question of how the loaded backpacks affect pain severity as measured by VAS at different anatomical locations, a one factor, repeated measures ANOVA was used to examine the differences in severity of pain at the neck, shoulder, mid back and low back, followed by Pairwise comparisons (paired t-test) to examine the effects at each weight.

Research Question 4: To answer the question “what is the recommended weight limit for backpacks carried by elementary school children ages 8 to 11?” the results were examined to identify a maximum backpack weight limit based on the minimal amount of backpack weight (of those tested) resulting in a significant difference in each outcome measure.

Chapter 2: Effect of Backpack Weight and Condition on Cervical Posture in Primary Schoolchildren

Background

Backpack use for carrying objects is commonplace among students of all ages⁶ with roughly 40 million students carrying backpacks weighing up to 46% of their body weight.^{2,209} Backpack use by school children has increased recently due to several factors including decreased availability of school lockers as a result of vandalism and security concerns,^{4,9} increased homework,⁴ larger textbooks,⁴ and other objects being carried to school⁶, all leading to both an increase in weight and duration of carriage.^{4,9} Postural compensations are required for the maintenance of balance and functional movement when carrying a loaded backpack. Postural compensations due to backpack carriage include an increased forward head position and an increased forward lean of the trunk as well as changes in pelvic positions and gait patterns.⁷ Other spinal effects reported include spinal creep,¹⁰⁹ asymmetrical spinal alignment during mechanical loading, and possible disc degeneration.¹⁰⁷ Studies of children and adolescents state a clear association between backpack load and measurable kinematic responses as well as physiological responses including cardiovascular, pulmonary, metabolic and nerve function changes^{12,63} and response in lung volume.¹⁰

Studies examining the effects of the weight of backpack loads on the cervical and shoulder postures of students have found that backpack weights of greater than 10% to 15% body weight (BW) result in increased forward head postures (FHP), preventing adolescents from maintaining an upright standing posture.^{10,12,210} Studies by Lai and Pascoe et al found significant changes in FHP at 15%BW loads, suggesting that postural responses in adolescents are sensitive to loads of 15%BW, and supporting the theory that

heavy loads have a significant effect on postural alignment.^{7,10} Chansirinukor et al found a significant decrease in the craniovertebral angle (CVA) after a 5 minute walk with the student carrying a backpack containing 15%BW load indicating that the duration of load carriage as well as the weight of load influences forward head posture.¹² Grimmer et al found significant relationships between backpack weight and forward head posture as measured by CVA, with the greatest differences in younger children, as well as a significant association between heavy backpack weights and complaints of spinal pain in adolescents.¹¹⁴ The recorded differences in the children's CVA measures placed 35% of the children in this study as being "at risk" for cervical complaints due to spinal stresses.¹¹⁴ The amount of change in the children's CVA measure amount is associated with headaches in adult women.¹¹³

As early as the 1960's, research with school children examined the physiological effect of carrying schoolbags, and resulted in the recommendation of a backpack weight limit of 10% body weight^{3,94,124} due to the changes in metabolic cost⁹⁴ and concerns that heavy loads may have a significant effect on postural alignment.⁷ Despite suggested maximum weight limits of 10%BW,^{3,94,124} studies around the world indicate great variety in the actual backpack weights carried by children of all ages.^{8,12,13,86,97,211} Studies worldwide have revealed a large proportion of these children carrying backpacks with loads far greater than 10% of body weight.^{2,11,97,98,114} Negrini et al found the daily load carried by Italian schoolchildren averaged 22% of bodyweight with a maximum of 46.2%.⁹⁷ One third of these children carried backpack weights that exceeded the 30% body weight/load ratio proposed for physically fit adults.^{6,97,98} In Hong Kong, local schoolchildren reportedly carry bags weighing approximately 20%BW.^{95,99}

A significant concern for medical practitioners and parents of today's children is the recognition that a history of back pain in youth is a strong predictor for musculoskeletal discomfort and back pain in adults^{13,38,93} and prolonged, repetitive strain may predispose children to back pain in their adult lives.¹² Researchers report that low back pain has been experienced by up to 51% of children.^{6,50,57,211,212,213,214,215} Additionally, complaints of back pain, shoulder pain, and muscle soreness have been reported among school aged children.^{11,49}

Child and adolescent spines are still developing, and have different spinal structures than adults.¹² External forces, such as the carriage of a backpack load, may affect the development of normal and correct skeletal alignment.¹² The repetitive carriage of excessively heavy backpacks on young bodies may be deleterious as the spinal ligaments and muscles are not fully developed until after 16 years of age.¹⁰ Both backpack weight and duration of time spent carrying a loaded backpack are risk factors for nonspecific back pain in youth.^{8,11,19} The relationship between the carrying of heavy backpack loads and reports of low back problems and pain has been identified for both children and adults.^{2,7,19,49,56}

Several professional medical organizations have expressed concerns and offered suggestions regarding the carriage of heavy backpacks by children including the American Physical Therapy Association, American Academy of Orthopaedic Surgeons, American Chiropractic Association, and American Occupational Therapy Association.^{169,170,171,172} Although children are considered a protected population in terms of scientific research, they are not protected from the excessive backpack loads carried for educational purposes in everyday life. While government agencies have

clearly stated guidelines to limit adults from carrying excessive loads, there are no government recommendations for weight limits for children's backpacks.

The purpose of this study was to examine the effects of carrying a backpack in elementary schoolchildren, and investigate the subsequent changes in forward head posture as measured by the craniovertebral angle and subjective complaints of pain due to backpack load and condition after walking for 6 minutes (replicating the estimated time required to walk from school entrance to classroom).

Methods

Design

This study was a two-factor (backpack load and condition) repeated measures design, with the subjects serving as their own controls. Each subject participated in all 3 backpack load conditions over three consecutive weeks of data collection.

Subjects

Subjects were recruited from flyers distributed to the 3rd to 5th grade classes as a local elementary school, as well as to local youth group. A convenience sample of eleven healthy primary schoolchildren, 8 female, 3 male, ages 8 through 11 (mean age = 9.7 ± 1.01 years) agreed to participate in this study after both a parental consent form and a youth assent form were signed. Subject demographics are listed in Table 2.1. Subjects were excluded if they presented with clinical presentation suggestive of serious pathology, or reported a history of a recent systemic illness, a neurological/muscular degenerative disorder, a stated pre-existing condition that prevented load carriage of a backpack using both shoulder straps, or a history of low back pain complaints. Subjects

were excluded if they could not participate in the study over three consecutive weeks and be present for all three data collections. This study was approved by the University of Miami Institutional Review Board.

Measures

The Craniovertebral angle (CVA) has been used in studies examining posture, headaches, temporal-mandibular joint dysfunction, as well as numerous backpack studies.^{12,62,114,115,116,198} The CVA is formed by the intersection of a line from the spinous process of C7 and the tragus of the ear (identified via the reflective markers) and a horizontal reference line^{12,84} as shown in Figure 2.1.

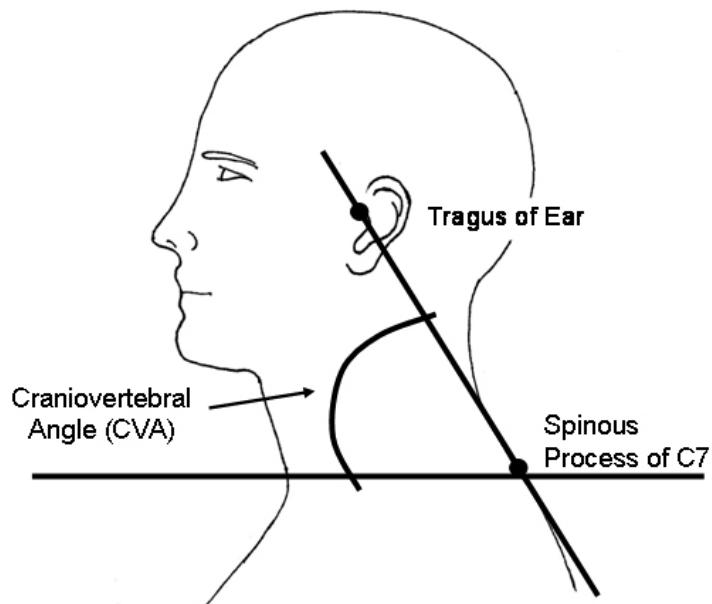


Figure 2.1 The Craniovertebral Angle (adapted from Chansirinukor et al, 2002¹²)

A smaller measurement indicates a more forward head position. A larger measurement indicates a more normal, upright, neutral head position. Resting (unloaded) head CVA measures for children range from 45.8 degrees in 10 year old children¹¹⁶ to

56.7 degrees in 13 to 16 year old children.¹¹⁵ The CVA decreases with increasing age in adulthood,¹⁹⁹ with adult resting CVA measures ranging from 51.8° in young adults (33-50 years) to 45.1° in older adults (50.1-69 years).⁶² The CVA is used for measuring forward head posture and is a highly observable response to a backpack.^{12,114,115,116} To assess changes in forward head positions due to load and fatigue, the cranivertebral angle was measured through the use of reflective markers and digital photography. The CVA has demonstrated high reliability and very high intrarater and interrater reliability for measurement of forward head posture.²⁰⁰ Various studies have utilized photographic analysis of posture to obtain clinical measurements of sagittal postural angles.^{197,198,200} Digital photography enables researchers to examine and measure various postural angles in a non-invasive manner.

The subjective complaint of “soreness” or pain intensity in the neck, mid and low back regions were measured after each walking trial using a 0 to 10 visual analog scale (VAS). The VAS has been shown to produce reliable information in youth.¹⁹⁰ See Appendix 5. The scale is divided into equal increments beginning with “no pain (“0”) and ending with “worst pain” (“10”). The post-walk pain survey displayed a body chart (modified from Young¹⁸⁹) with an arrow indicating neck, mid and low back regions to enable localization of pain. This survey was used after the final photograph was taken and the backpack had been removed.

Procedure

After each subject was enrolled in the study, basic anthropometric measurements were taken including age, height and weight. The subject’s weight was taken at the

beginning of each session to ensure accurate backpack loading as a percentage of the child's weight for each data collection date. Subjects then completed an initial questionnaire to obtain basic demographic information, followed by the placement of adhesive reflective markers on the spinous process of C7 and on the left side of the body at the following locations: the tragus of the ear, the acromion-clavicular joint, the greater trochanter, the lateral knee joint line and the lateral malleolus (visible in Figure 2.2). The markers were placed by an experienced Physical Therapist. A randomization table was used to determine the order of the backpack loads of 10%, 15% or 20% of the child's body weight (BW) across the three testing sessions. The backpack load was created through the use of school textbooks of various weights which were placed into the backpack with the largest books closest to the subjects back and secured with strapping to provide a stable, static load.

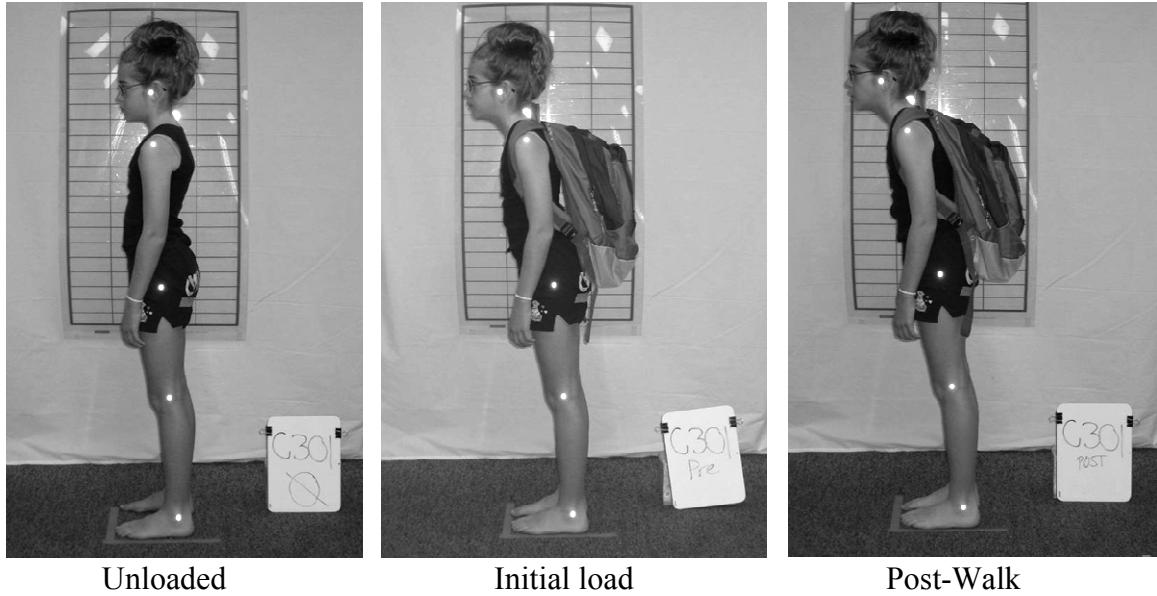


Figure 2.2 Backpack Conditions Tested

Subjects were photographed as they stood at an “L” marked on the ground in front of a posture chart. The lateral edge of the left foot was lined up along the longer length of the L, and the toes were placed at the edge of shorter length of the L as viewed in Figure 2.2. A digital camera was set on a tripod, 120cm high and 3 meters from the inverted L and a digital photograph was taken of the left-sided profile (sagittal view) of the subject. An identification tag was placed within photographic range with the subject’s ID and a code to identify the backpack condition being photographed.

Photographs were taken according to protocol set forth by Grimmer⁸⁴ and adapted for this study. Subjects looked directly ahead at a target while a photograph was taken with a digital camera 3 meters away fixed on a tripod. The 5.0 megapixel camera¹⁷⁸ with a resolution of 1600x1200 was set at the height of the subject’s shoulder. A level was used to maintain the camera’s position between sessions. The digital photographs were analyzed using Image Tool V.3 by The University of Texas Health Science Center at San Antonio (UTHSCA).¹⁸⁰

Subjects were photographed three times on each data collection date as illustrated in Figure 2.2. The first photograph was taken for baseline postural measurements as the subject stood without a backpack (unloaded condition). The subject was asked to stand as “normally” as possible with their feet placed along the “L” marked on the floor as discussed above, while viewing an object placed at eye level in front of subject. The subjects then donned a backpack containing the randomly assigned load. The backpack straps were adjusted so the top of the straps were aligned with the top aspect of the subject’s shoulders. A second photograph (initial load condition) was immediately taken once the backpack was positioned upon the subject’s midback, while the subject stood at

the L on the floor as above. Subjects were then directed to walk around a marked level walking area for 6 minutes at a comfortable walking speed while carrying the loaded backpack. After walking, subjects stood at the “L”, as before, and a third photograph (post-walk condition) was taken. To limit the effects of fatigue during repeated trials in one day, subjects returned during the next two consecutive weeks to repeat the study using the remaining randomly assigned weights of 10%, 15%, or 20%BW.

Data Analysis

Microsoft Excel was used to create the database and statistical analysis was completed using SAS 9.1.3.²⁰⁸ A two factor repeated measures ANOVA followed by post-hoc pairwise comparisons was used to test for the main effect of backpack load weight, the main effect of backpack load condition, and a weight x condition interaction. Results were considered significant at the 0.05 level of confidence.

Results

Craniovertebral Angle

A repeated measures ANOVA was used to examine the changes in CVA caused by various load weights (10%, 15%, 20%), followed by post hoc pairwise comparisons to compare changes due to weight and condition. For the unloaded condition, the mean CVA was $49.2^\circ \pm 1.0$. There was no significance differences the between baseline CVA measures taken at the beginning of each day of data collection ($p = .549$). The mean CVA angles for each weight and condition are listed in Table 2.2.

The interaction between weight and condition was significant ($F(4,40) = 2.54, p < .054$) indicating that there was a difference in the change in forward head posture across the wear time conditions. See Figure 2.3. A main effect of weight ($F(2, 20) = 4.78, p < .0201$) was observed between the backpack weight conditions (unloaded, 10%, 15%, 20%BW). At initial loading, there were immediate and statistically significant changes in CVA for the 15%BW and 20%BW backpack loads ($p = .0002$ and $p = .014$ respectively), but not for the 10%BW load. A main effect of backpack condition ($F(2, 20) = 18.34, p < .0001$) was observed between the conditions (unloaded, initial loading and post-walk). Pairwise comparisons identified significant differences in the CVA measures due to condition and are listed in Table 2.3. The difference in the CVA measures between the 10%BW and 20%BW loads at initial loading was statistically significant ($p = .0304$). None of the backpack load comparisons were significant for changes in CVA between initial loading and post-walk. After walking 6 minutes with the loaded backpacks, there were significant differences in the CVA measures from unloaded to post-walk for all 3 weight conditions (10%BW: $p = .0035$; 15%BW: $p = .0008$ and 20%BW: $p = .0065$ respectively). Finally, at post-walk, there were no statistically significant differences in the CVA measures between any of the backpack weight conditions ($p = .2668$).

Perceived Discomfort

The percentage of responses and mean pain scores after walking are listed in Table 2.4. The 10%BW load resulted in 45% of the subjects reporting pain after walking. The neck was the primary location of pain for 36% of the subjects with a mean visual analog scale (VAS) rating of 2.5 ± 1.91 after carrying the 10%BW load. At the 15%BW

load, 73% of the subjects reported neck pain after walking with the backpacks, with a mean VAS rating of 3.9 ± 2.17 . Another 45% of these subjects identified their mid back as the location of pain with a mean VAS of 3.2 ± 1.79 . After carrying the 15%BW load, 27% of the subjects reported pain on the low back with a mean VAS of 5.0 ± 1.73 . At the 20%BW load, general discomfort was reported by 73% of the subjects after walking. The neck was again the primary location of pain for 64% of the subjects with a mean VAS of 5.3 ± 2.62 , followed by the mid back for 45% of the subjects (mean VAS of 4.2 ± 1.64) and the low back for 27% of the subjects (mean VAS of 5.0 ± 1.73).

Discussion

The purpose of this study was to examine the effects of carrying a weighted backpack on forward head position and subjective complaints of pain in elementary schoolchildren. This study identified a unique relationship between various backpack weights, condition and the forward head postural compensation in schoolchildren ages 8 and 11 years of age. The donning a 10%BW backpack load, which is the suggested weight for children's backpacks, did not immediately decrease the CVA. The 15%BW and 20%BW loads immediately decrease the CVA at initial loading. After walking 6 minutes, the CVA decreased further for both the 10% and 15%BW loads, but not for the 20%BW load. After walking 6 minutes, there were no significant differences in the post-walk CVA among the backpack loads. Although the recommended 10% load is preferred initially, the forward head posture demonstrated after walking with the lighter 10%BW load is equivalent to the forward head posture demonstrated after walking with a heavier 20%BW load.

Donning of the weighted backpacks resulted in changes in the CVA measures for all weight conditions, ranging from a difference of 0.25° (at 10%BW) to 6.39° (at 20%BW). After walking for 6 minutes, the mean change in CVA from unloaded to post-walk ranged from 3.53° (at 10%BW) to 7.16° (at 20%BW). These differences, reported in Table 3, represent a magnitude of (or percent of) change up to 14.2% from the unloaded CVA measures and indicate the high responsiveness of children's postures to external load influences. The larger differences in CVA both before and after walking for the 15%BW and 20%BW loads closely approximate the mean differences found by Watson and Trott (4.8°)¹¹³ and Yip (5.1°)⁶⁸ in adults with and without headaches, potentially putting the children at risk for headaches.^{68,114} These responses are consistent with previous studies identifying decreased CVA measurements with increased backpack loads, indicating a more forward head.^{114,115,116} Additionally, Grimmer reported significant associations between heavy backpack weights and complaints of spinal pain in adolescents.¹¹⁴

In this study, the forward head response was increased after a period of walking in addition to the backpack weight, consistent with the findings of Chansirinukor.¹² In this investigation, the 10%BW load did not result in an immediately statistically significant change in forward head postures, there was a statistically significant change after walking for 6 minutes, indicating that for lighter loads, the condition of time spent carrying the load also influences forward head postures. Additionally, Lai found that cervical and shoulder postures were influenced by both amount and duration of weight carried by a backpack, suggesting that potential problems may occur from backpack weights greater than 10%.¹⁰ Orloff & Rapp's examination of spinal curvature and load carriage of a

13.8%BW backpack found significant increases in the thoracic & lumbar spinal curvatures as the subjects fatigued while carrying the weighted backpack.⁵⁶ The present study found a strong interaction of backpack weight and condition on CVA measures. Larger backpack weights had an immediate effect on forward head posture while lower weights produced a similar forward head posture when worn for a longer period.

The final head positions for all three load conditions after walking 6 minutes were not significantly different, suggesting a common endpoint of forward head position for backpack loads up to 20% body weight load or perhaps a “maximum forward head position”. This has not been discussed in prior studies and calls for further investigation. Interestingly enough, while many medical associations recommend setting backpack limits at the lighter load of 10%BW, this study has identified that the forward head position after walking with a 10%BW load resulted in a similar forward head position as measured after walking with a 20%BW load. This suggests that lighter loads may have a greater impact on children’s posture than previously expected.

In this investigation, walking with loaded backpacks resulted in subjective complaints of pain for all backpack loads tested. For the 15% & 20%BW conditions, more than 50% of the subjects reported discomfort after walking, with the neck as the primary location of reported pain. Children reported higher pain levels with increased backpack loads during a study examining lumbar disk height changes due to 10%, 20%, and 30%BW backpack loads in children.¹¹¹ Significant changes in the height and symmetry of the disks as well as a linear correlation of backpack load to compression of the intervertebral discs were observed at each spinal level from T12-L1 to L5-S1.¹¹¹ Previous studies have demonstrated links between backpacks, forward head posture and

pain or headaches with changes in CVA greater than 4.8° .^{68,114} Further examination of these subjective complaints in children in relation to posture and backpack use is warranted.

Neck pain in youth has a cumulative annual incidence of 28.4% among adolescents 12 to 16 years of age,¹¹⁴ with 50% of children 12 to 18 years olds reporting occasional symptoms of neck and upper limb pain.^{17,21} While roughly half of the children in this study reported discomfort after walking with the 10% and 15% body weight loads, almost 75% of the children reported discomfort after carrying the 20%BW load for 6 minutes. Across all loads tested in this study, the neck was the primary location for pain, followed by the mid back. Studies in the United States and Europe report that children are carrying 17%, 20% and 22% backpack loads, with maximum weights as high as 41% and 46%BW.^{4,7,11,57,97} Forward head posture has been associated with neck pain, headaches and disability in adults,^{17,62,66,67,68} radiating pain into the head and temporal-mandibular joint,^{17,21} changes in respiratory accessory muscle activity and changes in the resting positions of the tongue and mandible.⁶⁹

This was a pilot study, designed to examine the effects of backpack weight and condition on the forward head postures of children. Future research should investigate the effects of weighted backpacks on children including examination of forward trunk lean, pelvic tilt, and tragus-to-vertical measurements, in an effort to develop a clinical measurement to identify those children at risk for later problems. Results from studies like this can contribute to the body of knowledge and be useful in establishing backpack weight limits for children, similar to those weight limits for adults. While government agencies have clearly stated regulations to limit adults from carrying excessive loads,

there are only recommendations for weight limits for children's backpacks.

Child and adolescent spines are still developing, and are different from the spinal structures of adults.¹² External forces, such as a backpack load may affect the development of normal and correct skeletal alignment.¹² The forward head position reported here as a compensatory response to carrying a loaded backpack may have far reaching consequences into adulthood as children are subjected to carrying heavy backpacks on a regular basis for educational purposes. Clinicians and parents should be aware of the amount of weight and time that children spend carrying loaded backpacks, as they may be carrying relatively excessive backpack loads on their immature spines and consequently biasing these undeveloped bodies for potential injury. Hong et al suggested the altered biomechanics required by children to carry increased loads on a daily basis "might be harmful and influence their normal musculoskeletal developmental growth" and recommended a backpack load limit of 10% body weight "since it causes the least disturbance of metabolic processes."⁹⁵ In this study, the 10%BW backpack load affected postural responses the least, while the 15% and 20%BW loads resulted in forward head positions which put the children at risk for headaches. This study supports a backpack load weight limit of 10% body weight for children.

Limitations

Limitations of this study included a small sample size and external influences while the children walked. The researcher was consistent in the cues given to "walk a regular, comfortable pace" however, siblings or parents would occasionally encourage the child to walk faster, possibly affecting the rate of fatigue of the subject. The subjects

were blinded to the percentage of weight being carried. The researcher was careful to maintain neutrality when speaking to the subjects in order to minimize risk of influencing their responses during the study.

Conclusion

The present study demonstrates the increased forward head posture observed in children while carrying loaded backpacks are associated with both backpack weight and condition. The greatest differences were noted at the 15% and 20%BW backpack loads with initial loading, but after 6 minutes of walking the forward head posture was similar for all backpack loads. Further analyses of the changes in forward head posture suggest that the condition as well as the weight of backpack loads markedly affect forward head posture and present a risk for neck pain in children.

Acknowledgements:

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Table 2.1 Subject Demographics (N=11)

Variable	Mean (SD)	Minimum	Maximum
Age (years)	9.7 (1.0)	8.0	11.0
Height (cm)	135.3 (9.7)	119.4	151.1
Mass (kg)	31.3 (7.3)	22.8	43.2
BMI	16.9 (2.5)	14.4	22.8
Unloaded CVA	49.2 (4.3)	42.0	58.5

Table 2.2 Mean (SD) and range (in degrees) of Craniovertebral Angles (CVA) at each weight and condition

		Backpack Load (as a percentage of bodyweight)		
Condition		10%BW	15%BW	20%BW
Unloaded	Mean	48.4 (4.2)	49.9 (4.3)	49.2 (4.8)
	Range	43.3 – 57.6	42.0 – 56.7	43.2 – 58.5
Initial Load	Mean	48.2 (6.2)	45.3 (4.8)	42.8 (5.3)
	Range	39.6 – 60.5	38.2 – 52.5	30.1 – 50.4
Postwalk	Mean	44.9 (4.5)	42.8 (5.7)	43.4 (5.1)
	Range	38.4 – 52.7	36.9 – 52.5	34.7 – 51.5

Table 2.3 Pairwise Comparisons of Craniocervical Angle (CVA).

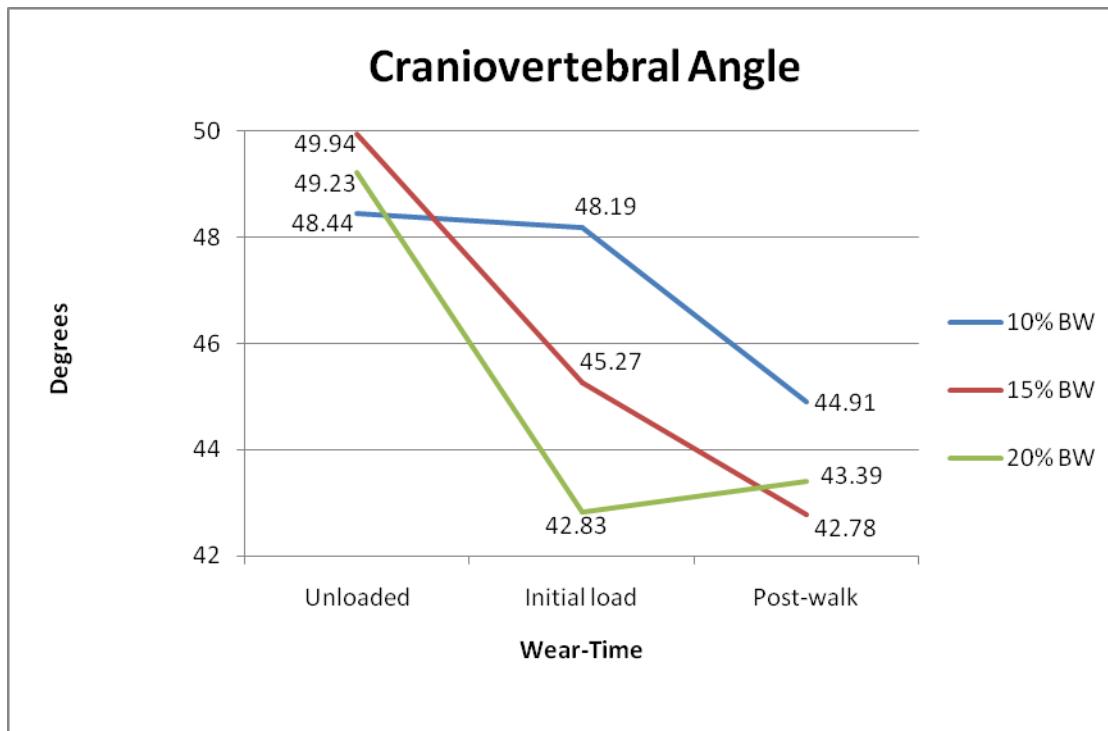
	10%BW Backpack	15%BW Backpack	20%BW Backpack
Unloaded vs Initial loading			
Mean difference (SD)	0.25° (6.8)	4.67° (2.8)	6.39° (7.1)
P value	.9055	.0002	.0141
Percent change	0.5%	9.4%	13.0%
Initial loading vs Post Walk			
Mean difference (SD)	3.28° (5.6)	2.49° (4.0)	-0.56° (4.2)
P value	.0804	.0680	.6697
Percent change	6.8%	5.5%	1.3%
Unloaded vs Post walk			
Mean difference (SD)	3.53° (3.1)	7.16° (5.0)	5.84° (5.7)
P value	.0035	.0008	.0065
Percent change	7.3%	14.3%	11.9%

Table 2.4 Mean pain scores and percentage of responses of pain Reported after 6MWT carrying a weighted backpack (N=11)

	10%BW load	15%BW load	20%BW load
Overall pain	45 %	55 %	73 %
Neck	36 %	73%	64%,
Mean VAS (SD)	2.5 (1.91)	3.9 (2.17)	5.3 (2.6)
Mid Back	36 %	45 %	45 %
Mean VAS (SD)	3.5 (1.29)	3.2 (1.8)	4.2 (1.64)
Low back	18 %	27 %	27 %
Mean VAS (SD)	2.0 (1.41)	5.0 (1.73)	5.0 (1.73)

(Survey allowed multiple responses)

Figure 2.3 Craniovertebral Angles while carrying a loaded backpack at Unloaded, Initial load and Post-walk, after six minutes of walking at normal, free walking speed.



Chapter 3: Postural Compensations and Subjective Complaints Due to Backpack Loads and Wear Time in Schoolchildren Aged 8 to 11

Background

Backpacks are commonly used in the United States by more than 40 million students,^{2,3} 1.4 million active military personnel,⁹⁰ 34 million hikers⁹¹ and 4 million registered Boy Scouts and Boy Scout leaders.⁹² Increased complaints about back, neck and shoulder pain have resulted in increased research about the effects of heavy backpack load carriage on children.^{4,5,6,7,8,9,10,11} Backpack use by school children has increased recently due to several factors including decreased availability of school lockers as a result of vandalism and security concerns,^{4,9} increased homework,⁴ larger textbooks,⁴ and other objects being carried to school,⁶ all leading to both an increase in backpack weight and amount of time spent carrying backpacks.⁹

Backpacks are associated with kinematic and physiological changes, as well as complaints of back and neck pain. There is concern about children developing backpain due to backpack use, as a history of backpain in childhood is the strongest predictor of having musculoskeletal discomfort and back pain as an adult.^{12,13,45,46,47,93} Studies examining back pain prevalence in adults report a one-year prevalence of an episode of low back pain at 50%, with a lifetime prevalence of low back pain of 70-80%,^{38,39,40} while the lifetime prevalence of low back pain in children ranges from 12% in 12 year olds to as high as 74% in 17 year old students^{11,44,49,50,51,52}. Backpacks have been linked to low back problems and pain in youth^{2,19,49,56} with the identification of both weight and duration of backpack carriage as a risk factor for nonspecific back pain in youth.^{8,11,19} Negrini et al's examination of Italian youth found 46.1% of the 6th graders studied

reported back pain caused by their school backpacks.⁸ The severity of back pain has caused approximately 16-23% of children to miss school activities or seek medical attention.^{9,44,57,58}

Neck pain is a common complaint, with one year prevalence over 37% for adults, and women reporting neck pain more frequently than men in 23 of 30 studies examined by Fejer.⁶¹ Neck pain in youth has a cumulative annual incidence of 28.4% among adolescents 12 to 16 years of age,⁴⁹ with 50% of children 12 to 18 years olds reporting occasional symptoms of neck and upper limb pain.^{17,21} School backpacks weighing more than 15% to 20% of a child's body weight (BW) are associated with back pain, and improper use of the backpack can result in changes of posture and gait.⁶ Studies have reported children in the United States carry backpack loads ranging from 17%BW⁷ and 20%BW to 41%BW.¹¹ Children in France carry an average backpack load of 19%BW with a maximum of 38%BW,⁵⁷ while Italian children average 22%BW with a maximum reported backpack load of 46.2%BW.⁹⁷

Children demonstrate postural compensations to maintain a relatively upright position while carrying a loaded backpack. A classic compensation is an increased forward head position (FHP) which generally involves cervical spine hyperextension, with shortened cervical extensors and lengthened cervical flexors,¹⁷ and protraction of the head forward from neutral which changes the alignment of the anterior and posterior neck muscles. The FHP is associated with increased tension, fatigue and compressive forces within the posterior cervical region.⁶⁹ The forward head position is measured by the craniovertebral angle (CVA), which is formed by a line from the tragus of the ear to the spinous process of C7 and the horizontal, intersecting at C7. A smaller CVA

measurement indicates an increased forward head position. A larger CVA measure indicates a more upright, erect head and neck posture.¹²

To maintain a relatively upright posture and keep one's eyes level with the horizon in response to carrying a loaded backpack, children also demonstrate a forward trunk lean (FTL). One study examining postural responses to backpack loads in 12 to 13 year old boys found statistically significant increases in forward trunk lean at a 5%BW backpack load.¹¹⁹ Results of gait studies indicate forward trunk lean increases during stance and gait with backpacks of 10%, 15% and 20%BW in 9 year old children.¹²⁰ A direct relationship between backpack weight and forward trunk lean during walking has also been noted in children carrying backpack loads of 15% and 25%BW.¹¹⁷ An examination of the trunk postures and peak lumbosacral forces of young adult men carrying 15% and 30% backpack loads during gait found increased trunk flexion (or forward trunk lean) and lumbosacral forces for both loads compared to unloaded gait. The 15%BW load produced a 7.8° compensatory flexion movement, and the 30%BW backpack load generated a 12.6°compensatory flexion movement. The average forward trunk lean angle while carrying the 30%BW load was 4.26°. As the same time, the weighted backpacks resulted in peak lumbosacral forces of 26.7% and 64% greater than unloaded lumbosacral forces (for the 15% and 30%BW loads respectively) during walking.¹¹⁸

The purpose of this study was to examine 1) the effects of backpacks weight (up to 20%BW) on children's posture as measured by changes in the cranivertebral angle, the forward trunk lean angle and pelvic tilt, subjective complaints of pain and walking endurance; 2) the effects of backpack weight (up to 20%BW) on the reports of perceived

exertion (or fatigue) and aerobic endurance (walking distance) after walking 6 minutes; and 3) the effect of backpack weight (up to 20%BW) on pain severity as measured by VAS at different anatomical locations after walking for 6 minutes. In addition, a final goal was identify and recommend a weight limit for backpacks carried by elementary school children based on the evidence.

Methods

Design

This study used a two-factor repeated measures design, with the subjects serving as their own controls. Over three consecutive weeks, subjects were randomly assigned backpacks weighting 10, 15 or 20 percent of their body weight. Measurements were taken prior to donning the backpack (unloaded), immediately after donning the backpack (initial load) and after 6 minutes walking with the backpack (post-walk).

Subjects:

Subjects were recruited from flyers distributed to the 3rd to 5th grade classes as a local elementary school, as well as to local youth group. A convenience sample of 62 healthy primary schoolchildren, 41 female, 21 male, ages 8 through 11 (mean age = 9.77 ± 1.07 years) met criteria to participate in this study after both a parental consent form and a youth assent form were signed. Subject demographics are listed in 3.1. Subjects were excluded if they reported or presented with clinical presentation suggestive of serious pathology, a systemic illness, neurological/muscular degenerative disorders, a stated pre-existing condition that prevented them from carrying a loaded backpack using both shoulder straps, or a history of low back pain

complaints limiting backpack use. Informed consent and assent were obtained for all subjects.

Sample size was estimated for a paired t-test comparing postural angle differences for the three backpack loads on the initial and post walk measure differences. The calculation was based on a large effect size ($d=0.70$). Based on an alpha level of 0.05, 60 subjects were required to achieve a power of 0.80. A total of 64 subjects were screened, met criteria and enrolled in this study. Two subjects did not fully complete the study: one subject participated in all baseline testing but withdrew before the backpack component of the study. The other subject missed the last day of data collection due to a scheduling conflict. 62 subjects were included in the data analysis.

Procedure

After consent was given and each subject was enrolled in the study, basic anthropometric measurements including age, height, weight and the weight of each subjects' own school backpack were recorded. The subject's weight was taken at the beginning of each session to ensure accurate backpack loading as a percentage of the child's weight for each data collection date.

For the postural angle measurements, adhesive reflective markers were placed on the spinous process of C7 and on the left side of the body at the following locations: the tragus of the ear, the acromion-clavicular joint, the greater trochanter, the anterior superior iliac spine, the posterior superior iliac spine, the lateral knee joint line and the lateral malleolus (visible in Figure 3.1) by an experienced Physical Therapist.

Subjects stood on a thin pad of paper at an “L” marked on the ground in front of a posture chart. The lateral edge of the left foot was lined up along the longer length of the L, and the toes were placed at the edge of shorter length of the L as viewed in Figure 3.1.

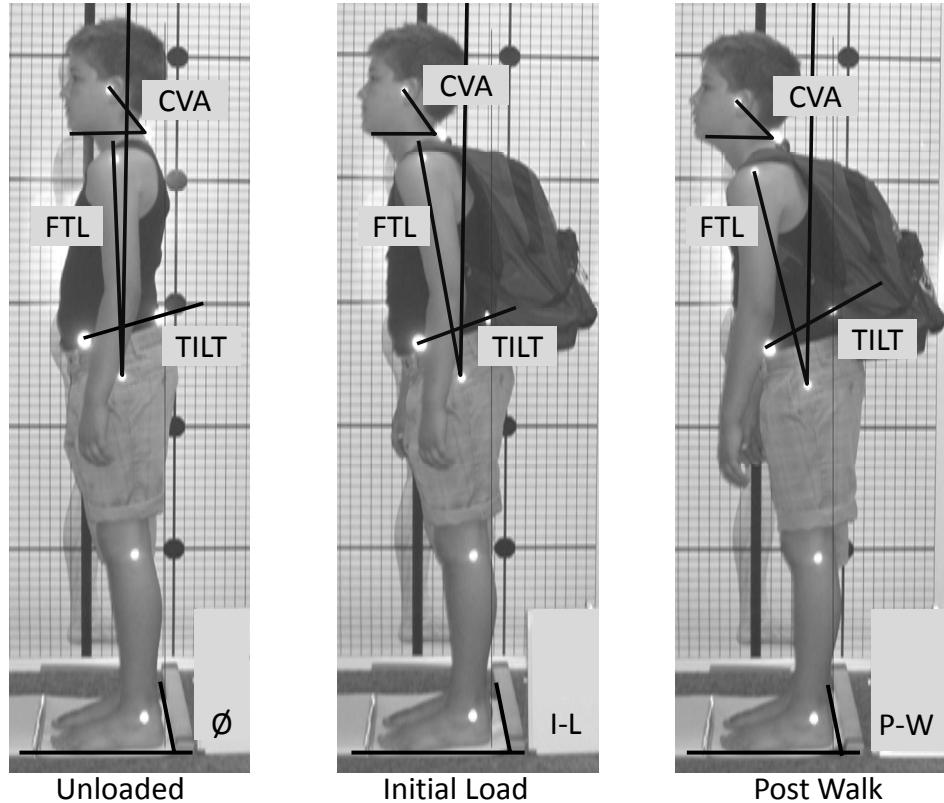


Figure 3.1. Craniovertebral Angle, Forward Trunk Lean, and Pelvic Tilt angles at Unloaded, Initial Load, and Post Walk.

The subject’s feet were traced while he/she stood unloaded on the paper, prior to donning a backpack. The paper was marked with the subject’s ID number so that the subject’s position would be consistent across all trials. A digital camera was set on a tripod, 120cm high and 3 meters from the inverted L and a digital photograph was taken of the left-sided profile (sagittal view) of the subject. An identification tag was placed

within photographic range with the subject's ID and a code to identify the condition being photographed.

Photographs were taken according to protocol set forth by Grimmer⁸⁴ and adapted for this study. Subjects looked directly ahead at a target while a photograph was taken with a digital camera 3 meters away fixed on a tripod. The 5 megapixel camera¹⁷⁸ with a resolution of 1600x1200 was set at the height of the subject's shoulder. A level was used to maintain the camera's position between sessions.

The backpack load was created through the use of school textbooks of various weights which were placed into the backpack with the largest books closest to the subjects back and secured with strapping to provide a stable, static load. A randomization table was used to determine the order of the backpack loads of 10%, 15% or 20% of the child's body weight (BW) across the three testing sessions. The actual data collection procedure required several steps.

Step 1: After baseline anthropometrics were measured, the subject walked for 6 minutes at a comfortable self-paced speed without a backpack to provide a baseline comparative 6MWT measure. At the end of the 6 minutes, the distance walked was recorded and an OMNI score of perceived exertion was obtained. This was followed by a rest period during which the subject completed the initial questionnaire with the primary researcher.

Step 2: The reflective markers were placed along the left side of the subject's body as discussed above. In the meantime, the backpack was prepared with the randomly assigned backpack load.

Step 3: The subject stood on the pad of paper at the L in front of the posture graph and his/her feet were traced, prior to donning a backpack. A photograph (“unloaded”) was taken of the left side of the subject while he/she stood unloaded. The subject was asked to stand as “normally” as possible (See Figure 3.1) while viewing a target placed at eye level in front of subject.

Step 4: The subject donned the backpack, positioned with the center of the load approximately at the level of T10, and a second photograph (“initial load”) was taken immediately while the subject stood at the L, on their traced footprints. The subject was then asked to walk for 6 minutes at a comfortable self-paced speed while wearing the backpack around a marked course.

Step 5: At 6 minutes, the distance walked was recorded and an OMNI score was obtained. The subject returned to the photograph location, stood on their traced footprints, looked ahead at the target and a third picture (“post-walk”) was taken. The backpack was removed and the subject completed a post-walk pain survey. The subject received a token prize after completing each data collection session.

To limit the effects of fatigue during repeated trials in one day, subjects returned during the next two consecutive weeks and were retested with the remaining randomly assigned backpack weigh conditions. After data collection was complete, the digital photographs were analyzed by an independent researcher using Image Tool V.3 by The University of Texas Health Science Center at San Antonio (UTHSCA).¹⁸⁰

Outcome Measures

The Six Minute Walk Test (6MWT):

The Six Minute Walk Test measures the distance that a subject or patient can quickly walk on a flat, hard surface in 6 minutes. The 6MWT is a measure of the functional exercise capacity as it is able to quantify functional endurance and is sensitive to change.¹⁹² Originally developed for use with patients with pulmonary disease, the 6MWT has been used in epidemiologic research with a variety of patient populations, including adults with heart failure, cystic fibrosis, and liver transplants as well as children with pulmonary hypertension, cystic fibrosis and organ pre-transplant assessment^{179,193} and spinal muscular atrophy.¹⁹² For the current study, the 6MWT provides insight regarding functional walking endurance in children in response to walking with a loaded backpack.

The 6MWT is easy to use, low cost and clinically accessible without requiring expensive equipment, and has been established as a reliable and valid functional test for assessing exercise tolerance and endurance in children.¹⁹⁴ Normative values have been established for the 6MWT for children 4-11 years old,¹⁹⁵ 7-16 years old¹⁹⁴ and 3-18 years old.¹⁹⁶ Subjects were instructed to “walk at a comfortable pace” for 6 minutes around a marked “course” indicated by red cones. The distance walked in 6 minutes was recorded. An unloaded 6MWT was administered on the first day of data collection, prior to donning of a weighted backpack to obtain baseline, normative values of the unloaded 6MWT in this sample population.

Children's OMNI-Walk/Run Scale:

The Children's OMNI Walk/Run Scale is a scale of perceived exertion that contains both pictorial and verbal descriptors that correspond with a numerical response range of 0 to 10 representing the exercise-related feelings of fatigue.¹⁸² It is a valid measure of psychophysiological responses in children and has been correlated with VO₂ max & heart rate in children 6 to 13. Prior studies have utilized BORG and BORG CR10 scores with older subjects, finding increased ratings of perceived exertion with increased backpack loads carried.^{1,184,185,186,187}

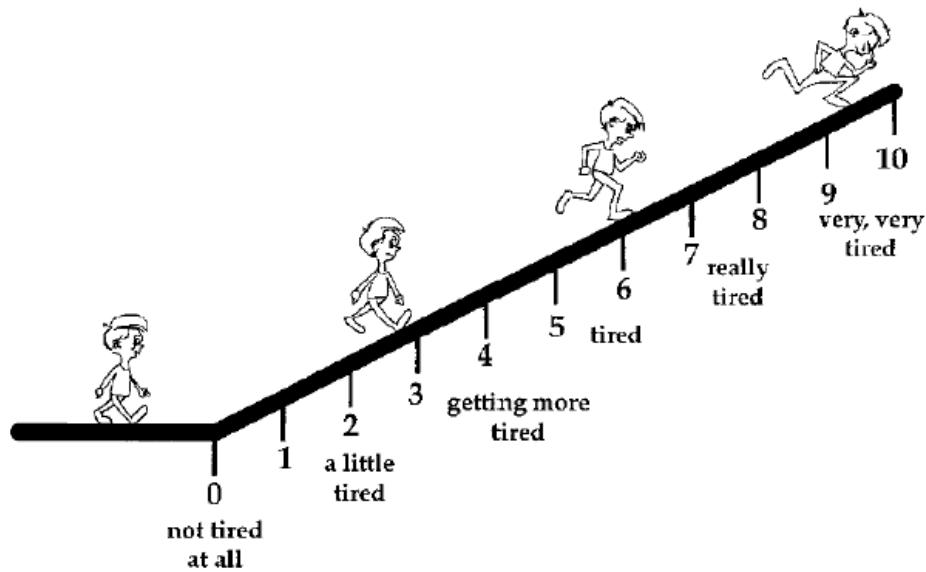


Figure 3.2 The Children's OMNI Scale of Perceived Exertion for walking/running.

The OMNI was developed as a perceived exertion rating tool because children younger than 11 cannot consistently assign numbers to words that describe exercise-related feelings and the exercise-related language of some scales are not part of their regular vocabulary.¹⁸³ At the end of the 6MWT, the Children's OMNI Scale was used to determine perceived effort immediately after walking with the backpack. The OMNI

(shown in Figure 3.2) was recorded after walking without a backpack for a baseline comparison, as well as after walking with each backpack weight.

Post-Walk Pain Survey with Visual Analog Scale (VAS):

A short post-walk survey was used to measure the subjective complaints of “soreness” or severity of pain in the neck, mid and low back regions after each walking trial.. The survey included a visual analog scale (VAS) and a body diagram (modified from Young¹⁸⁹). The VAS has been shown to produce reliable information in youth.¹⁹⁰ The use of body diagrams and other visual methods for indicating the region of pain have been used in previous studies and are ideal methods for localizing problems.¹⁹⁰ The VAS is divided into equal increments from 0 to 10, beginning with “no pain (“0”) and ending with “worst pain” (“10”). The body diagram is a sagittal line drawing of the spine with arrows pointing to the neck, mid and low back regions to enable localization of pain.

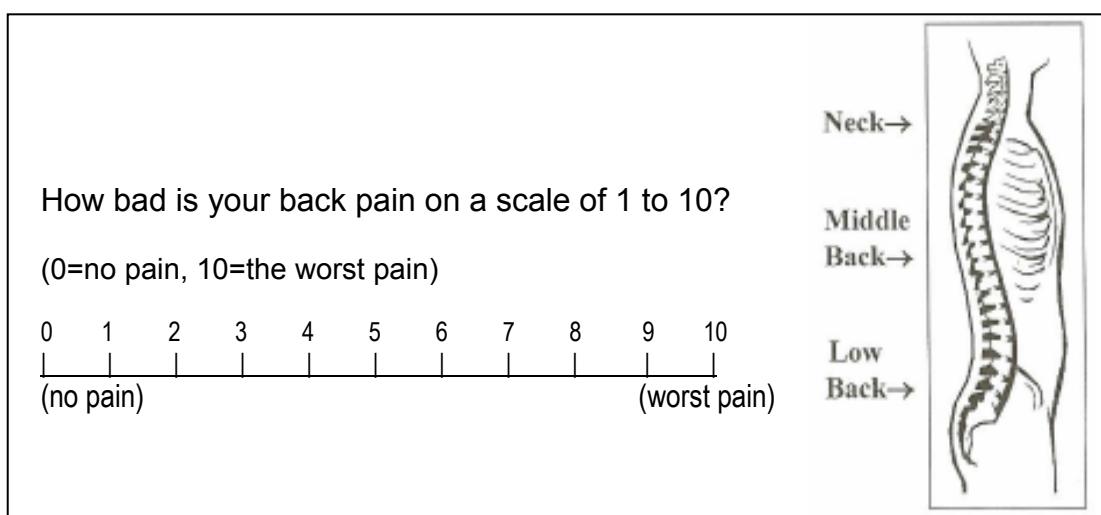


Figure 3.3 Excerpt from the Post-walk Pain Survey showing the VAS and body diagram. (Body diagram adapted from Young et al)

This procedure was repeated after walking for each of the three backpack weights tested. (See Figure 3.3 for an excerpt of full survey shown in Appendix 5).

Postural Angles

Digital photography enables researchers to examine and measure various postural angles in a non-invasive manner. While X-rays are considered the “gold standard” for imaging due to the visualization of skeletal bone rather than measuring through soft tissues, digital photographs limit radiograph exposure. When carrying a loaded backpack, there are a number of postural measures which can be measured via digital photography. Various studies have verified the reliability of digital photographs for obtaining clinical measurements of sagittal postural angles^{197,198}.

The following measures are seen in Figure 3.1 and were obtained through analysis of the digital photographs: Craniovertebral Angle (CVA), Forward Trunk Lean, and Pelvic Tilt. Photographic analysis of posture has been used to examine head and neck postures¹⁹⁹ and obtain clinical measurements of sagittal postural angles^{197,198,200} as early as 1941¹⁹⁹ in a non-invasive manner.

Craniovertebral Angle (CVA):

The forward head posture (FHP), or poke neck as it has also been called, is measured by the craniovertebral angle (CVA) and is defined as the angle between a horizontal line through the C7 spinous process and a second line through the spinous process of C7 and the tragus of the ear.¹⁰ See Figure 3.4. A smaller measurement indicates a more forward head position. A larger measurement indicates a more normal,

upright head position. The CVA has been used in studies examining posture, headaches, temporal-mandibular joint dysfunction, as well as numerous backpack studies.^{12,62,114,115,116,198,200} Normal CVA values for 12 year old children range from 46.9° to 49.4°.¹¹⁴

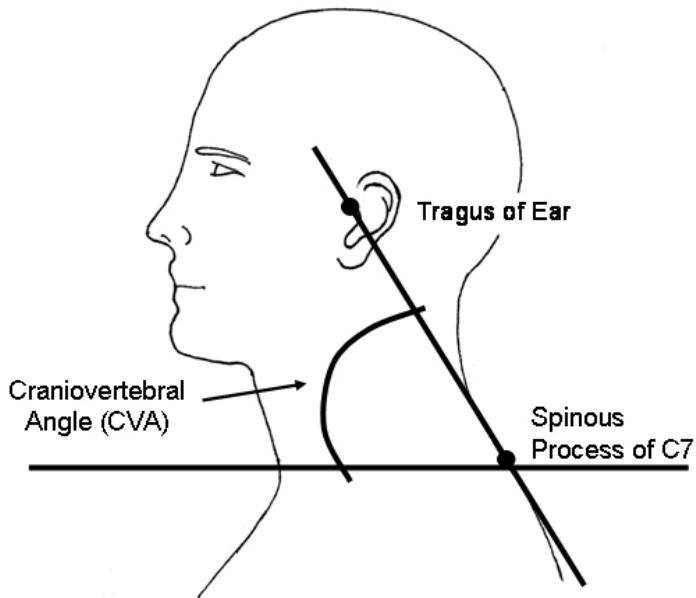


Figure 3.4 The Craniovertebral angle (adapted from Chansirinukor et al, 2001¹²)

The CVA has demonstrated high reliability and very high intra-rater^{12,113,199,216} and inter-rater reliability⁶⁵ for measurement of forward head posture. To assess changes in forward head positions due to load and fatigue in this study, the craniovertebral angle was measured through the use of reflective markers and digital photography.

Forward Trunk Lean (FTL):

Forward trunk lean, seen below in Figure 3.5, is the angle formed by the intersection of the line from the acromion to the greater trochanter and a vertical

reference line.¹⁰ This measure has shown significant changes associated with increased load carried.^{5,7,119,120,133,135,202,203} FTL has demonstrated good intra-rater reliability for measurement of trunk flexion.¹⁹⁸ Neutral erect posture should be close to 0°. A positive FTL measurement indicated the subject was leaning forward (in flexion) of vertical. A negative FTL measurement indicated the subject was leaning backwards, in extension.

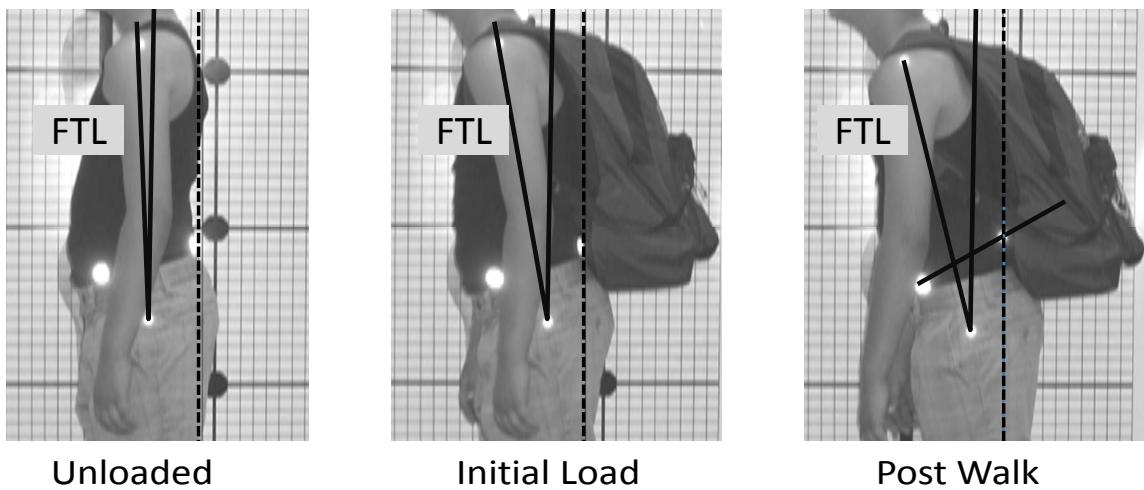


Figure 3.5 The Forward Trunk Lean (FTL) angle

Pelvic Tilt (TILT):

According to Kendall & McCreary, a neutral pelvis is one in which the anterior superior iliac spines are in the same horizontal plane as the posterior superior iliac spines.¹⁷ An anteriorly tilted pelvis will demonstrate a greater angle between the ASIS/PSIS plane and the true horizontal plane, thus increasing sacral inclination and lumbar lordosis.^{17,21} Children demonstrate an increased pelvic tilt during early gait, but demonstrate adult-like movement patterns by 7 years of age.²⁵ Smith found a significant change in pelvic tilt when wearing a backpack containing 15%BW.²⁰⁴ The pelvic tilt of young subjects is affected by a 17%BW backpack load according to Pascoe.⁷ In addition,

Brackley found increased lordosis angles of 10-year-old children after carrying a 15%BW load.¹¹⁶ The pelvic tilt angle measurement has shown good intr-rater reliability^{205,206,217} as well as inter-rater reliability²⁰⁵. This was measured as an angle formed by a line between the ASIS and PSIS intersecting a horizontal line using the ImageTool digitizing software. See Figure 3.6. A measurement with a larger number indicated an increase in anterior pelvic tilt. A smaller measurement indicated a more posterior pelvic tilt.

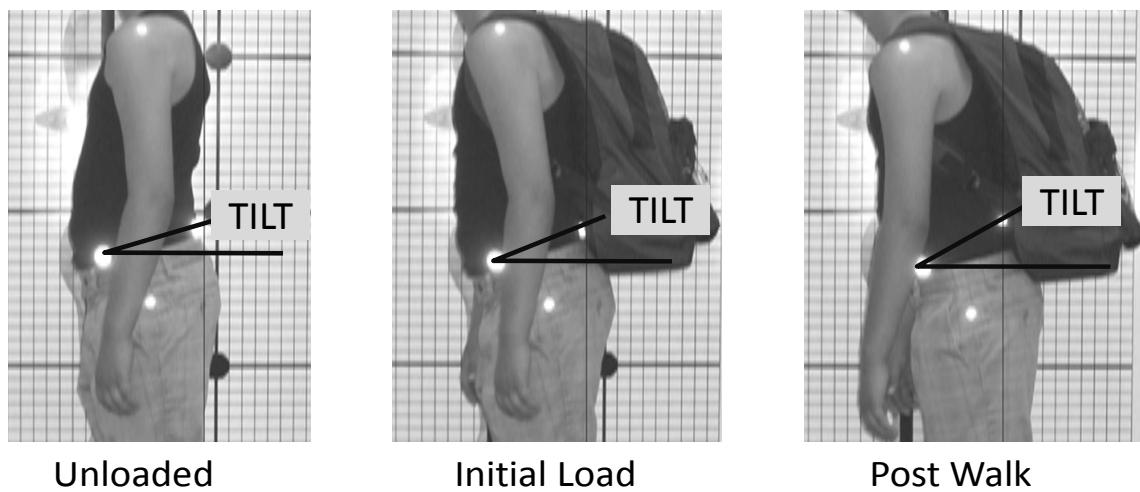


Figure 3.6 The Pelvic Tilt (TILT) angle

Statistical Analysis

This study was a two-factor repeated measures design, with the subjects serving as their own controls. Each subject participated in all conditions over three consecutive weeks of data collection. Microsoft Excel was used for initial database documentation and statistical analysis was completed using SAS 9.1.3.²⁰⁸ A two-factor, repeated measures analysis of variance was used, followed by pairwise comparisons, to test for the main effect of backpack load, the main effect of testing condition and a weight X

condition interaction in the postural angles of CVA, FTL and TILT. One-factor, repeated measures ANOVAs were used to examine differences in OMNI perceived exertion scores, 6MWT distance, and VAS pain scores among the weights after walking 6 minutes, followed by pairwise comparisons (paired t-test) to examine the effects at each weight. A frequency procedure was used to examine the pain complaints by region after walking with each backpack load. Results were considered significant at the 0.05 level of confidence.

Results

Sixty-two subjects completed the study and were included in the analysis. There were 21 boys and 41 girls. The mean age was 9.8 ± 1.0 years. The average height was 143.5 cm (56.6 inches) and the average weight was 39.01kg (94.3 pounds). (Table 3.1). There were no significance differences between each of the unloaded CVA, FTL and TILT angle measures across the three test days as would be expected. See Table 3.2 for the mean unloaded angles.

Effect of Backpack Weight and Condition on CVA

A main effect of weight ($F(2, 122) = 9.0, p = .0002$) was observed among the backpack weights. In general, the CVA decreased as the load increased at both initial load and post walk conditions. The interaction between weight and condition was significant ($F(4,244) = 6.61, p < .0001$) and indicated differences among the weights in the changes in CVA across the testing conditions. See Figure 3.7.

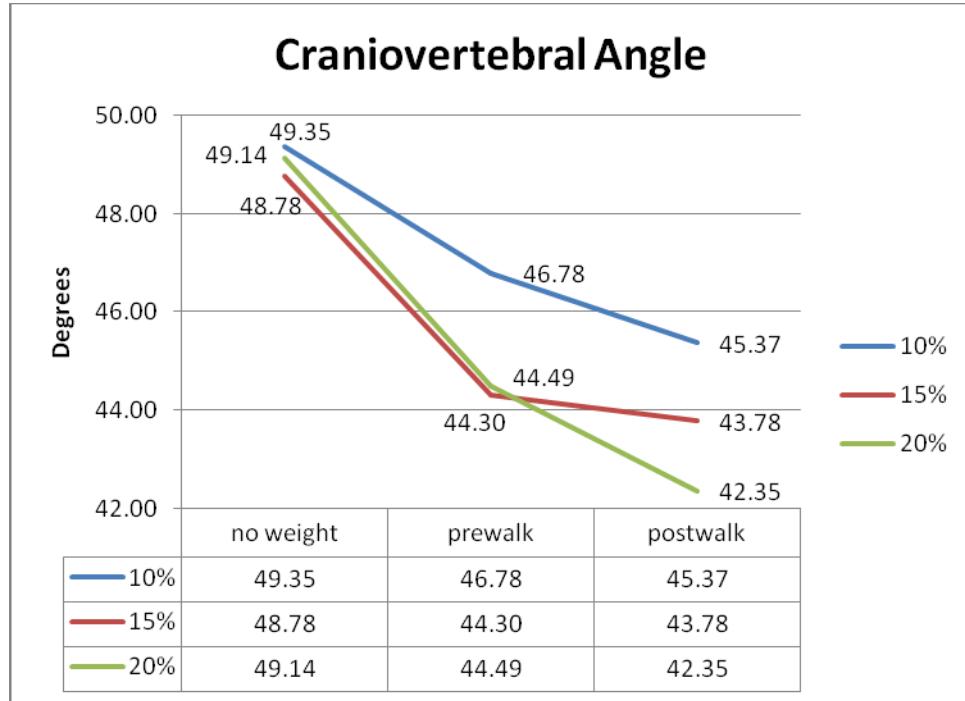


Figure 3.7. Craniovertebral Angle (CVA) changes while carrying a loaded backpack

All weight conditions produced an immediate and significant change in CVA upon initial loading (10%BW: $p < .0001$; 15%BW: $p < .0001$ and 20%BW: $p < .0001$). The change was less for the 10% load than for the other two conditions. Significant differences in the CVA were noted between the 10%BW and 20%BW loads ($p < .0001$) and the 10% and 15%BW loads ($p < .0001$). At post-walk, there was an additional decrease in the CVA angle for all 3 weight conditions but the percent decrease differed among the 3 weight conditions as listed in Table 3.2. There were significant differences between the post-walk CVA measures for all backpack weights ($p < .0001$), with the 20%BW load producing the smallest CVA, indicating an increased forward head with the heavier load.

A main effect of condition ($F(2, 122) = 110.93, p < .0001$) was statistically significant. In general, the CVA measures decreased significantly at both initial load and

post-walk for all weights. Pairwise comparisons identified significant differences in the post-walk CVA as seen in Table 3.3. The differences in the CVA from initial load to post-walk were statistically significantly for the 10%BW and 20%BW loads ($p = .0073$ and $p < .0001$ respectively), but not the 15%BW load. The differences in the CVA from unloaded to post-walk were statistically significant for all loads (10%BW: $p < .0001$; 15%BW: $p < .0001$ and 20%BW: $p < .0001$). The mean CVA changes for each backpack weight (10%BW, 15%BW, and 20%BW) are listed in Table 3.2.

Effect of Backpack Weight and Condition on FTL

A main effect of weight ($F(2, 122) = 10.40, p < .0001$) was observed among the backpack weights. In general, the forward trunk lean angle increased with heavier backpack loads. The interaction between weight and condition was significant ($F(4,244) = 14.37, p < .0001$) and indicated differences among the weights in the changes in FTL across the testing conditions. See Figure 3.8.

All weight conditions produced an immediate and significant change in FTL upon initial loading (10%BW: $p < .0001$; 15%BW: $p < .0001$ and 20%BW: $p < .0001$). The change was less for the 10% load than for the other two conditions. Significant differences in the FTL were noted between the 10%BW and 20%BW loads ($p < .0001$), the 10% and 15%BW loads ($p = .0454$), and the 15% and 20% loads ($p = .0318$). At post-walk, there was an additional increase in the FTL angle for all 3 weight conditions, but the percentage of increase differed among the 3 weight conditions as listed in Table 3.2. There were significant differences between the post-walk FTL angles for all backpack weights ($p < .0001$), with the 20%BW load producing the greatest FTL, indicating an increased forward trunk lean with the heavier load.

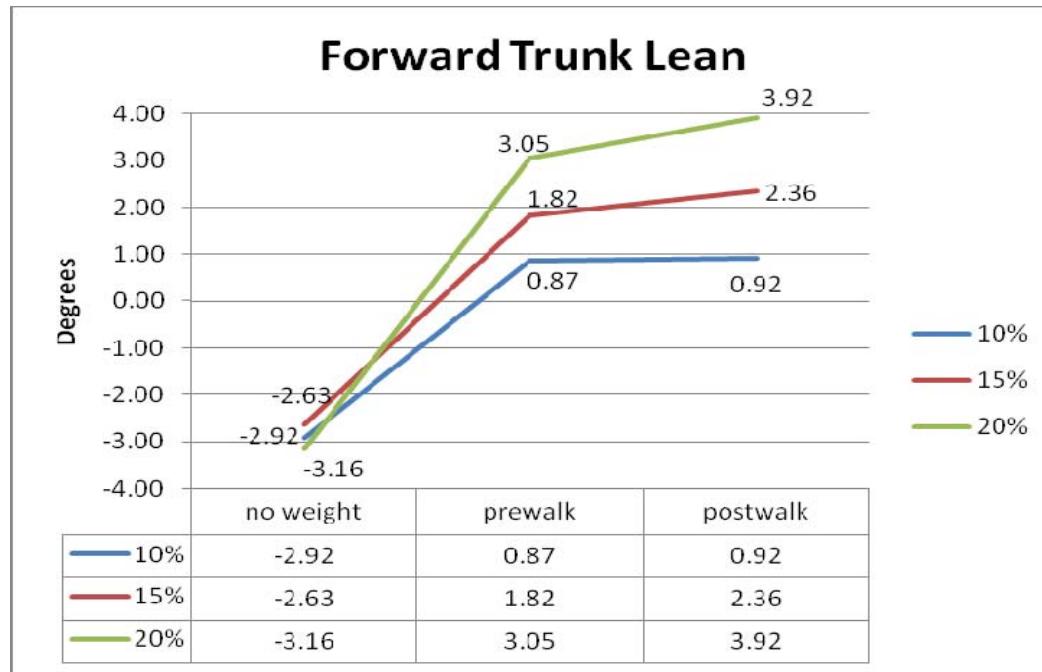


Figure 3.8. Forward Trunk Lean (FTL) changes while carrying a loaded backpack

A main effect of condition ($F(2, 122) = 226.99, p < .0001$) was observed between the testing conditions. The FTL angles increased significantly at both initial loading and post-walk. Pairwise comparisons identified significant changes in the post-walk FTL measures as seen in Table 3.3. The differences in FTL from initial walk to post-walk were statistically significant for the 15%BW and 20%BW loads ($p = .0478$ and $p = .0322$ respectively), but not the 10%BW load. The differences in FTL from unloaded and post-walk were statistically significant for all loads (10%BW: $p < .0001$; 15%BW: $p < .0001$; and 20%BW: $p < .0001$). The mean TFL angle changes for each backpack weight (10%BW, 15%BW, and 20%BW) are listed in Table 3.2.

Effect of Backpack Condition on Pelvic TILT

There was no main effect of weight ($F(2, 122) = 0.75, p = .4729$) among the backpack weights. In general, the pelvic tilt did not increase with heavier backpack loads

and there were no significant differences in the TILT among the backpack weights at unloaded, initial load or post walk. The interaction between weight and condition was not significant ($F(4,244) = 0.08, p = .9886$) and did not indicate differences among the weights in the changes in TILT across the testing conditions. See Figure 3.9. A main effect of condition ($F(2, 122) = 70.74, p < .0001$) was observed between the testing conditions.

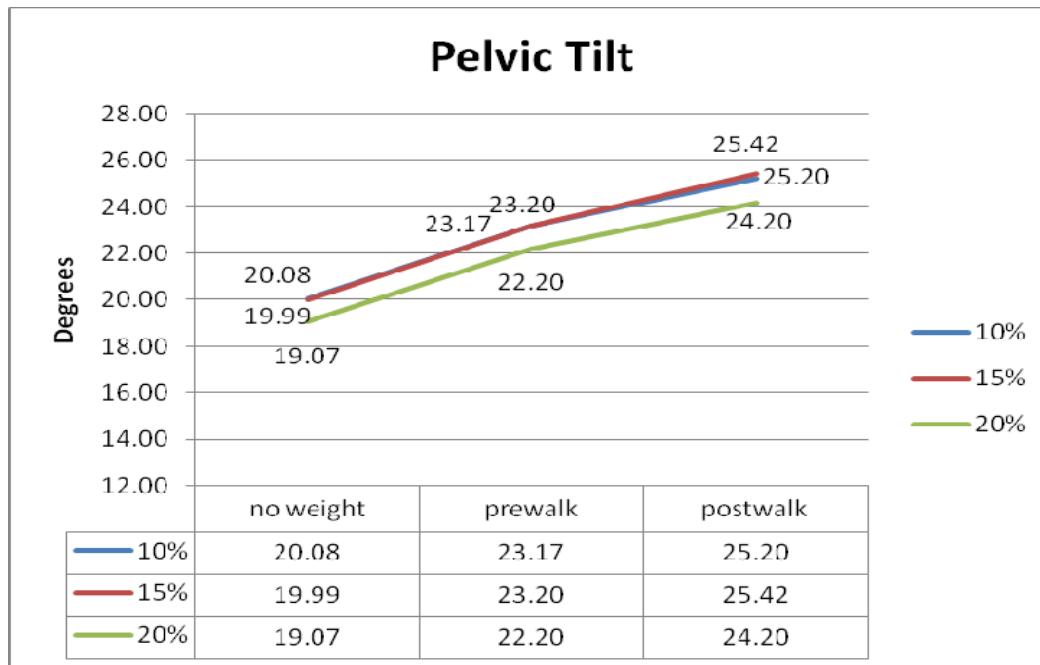


Figure 3.9 Pelvic Tilt angles (TILT) changes while carrying a loaded backpack

In general, TILT increased over time, after walking, moving into a greater anterior pelvic tilt. The pelvic tilt angles increased significantly at post-walk. Pairwise comparisons identified significant changes in the post-walk TILT measures as seen in Table 3.4. The differences in TILT from unloaded to initial walk were statistically significant for all loads (10%BW: $p < .0001$; 15%BW: $p < .0001$ and 20%BW: $p < .0001$). The differences in TILT from initial loading and post-walk were statistically

significant for all loads (10%BW: $p = .0019$; 15%BW: $p = .00097$ and 20%BW: $p = .0129$). The differences in TILT from unloaded walk to post-walk were statistically significant for all loads (10%BW: $p < .0001$; 15%BW: $p < .0001$ and 20%BW: $p < .0001$). There were no significance differences in the post-walk TILT measures among the backpack weights ($p = .5884$). See Figure 3.9. The mean TILT angle changes for each backpack weight (10%BW, 15%BW, and 20%BW) are listed in Table 3.2.

Effect of Backpack Weight on 6MWT Distance

Repeated measures ANOVA testing identified a main effect of backpack weight ($F(3, 177) = 20.33, p < .0001$) in the 6MWT distance among the backpack weights.

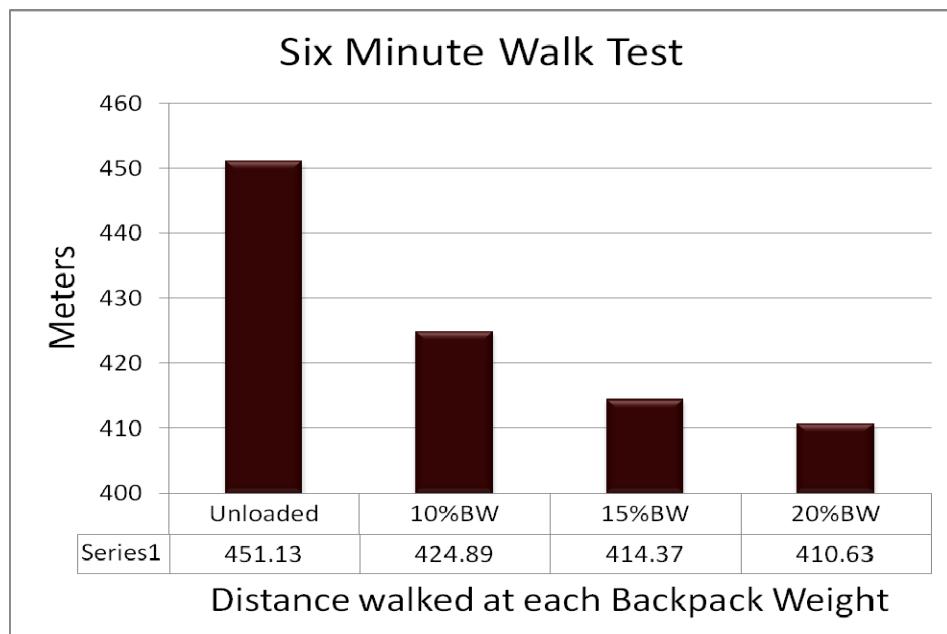


Figure 3.10 6MWT scores after walking 6 minutes with loaded backpack

The distance walked in six minutes at a free walking speed while carrying the backpacks decreased with increased backpack loads. See Figure 3.10. Pairwise comparisons identified significant differences between the unloaded 6MWT distance and

the 6MWT distance for all 3 backpack weights tested (10%BW: $p < .0001$; 15%BW: $p < .0001$ and 20%BW: $p < .0001$ respectively). A significant difference in the 6MWT distance was observed between the 10%BW and 20%BW ($p = .0179$). The mean 6MWT distances and ranges for each backpack weight (10%BW, 15%BW, and 20%BW) are listed in Table 3.4.

Effect of Backpack Weight on OMNI – Ratings of Perceived Exertion/Fatigue.

Repeated measures ANOVA testing identified a main effect of backpack weight ($F(3, 177) = 32.67, p < .0001$) in the OMNI walk/run ratings of perceived exertion scores among the backpack weights. See Figure 3.11.

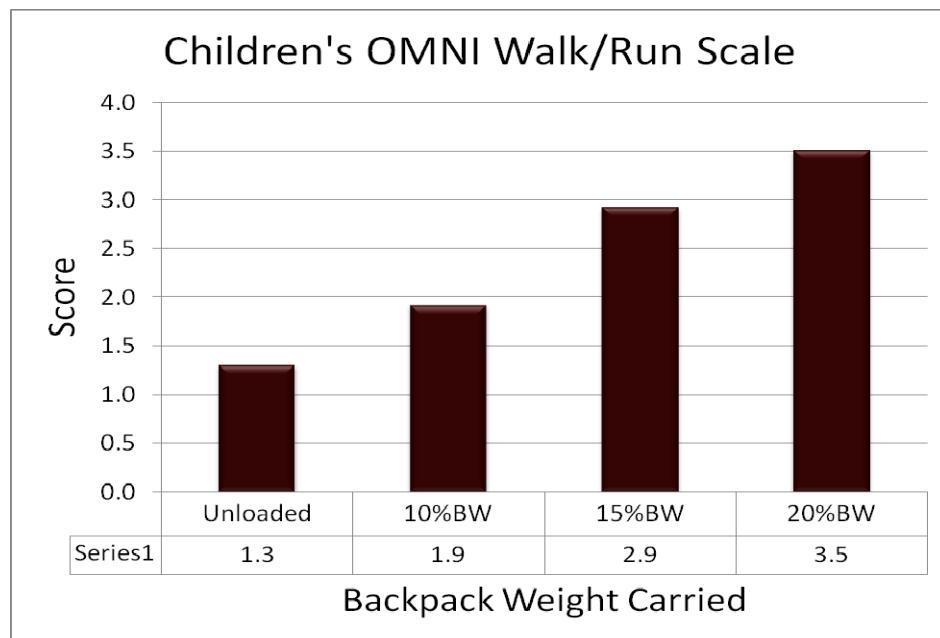


Figure 3.11 OMNI scores after walking 6 minutes with loaded backpack

The ratings of perceived exertion increased with heavier backpack loads, but were less for the 10% load than the other two conditions. Pairwise comparisons identified

significant differences between the unloaded OMNI score and the OMNI scores for all 3 backpack weights (10%BW: $p < .0001$; 15%BW: $p < .0001$ and 20%BW: $p < .0001$ respectively). Significant differences in the OMNI scores were noted between the 10%BW and 15%BW loads ($p < .0001$) and between the 10%BW and 20%BW loads ($p < .0001$), but not between the 15%BW and 20%BW loads. The mean OMNI scores and ranges of scores for each backpack weight (10%BW, 15%BW, and 20%BW) are listed in Table 3.4.

Effect of Backpack Weight on Pain Severity at Different Body Regions

Repeated measures ANOVA testing identified main effects of backpack weight on pain severity as measured by VAS scores in the neck ($F(2, 116) = 14.57, p < .0001$), (Table 3.5) mid back ($(F(2, 118) = 6.56, p = .0020$) and shoulders ($(F(2, 114) = 18.73, p < .0001$) among the backpack weights, but not for low back ($F(2, 118) = 0.81, p = .4465$).

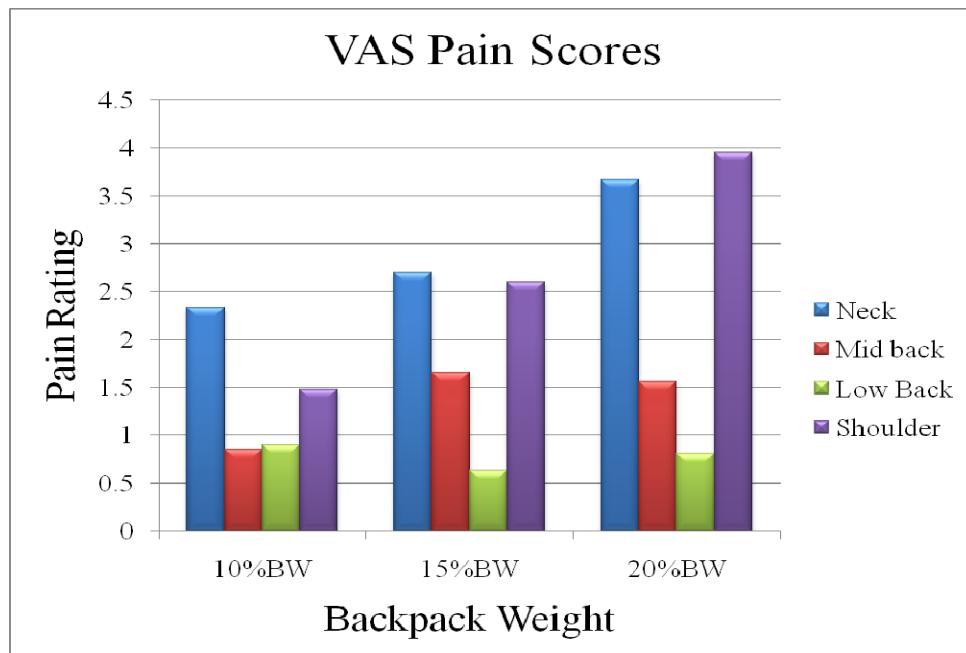


Figure 3.12. VAS pain scores by Body region and Backpack Weight

The pain ratings were the lowest for the 10% load and increased with heavier backpack loads for the neck, mid back and shoulders. See Figure 3.12 for the distribution of VAS pain scores by body region.

Pairwise comparisons (Table 3.5) identified differences between VAS pain score for all 3 backpack weights. Significant differences in the VAS pain scores were noted for the neck between the 10%BW and 20%BW ($p < .0001$) and between the 15%BW and 20%BW loads ($p < .0001$). Significant differences in the VAS pain scores were noted for the mid back between the 10%BW and 15%BW ($p = .0011$) and between the 10%BW and 20%BW loads ($p < .0010$). Significant differences in the VAS pain scores were noted for the shoulders between the 10%BW and 15%BW ($p < .0045$), between the 10%BW and 20%BW loads ($p < .0001$), and between the 15%BW and 20%BW loads ($p = .0015$). The mean VAS pain scores and ranges of pain scores for each body region and backpack weight (10%BW, 15%BW, and 20%BW) are listed in Table 3.4.

Frequency of Reported Pain

A frequency procedure was run to examine the frequency of pain complaints by region. Pain was reported in all regions after walking for 6 minutes with the various backpack weights, although a smaller proportion of subjects reported pain for the 10% load than for the other two conditions. See Figure 3.13.

After walking 6 minutes with the 10%BW backpack, 51.67% of the subjects reported that they felt pain, but only 41.51% said that it bothered them. When asked the location of their worst pain, 32.76% identified their neck, and 24.14% identified their shoulders.

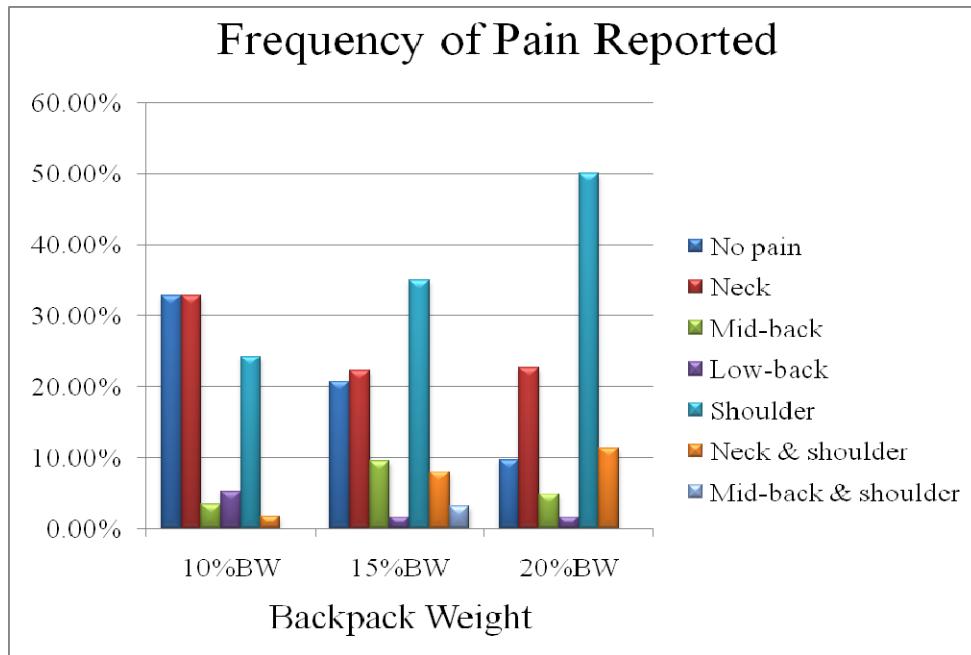


Figure 3.13. Frequency of Pain Reported by Body region and Backpack Weight

After walking 6 minutes with the 15%BW backpack, 71.19% of the subjects reported that felt pain, and 60.34% said that it bothered them. When asked the location of their worst pain, 34.92% identified their shoulders, and 22.22% identified their neck. After walking 6 minutes with the 20%BW backpack, 81.36% of the subjects reported that felt pain, and 72.41% said that it bothered them. When asked the location of their worst pain, 50.00% identified their shoulders, and 22.58% identified their neck. The frequencies of pain complaints by region and backpack loads are listed in Table 3.6

Discussion

The purpose of this study was to examine the effects of carrying weighted backpacks up to 20%BW on elementary schoolchildren. Changes in postural angles were investigated at initial loading and after a 6 minute walk in comparison to unloaded

posture. Perceived exertion, 6MWT distance and pain severity after walking were also examined for differences due to backpack weight. The results of the present study indicate that donning backpacks weighing 10%, 15% and 20% body weight produced immediate and significant changes in the children's postures, pain complaints, distance walked and ratings of perceived exertion.

The postures at initial loading demonstrated increased forward head postures, increased forward lean and an increase in anterior pelvic tilt. There were additional increases in these measures after walking for six minutes; an amount of time similar to what is needed walk to a classroom from a school entrance, while carrying loaded backpacks. The CVA and FTL measures were responsive to the backpack weights, resulting in greater differences at post-walk with the heavier weights. The pelvic tilt angle, while it increased significantly from unloaded to initial load to post-walk, did not differ among the backpack weights at each testing condition.

The lightest weight tested, a backpack weighing 10% of each subject's body weight, resulted in postural changes after walking which were associated with neck and low back pain as well as reports of fatigue, decreased walking distance. The VAS pain scores reported by the children were highest in the neck and shoulder. These children compensate for the backpack load by leaning forward, protracting their heads, and as suggested by the increase in pelvic tilt, increasing their lordosis to compensate for the weighted backpack.

With the heavier 15%BW load, these postural trends continued, with significant changes from the 10%load for CVA, FTL and TILT. These children are continuing to lean forward, with a forward trunk, an anteriorly tilted pelvis, and a significant increase

in forward head position compared to the lighter load. With the 15%BW backpack load, the neck and shoulders VAS pain scores increased, their OMNI scores increased, indicating greater perceived exertion compared to unloaded, and the 6MWT distance decreased.

With the heaviest weight of 20%BW, the postural compensations progressed, with significant changes of the CVA, FTL and TILT before and after walking. With the 20%BW load, there was a significant increase in forward head posture and in forward trunk lean. When carrying 20%BW backpacks, the children's trunks are flexed in postures that are significantly different from their normal upright standing posture. These forward flexed postures are known to increase the lumbosacral compression by at least 67% compared to unloaded posture.¹¹⁸

At both the 15% and 20% loads, there was continued evidence of decreased 6MWT distance, and increased reports of perceived exertion/fatigue. The post-walk CVA for all loads reflected statistically significant changes from unloaded (10%BW: p<.0001; 15%BW: p<.0001; and 20%BW: p<.0001), and a magnitude of change up to 13.8% from unloaded (see Table 3.3) which put the children at risk for headaches and musculoskeletal changes at the 15%BW and 20%BW backpack loads.^{68,114} The differences in the CVA measure from both unloaded to initial loading and from unloaded to post-walk for the 15%BW and 20%BW loads closely approximate the mean differences found by Watson & Trott (4.8°)¹¹³ and Yip (5.1°)⁶⁸ in adults with headaches, potentially putting these children at risk for headaches.^{68,113}

There were significant differences in FTL due to the weighted backpacks. Differences between unloaded and initial load FTL ranged from 3.79° to 6.21° among all

weights. Differences between unloaded and post-walk FTL measures ranged from 3.84° to 7.08° among all weights. These differences represent an increase in the trunk flexion angle of up to 224% from unloaded trunk posture. Changes in trunk posture are known to effect the relative orientation of the spine and the stress distribution within the spine.¹⁰⁷ These changes in trunk posture may lead to strain on the body and subsequent muscle fatigue and micro trauma, potentially culminating in a musculoskeletal disorder.^{107,218} Intradiscal pressures at L4-L5 increase approximately 440% when just “bent forward” or when holding a 28%BW load close to the body.¹⁰⁸ In addition to increased intradiscal pressures, forward trunk lean increases the shear forces within the spine due to changes in muscle tension and joint surface alignment.^{218,219} Walking with backpack loads of 15% and 30%BW have been shown to increase trunk flexion, leading to an increase in lumbosacral forces of 26.7 and 64% respectively, compared to unloaded postures.¹¹⁸

Subjective complaints of pain and functional endurance were impacted by the backpack weights. Scores of perceived exertion and fatigue while walking and VAS pain scores reported after walking increased with increased weights. Although less complaints were reported for the 10% load than for the other two conditions, the difference in the OMNI score from unloaded was still significant for the lightest weight tested. The 6MWT distance demonstrated a similar trend. While the distance walked decreased inversely to the backpack load, all the loads demonstrated significant differences from the distances walked by the children without a backpack load.

As discussed previously, there has been much concern about the weights and effects of the loaded backpacks carried by children. Upon examining these results to identify a recommended backpack weight, this study identified differences in all

measures for all three weights tested, including increased forward head posture, increased forward trunk lean, increased pelvic tilt, increased reports of perceived exertion, increased complaints of pain in several body regions, and decreased functional exercise capacity. While many of these differences are significantly different from the unloaded condition, there is less of an influence from the 10%BW backpack load as compared to the other two conditions. An ideal recommendation would prohibit children from carrying any backpacks, but that is not realistic when 90% of children worldwide currently utilize backpacks. Prior suggestions for weight limits have varied between 10%BW and 15%BW. The results of this study support setting the weight limit to 10% of a child's body weight due to the postural compensations and subjective complaints associated with the heavier loads.

Limitations

This study had a number of limitations that should be considered. Although the initial questionnaire asked if the subject had pain, a post-walk survey was not conducted after the unloaded 6MWT, so a full comparison of VAS pain scores against the unloaded condition was not possible.

Although this study was designed to limit bias as much as possible, the subjects could not be blinded to the study purpose of examining the effects of backpacks on children. They were blinded to the weight being tested and the actual postural angles that the study was measuring. The researcher who placed the markers and took the photographs was also blinded to the load being carried. Only the research assistant who measured the subject's weight and loaded the backpack each day knew the percentage of

body weight for the each testing session. The photographs were analyzed by an independent researcher who was blinded to the purpose of the measurements.

The 6MWT data may have been influenced somewhat by occasional encouragements provided by family members to the children while they were walking. Consistency in the instructions and cues for the 6MWT were attempted, though family members would periodically encourage the participant to “walk faster”.

The post walk pain survey did not originally contain a question about pain in the shoulders, but as the subjects reported the location of their “worst pain” as their shoulders, we verbally added “shoulders” as a location, and asked the subjects to rate the pain using the same VAS scale. The data obtained was included in the analysis and results. Only the primary researcher administered the post walk pain survey, and as such was able to maintain consistency of asking about shoulder pain after every 6MWT.

Directions for Future Research

Future research should continue to investigate the issue of children and the weighted backpacks they carry to develop additional strong objective scientific evidence and expand the scientific knowledge of the effects of these loaded backpacks. Additionally, future research should examine the relationships between the biomechanical, physiological and subjective responses to develop a clinical measurement to identify children who carry weighted backpacks who will be at risk for later problems. Skill (or experience) of backpack use in children should also be explored, as well as further assessment of the effectiveness of backpack education programs in youth.

Conclusion

Carrying loaded backpacks resulted in changes in forward head posture, forward trunk lean, pelvic tilt angle, 6MWT distance, and complaints of pain and perceived exertion in schoolchildren ages 8 to 11. The results of this study suggest that backpacks weighing 10%, 15% and 20%BW all lead to postural changes, but the 10%BW backpack resulted in the least amount of change in these measures. This study also found that the postural angles changed additionally after walking 6 minutes. There were differences in the postural angles among the weights across testing conditions from unloaded to initial load to post-walk. Based on these results, parents and clinicians may see these changes in children walking and carrying backpacks weighing 10%, 15% or 20% of the child's body weight.

Acknowledgements:

The authors would like to thank Physical Therapy Institute Inc., Delray Beach, Florida for the privilege of using the clinic for data collection and the authors would also like to acknowledge the assistance of Laura Demers, DPT, and UM students Megan Petrovsky, SDPT and Brian Demers during the course of data collection.

Table 3.1 Subject Demographics (N=62)

Variable	Mean (SD)	Min.	Max.
Age (years)	9.77 (1.07)	8.0	11.0
Height (cm)	143.50 (10.10)	127.00	176.53
Weight (kg)	39.01 (9.26)	22.97	65.56
BMI	18.73 (3.00)	13.68	26.18
Unloaded Baseline CVA*	49.09 (5.34)	57.69	63.43
Unloaded Baseline FTL*	-2.90(2.98)	-10.74	5.53
Unloaded Baseline TILT*	19.72 (5.87)	6.02	34.37

*Mean for all unloaded trials per measure

Table 3.2 Craniovertebral Angle (CVA), Forward Trunk Lean (FTL) and Pelvic Tilt (TILT) Percent Body Weight Load and Condition

		Backpack Load (as a percentage of bodyweight)		
Condition		10%BW	15%BW	20%BW
Unloaded CVA	Mean (SD)	49.35 (5.26)	48.78 (5.59)	49.14 (5.24)
	Range	32.02 - 63.43	35.63 - 61.49	36.21 - 57.78
Initial load CVA	Mean(SD)	46.78 (5.21)	44.30 (6.36)	44.49 (6.34)
	Range	32.02 - 63.28	32.66 - 61.76	26.17 - 57.69
Post-walk CVA	Mean(SD)	45.37 (5.85)	43.78 (6.30)	42.35 (6.10)
	Range	20.82 - 60.91	27.31 - 61.44	27.84 - 55.51
Unloaded FTL	Mean(SD)	-2.92 (3.21)	-2.63 (3.05)	-3.16 (2.67)
	Range	-10.74 - 5.39	-9.92 - 5.53	-8.53 - 2.32
Initial load FTL	Mean(SD)	0.87 (3.21)	1.82 (3.40)	3.05 (3.78)
	Range	-6.05 - 8.99	-12.91 - 10.68	7.61 - 15.16
Post-walk FTL	Mean(SD)	0.92 (3.40)	2.36 (3.19)	3.92 (4.99)
	Range	-7.04 - 9.38	-5.94 - 12.51	-4.95 - 28.20
Unloaded TILT	Mean(SD)	20.08 (5.75)	19.99 (6.12)	19.07 (5.78)
	Range	6.02 - 34.37	7.31 - 31.39	8.13 - 34.34
Initial load TILT	Mean(SD)	23.17 (7.51)	23.20 (7.02)	22.20 (6.92)
	Range	5.01 - 36.92	9.32 - 37.03	1.11 - 38.24
Post-walk TILT	Mean(SD)	25.20 (6.85)	25.42 (7.56)	24.20 (8.82)
	Range	6.91 - 37.01	10.84 - 39.98	3.58 - 48.16

Table 3.3 Pairwise Comparisons of Craniovertebral Angle (CVA), Forward Trunk Lean (FTL) and Pelvic Tilt (TILT) by Load and Condition

	10%BW Backpack	15%BW Backpack	20%BW Backpack
Unloaded vs Initial load CVA			
Mean difference (SD)	2.57° (3.88)	4.48° (4.47)	4.65° (4.25)
P value	<.0001	<.0001	<.0001
Percent change	5.21 %	9.18 %	9.46 %
Initial load vs Post walk CVA			
Mean difference (SD)	1.41 (0.51)	0.52 (0.58)	2.14 (0.46)
P value	0.0073	.3733	<.0001
Percent change	3.01%	1.17%	4.81%
Unloaded vs Post walk CVA			
Mean difference (SD)	3.99° (3.53)	5.00° (4.49)	6.79° (4.13)
P value	<.0001	<.0001	<.0001
Percent change	8.09 %	10.25 %	13.82 %
Unloaded vs Initial load FTL			
Mean difference (SD)	3.79° (2.75)	4.45° (3.06)	6.21° (3.03)
P value	<.0001	<.0001	<.0001
Percent change	129.79 %	169.20 %	196.52 %
Initial load vs Post walk FTL			
Mean difference (SD)	0.05 (.32)	0.54 (0.27)	0.87 (0.39)
P value	.8745	.0478	.0322
Percent change	5.75%	29.67%	28.52%
Unloaded vs Post walk FTL			
Mean difference (SD)	3.84° (2.98)	4.99° (2.92)	7.08° (4.07)
P value	<.0001	<.0001	<.0001
Percent change	131.51 %	189.73 %	224.05 %
Unloaded vs Initial load TILT			
Mean difference (SD)	3.09° (4.40)	3.21° (4.33)	3.13° (4.43)
P value	<.0001	<.0001	<.0001
Percent change	15.39 %	16.06 %	16.41 %
Initial load vs Post walk TILT			
Mean difference (SD)	2.03 (0.63)	2.22 (0.62)	2.00 (0.78)
P value	.0019	.0007	.0129
Percent change	8.76%	9.57%	9.01%
Unloaded vs Post walk TILT			
Mean difference (SD)	5.12° (3.96)	5.44° (4.87)	5.13° (6.29)
P value	<.0001	<.0001	<.0001
Percent change	25.50 %	27.21 %	26.90 %

Table 3.4 Six Minute Walk Test (6MWT), OMNI score and Neck, Mid Back, Low Back and Shoulder Pain (VAS) by Percent Body Weight Load

Variable	Backpack Load (as a percentage of bodyweight)			
	Unloaded	10%BW	15%BW	20%BW
6MWT				
Mean(SD)	451.13 (53.82)	424.89 (44.49)	414.37 (40.77)	410.63 (42.24)
Range	292.61 - 577.90	333.15 - 521.82	339.24 - 521.51	310.60 - 502.92
OMNI				
Mean (SD)	1.30 (1.5)	1.92 (1.76)	2.92 (2.15)	3.5 (2.3)
Range	0 - 6	0 - 7	0 - 10	0 - 8
VAS neck				
Mean(SD)	na	2.33 (2.36)	2.70 (2.59)	3.67 (2.66)
Range		0 - 10	0 - 10	0 - 10
VAS mid back				
Mean(SD)	na	0.85 (1.41)	1.65 (2.22)	1.56 (2.05)
Range		0 - 8	0 - 8	0 - 9
VAS low back				
Mean(SD)	na	0.90 (1.86)	0.63 (1.29)	0.81 (1.67)
Range		0 - 10	0 - 6	0 - 6
VAS Shoulder				
Mean(SD)	na	1.48 (2.02)	2.60 (2.95)	3.95 (3.26)
Range		0 - 7	0 - 10	0 - 10

na – post walk pain survey not administered after unloaded 6MWT

Table 3.5 Pairwise Comparisons of VAS Pain Scores by Backpack Weight

	Body Region			
	Neck	Mid back	Low back	Shoulders
10%BW - 15%BW				
Mean Difference (SD)	-0.38 (1.99)	-0.79 (1.79)	0.245 (1.75)	-1.08 (.37)
p value	.1448	.0011	.2763	.0045
10%BW - 20%BW				
Mean Difference (SD)	-1.29 (1.81)	-0.73 (1.64)	0.12 (1.73)	-2.33 (2.74)
p value	<.0001	.0010	.6030	<.0001
15%BW - 20%BW				
Mean Difference (SD)	-1.08 (2.01)	0.03 (2.07)	-0.18 (1.35)	-1.33 (3.11)
p value	<.0001	.9028	.3046	.0015

Table 3.6 Proportion of Subjects Reporting Pain by Backpack Load

		10%BW	15%BW	20%BW
Do you have discomfort?				
Yes	51.67%	71.19%	81.36%	
No	48.33%	28.81%	18.64%	
Does it bother you?				
Yes	41.51%	60.34%	72.41%	
No	58.49%	39.66%	27.59%	
Where is your worst pain?*				
No pain	32.76%	20.63%	9.68%	
Neck	32.76%	22.22%	22.58%	
Mid-back	3.45%	9.52%	4.84%	
Low-back	5.17%	1.59%	1.61%	
Shoulder	24.14%	34.92%	50.00%	
Neck & shoulder	1.72%	7.94%	11.29%	
Mid-back & shoulder	0.0%	3.17%	0.0%	

*Percentage of all subjects who reported that location.

Chapter 4: Summary and Conclusions

The primary purpose of the study was to examine the effects of backpack weights (up to 20%BW) on children's posture, subjective complaints and endurance. In addition, a secondary goal was to use these findings to identify and recommend a weight limit for backpacks carried by elementary school children. As of this writing, millions of children use backpacks on a regular basis, some of them carry backpacks weighing up to 46% of their body weight,⁹⁷ an amount that is far greater than the weight limit recommended for adults. Currently, there are no laws or formal guidelines in the United States that limit the amount of weight that children may carry on their backs. Carrying an excessively weighted backpack may have far reaching implications, including postural compensations to accommodate the load, subjective pain complaints, complaints of perceived exertion, and decreased walking endurance.

The observation of children's postures when wearing loaded backpacks suggests that there is a relationship between the amount of weight carried and the resulting postural compensations and subjective complaints. The postural changes observed in immediate response to the placement of a loaded backpack upon a child's back are easily identified by physical therapists. The changes in posture present after walking with various backpack loads are less obvious. To identify how backpacks affect the children who carry them, we addressed the following research questions:

Research Question 1: How do loaded backpacks (of 10, 15, and 20%BW) affect the postures (craniovertebral angle, forward trunk lean and pelvic tilt) of the children who carry them?

Initial loading of backpacks weighing 10%, 15% and 20% of the subject's body weight produced significant changes in the forward head position. The decrease in CVA was similar for the heavier weights of 15%BW and 20%BW, but was less for the 10%BW backpack. After walking for 6 minutes, the CVA decreased further leading to even more of a forward head position. The percent change was greatest for the 20%BW load. These findings are consistent with previous investigations of changes in head position due to loaded backpacks.^{12,115} Prior studies have found significant changes from unloaded to loaded postures at 15%BW and 17%BW.

In the main study (Chapter 3), the CVA changed significantly from unloaded to initial loading for all weights, ranging from an average difference of 2.57° for the 10%BW load to 4.48° and 4.65° for the 15% and 20%BW loads respectively. While these differences were statistically significant, only the 15% and 20% load produced changes of approximating or exceeding 5°, indicating a significant risk of symptoms due to spinal stress.^{113,114} Within each weight condition, there were children whose change in CVA from unloaded to initial loading potentially placed them at risk for headache or neck pain. At the 10%BW load, 26% of the children demonstrated a change in CVA of greater than 5° from unloaded to initial load, with a maximum change of 11°. At the 15%BW load, 45% of the children demonstrated a change in CVA of greater than 5° from unloaded to initial load, with a maximum change of 18.5°. At the 20%BW load, 47% of the children demonstrated a change in CVA greater than 5°, with a maximum change of 19.8°.

After walking for six minutes, the changes in CVA progressed further. The 10%BW load on average approached a 5° change at post walk, but did not exceed it.

However, 32% of the subjects demonstrated a change in CVA greater than 5° from unloaded to post walk, with a maximum difference of 13.7°. Both the 15%BW and 20%BW backpack conditions resulted in changes from the unloaded condition that were 5° or more, potentially placing the subjects at risk for headache or neck pain. Forty-two percent of the subjects carrying the 15%BW load demonstrated a change in CVA of greater than 5° from unloaded to post walk, with a maximum change of 18.3°. Sixty-eight percent of the children carrying the 20%BW load demonstrated a change in CVA greater than 5°, with a maximum change of 19.6°.

The findings of this study suggest that carrying loads of even 10% of body weight and above should be avoided, since these loads induce significant changes both at initial loading and post walk with the additive effect of walking time.

Grimmer et al found significant associations between heavy backpack weights and complaints of spinal pain in adolescents as well as a significant relationship between backpack weight and forward head posture as measured by CVA, with the greatest difference in younger children.¹¹⁴ Cheung found significant changes in CVA of 5.23° in children with neck pain carrying a 10%BW backpack load, as opposed to children without neck pain who demonstrate a significant difference in CVA of 5.03° at a 15%BW load.¹¹⁵

In the forward head position, the head is protracted on the neck and upper trunk, with cervical spine hyperextension.¹⁷ This protraction results in lengthened and weakened cervical flexors,^{62,69,113,220,221} shortened posterior muscles,^{21,62,69,220,221} and atrophy of the suboccipital muscles.²²¹ When the head is positioned forward of the line of gravity of neutral upright standing posture, the alignment of the muscles within the anterior and

posterior neck change,²¹ creating excessive compression on the apophyseal joints and posterior surfaces of the vertebral bodies.^{62,69,220}

The forward head posture has been related to cervicogenic headache,^{113,221} chronic tension-type headaches, unilateral migraine headaches²²¹ and neck pain.^{62,69,113,220,221,222} Adult women with cervicogenic headaches demonstrated significant mean change in CVA of 4.8° compared to women without headaches.¹¹³ This finding was supported by Yip who found the CVA in adults with neck pain was 5° less than those without neck pain.⁶⁸ Additionally, the forward head posture predisposes individuals toward pathological conditions such as: temporomandibular disorders, vertebral bodies disorders, thoracic outlet syndrome symptoms, facial pain,^{220,222} and even scapula and shoulder dyskinesia.²²⁰ The recurring exhibition of forward head postures in children who carry backpacks may potentially lead to these issues.

It is known that a history of backpain in childhood is a predictor of backpain in adulthood.^{12,214,223} It is not yet known if a history of neck pain in childhood is a predictor of pain in adulthood, but the predisposition to potential pathological conditions associated with the forward head posture in adults suggests there may be a relationship.

It is interesting to note that in the pilot study (Chapter 2), there was no significant difference among the backpack weights in the post-walk CVA, suggesting a ceiling effect or a maximum forward head position due to weight, elapsed backpack wearing time or a combination of the two. This was not present in the main study (Chapter 3).

Backpacks weighing 10%, 15% and 20% of the subject's body weight changed the FTL significantly upon initial loading for all three backpack weights tested. After walking for 6 minutes, the FTL increased even further, leading to a more flexed trunk

position which was significantly different from the unloaded trunk angle. The percent change was greatest for the 20%BW load. These results are consistent with previous investigations of changes in trunk lean due to loaded backpacks,^{7,12,96,116,118,119} which have found significant differences in the upright trunk posture of children due to backpack weights of 5%, 15%, 17%, and 20%BW.^{7,12,96,116,119} The backpack weights create significant increases in forward trunk lean both while standing and after walking.^{7,116}

The children in the main study demonstrated significant increases in the forward trunk lean at initial load. At the 10%BW load, the change in FTL averaged 3.79°; at the 15%BW load, the change in FTL averaged 4.45°; and at the 20%BW load, the change in FTL averaged 6.11°. The greatest change in FTL at initial load was 14.73° at the 10%BW. After walking, the children demonstrated greater changes in FTL measures with increased loads. At the 10%BW, the change in FTL averaged 3.84°; at the 15%BW load, the change in FTL averaged 4.99°; and at the 20%BW load, the change in FTL averaged 6.96°. The greatest changes in FTL at post walk were 26.15° at the 20%BW load, and 14.30° for the 10%BW load. A maximum change in FTL of 10.53° was observed at the 15%BW load.

These results follow the trends of increased forward trunk flexion reported in prior studies.^{116,118} The trunk flexion motion of young, military trained, adult men demonstrated a difference from unloaded to loaded of 7.81° while walking with a 15%BW load, which progressed to a greater difference of 12.64° between unloaded and loaded with a 30%BW load.¹¹⁸ The trunk flexion motion of 10 year old children demonstrated a change of 6.82° from unloaded to initial loading with a 15%BW

backpack. After walking 1000 meters, this increased to an 8.24° difference.¹¹⁶ Prior studies have identified significant changes in FTL from unloaded postures at 5%, 15%, 17%, and 20%BW.^{7,12,96,116,119} The findings of this study suggest that loads of 10%BW and more should be avoided as significant increases occurred in FTL for backpack loads of greater than 10%BW.

Carrying a weighted backpack requires an alteration in the body position to counteract the deviation from a normal upright posture. A weighted backpack load requires a forward inclination of the trunk to bring the new combined COM of the individual and the backpack load forward over the BOS. To counterbalance the load, trunk flexion increases as the backpack weight increases. Biomechanical modeling of the lumbosacral forces from 15%BW and 30%BW backpack loads compared to unloaded found that the peak lumbosacral forces increased with both backpack loads.¹¹⁸ The mean lumbosacral force in the unloaded condition was 1.5 times body weight. This increased to 1.9 times body weight with the 15%BW load, an increase of 26.7% from unloaded.¹¹⁸ The peak lumbosacral force increased to 2.46 times body weight with the 30%BW load, an increase of 64% from unloaded.¹¹⁸ Biomechanical modeling of the lifting of a load (such as a box) that weighs 25% of body weight produces a compressive force on L2 that is four times body weight assuming the lifted load is positioned close to the body.²¹ This may be an excessive amount of force for young growing bodies to repeatedly tolerate.

The long term implications of the forward trunk lean posture demonstrated in this study due to repeated exposure to heavy backpack loads are not fully known. One long-term effect of carrying a loaded backpack may be permanent postural changes causing compressive forces upon the spine potentially leading to pathological back problems such

as degenerative disk disease or disk herniation²⁰⁴ and back pain later in life due to exposure to these compressive forces.⁴ Studies have shown successively larger backpack loads of 15% and 30% body weight result in greater trunk forward lean and greater lumbosacral forces.¹¹⁸ Backpack carriage has been linked with spinal pain¹¹⁹ and as discussed above, a history of backpain in childhood is a predictor of backpain in adulthood.^{12,214,223} A child's posture should be examined in relation to complaints of back pain and the amount of weight carried daily in a backpack.

Loaded backpacks weighing 10%, 15% and 20% of the subject's body weight changed the pelvic tilt (TILT) angle significantly upon initial loading for all three backpack weights tested. After walking for 6 minutes, the TILT increased even further leading to a more anteriorly tilted pelvis and was significantly different from the unloaded pelvic tilt angle. These results are consistent with previous investigations of changes in pelvic tilt due to loaded backpacks.^{7,204,224}

The children in the main study demonstrated a significant increase in the pelvic tilt angle at initial loading. For the 10%BW load, the change in TILT averaged 3.09° at initial loading, with a maximum of 11.40°. For the 15%BW load, the change in TILT averaged 3.21° at initial loading, with a maximum of 12.70°. For the 20%BW load, the change in TILT averaged 3.13° at initial loading, with a maximum of 11.15°.

These subjects demonstrated an increase in the anterior pelvic tilt angle from unloaded to initial load and initial load to post walk that was similar between the loads. After walking, the children demonstrated greater TILT measures with increased loads. At the 10%BW, the TILT averaged 5.12° at post walk, with a maximum TILT of 15.60° observed. At the 15%BW, the TILT averaged 5.44° at post walk, with a maximum TILT

of 23.56° observed. At the 20%BW, the TILT averaged 5.05° at post walk with a maximum TILT of 22.46° observed. While the increases from unloaded to initial load and initial load to post walk were significantly different, there were no significant differences among the weights at each of these testing conditions, indicating that the pelvic tilt after the initial anterior tilt at initial loading, further anterior tilting was due to the amount of time the backpacks were carried, rather than to the increase in weight.

These results indicate that pelvic tilt increased due to backpack loads, consistent with Smith and Pascoe.^{7,204} Increases in anterior pelvic tilt have been found with the carriage of 20% and 40%BW backpack loads.^{7,204,224} Few studies have evaluated pelvic tilt changes over time due to backpack loads, although one study identified significant increases in lumbar lordosis curvatures before and after walking with a 15%BW backpack load.¹¹⁶

An increased pelvic tilt increases the sacral inclination, which in turn directly affects the lumbar lordosis, as an increase in the sacral inclination produces an increase in the lumbar lordosis.^{15,16} An increase in the normal lumbar lordosis is associated with tension on the anterior aspect of the vertebral column and compression on the posterior aspect, with uneven distribution of forces on the disc and vertebral body.¹¹⁶ The compressive and shear stresses of the lumbosacral junction are impacted by the addition of the backpack load to the body's weight resulting in increased the lumbosacral forces. An increased anterior pelvic tilt may also increase compressive force on the zygapophysial joints,^{21,116} increase pressures between posterior elements of the lumbar vertebrae²¹ and lead to musculoskeletal discomfort and possibly increased risk of injury.¹¹⁶

Long-term use of loaded backpack may result in changes in pelvic motions as well as changes in vertebral motion, gait alterations, and increased forces on structures.²⁰⁴ These may contribute to orthopedic, musculoskeletal, or soft tissue injuries.²⁰⁴ The findings of this study suggest that the effect of the time duration of backpack carriage is a significant issue and bears further investigation, as well as the relationship between pelvic tilt and forward trunk lean during backpack carriage.

Research Question 2: How do loaded backpacks (of 10, 15, and 20%BW) affect the functional walking endurance (6MWT walking distance) and ratings of perceived exertion/fatigue (OMNI) in children after walking 6 minutes with a loaded backpack?

The 6MWT distance, a measure of functional endurance, decreased significantly with increased backpack weight. The unloaded 6MWT averaged 451.13 meters. The mean distance walked with the 10%BW load was 424.89 meters, a decrease of 5.8% from unloaded. The mean distance walked with the 15%BW load was 414.37 meters, a decrease of 8.1% from unloaded. The mean distance walked with the 20%BW load was 410.63 meters, a decrease of 9.0% from unloaded. The walking speed decreased with increasing backpack loads from 1.25 meters/second (m/s) when unloaded, to 1.18 m/s at 10%BW, to 1.15 m/s at 15%BW and 1.14 m/s at 20%BW.

The results of this study agree with Chow who found significant decreases in walking speed of 13 year old children with increasing backpack loads from 0-15%BW.²²⁵ The walking speeds decreased significantly at a 5%BW load from 1.21 m/s when unloaded to just under 1.19 m/s at 5%BW, to just over 1.16m/s at 10%BW and just over

1.15 m/s at 15%BW.²²⁵ Carrying a load of 15%BW also resulted in decreased walking speeds with an 11.3% increase in double support time in young adults.²

Normative values of the 6MWT for children 4 to 11 years old in the United Kingdom reveal that in 6 minutes, 8 year olds walk an average of 483 meters, 9 year olds walk an average of 496 meters, 10 year olds walk an average of 506 meters and 11 year olds walk an average of 512 meters.¹⁹⁵ Geiger²⁰⁰⁸ used a measuring wheel that displayed the instantaneous walking distance to obtain 6MWT values for 3 to 18 year old children in Austria.¹⁹⁶ The subset of 9 to 11 year old boys walked an average of 667.3 meters, while the 9 to 11 year old girls walked an average of 655.8 meters.¹⁹⁶ Li measured 6MWT in 7 to 16 years old children in China with a mean age of 12.0 yrs and a mean distance walked of 664 meters, a average distance that spans the range of ages tested, from 7 year old children to 16 year old adolescents.²²⁶ Klepper reported a mean 6MWT distance of 518.5 meters for 9.6 year old children in the United States.²²⁷ These normative values are greater than the 6MWT results of this study. The children in the present study were not blinded to the purpose of investigating the effects of backpacks, which may have predisposed them to adopt a slower gait in an inverse twist of the Hawthorne effect. The normative values study by Geiger used a measuring wheel which may have increased the motivation of the subjects.¹⁹⁶ The study by Lammers required a tester follow the child to record heart rate and oxygen consumption, which may have altered the free walking speed of the subjects.¹⁹⁵ Or the subjects in the present study may have been less fit than the subjects in the normative studies.

According to the US Manual on Uniform Traffic Control Devices, administered by the Federal Highway Administration (FHWA) the “pedestrian clearance time” or the

walking speed for a pedestrian to cross a street is 4ft/sec, or 1.2 meters/sec.²²⁸ During a study of walking times by children at a crosswalk near a public school, researchers found that children 6 to 10 averaged 0.61 m/s while crossing the street.²²⁹ Children 11 to 15 averaged 0.76m/s, and children 16 to18 averaged 0.92m/s. The discrepancy between the “official” time and the actual walking times indicate that the required velocity is too fast for children, handicapped pedestrians or the elderly who may need more time to cross the street.²²⁹ The children demonstrated safe walking speeds when unloaded. However, the walking speeds decreased when the children carried heavier backpacks, putting children at risk for injury, as the walking velocities were less than the required speed to safely cross a street.

The findings of this study suggest that carrying loads of 10% of body weight and above should be avoided, since these backpack loads induce significant changes in functional walking endurance and reduce children’s walking velocities.

Training and experience of core (trunk) musculature may lessen some of the postural effects of backpack carriage. Studies have shown that experienced backpack users (hikers) experience decreased shoulder strap forces and less sagittal movements of their spines in comparison to novice hikers.^{82,83} Physical training with progressively increased backpack loads decreases energy cost, improves aerobic fitness, and increased walking speed for both soldiers and civilian women, similar to a training program with involving running and resistance training.⁷³ The 6MWT can be used as a tool to monitor change in physical abilities in children.²²⁷

Fatigue and perceived exertion, as measured by the OMNI score, increased significantly after walking while wearing a backpack loaded with 105, 15% or 20%BW.

Although the perceived exertion was greater for the 15% or 20%BW backpack compared to the 10%BW backpack, fatigue and exertion were increased at loads as little as 10% bodyweight. The unloaded OMNI score averaged 1.30, with a maximum reported score of 6 out of 10. After walking with the 10%BW load, the OMNI score averaged 1.92, a 47.7% increase from unloaded, with a maximum reported score of 7 out of 10. After walking with the 15%BW load, the OMNI score averaged 2.92, a 124.6% increase from unloaded, with a maximum reported score of 10 out of 10. After walking with the 20%BW load, the OMNI score averaged 3.5, a 169.2% increase from unloaded, with a maximum reported score of 8 out of 10. These scores represent fatigue complaints ranging from “a little tired” to “very, very tired”. Fatigue while carrying a backpack is associated with back pain.⁸ An investigation of children’s perceptions of their backpack loads found 79.1% of children in reported their bags felt heavy, 46.1% reported back pain and 65.7% reported fatigue from their backpacks.⁸

Increased fatigue was reported with heavier backpack loads. Fatigue in the trunk and extremities of children carrying loaded backpacks impairs proprioception, delays motor response,^{129,130} increases postural sway,¹³⁰ and alters the postural alignment.⁵⁶ Repeated and continued occurrences of fatigue may have greater impact on spinal structures and subjective complaints of pain and fatigue. Muscle fatigue in the lower extremity may lead to postural control and balance impairment, while muscle fatigue in the trunk and upper extremity affects shoulder proprioception.²³⁰ Fatigue also may lead to changes in spinal alignment with exaggerated curves demonstrating increased lumbar lordosis, increased curvatures in the upper thoracic region and a forward head.⁵⁶ As the postural alignment alters with fatigue, the postural muscles have to work harder while

carrying a backpack load and the passive tissues are stressed.⁵⁶ Due to the rate of muscle fatigue in the trapezius muscles of children while carrying loaded backpacks, backpack loads for children should be restricted to no more than 15% body weight for walks of up to 20 min duration.²³⁰

The findings of this study suggest that loads of 10%BW and more should be avoided as significant increases occurred in the OMNI fatigue scores and 6MWT after walking 6 minutes with loaded backpack.

Research Question 3: After walking 6 minutes with a loaded backpack, what is the effect of backpack weight on pain severity as measured by VAS on the neck, shoulders, mid back and low back?

The VAS scores of pain severity in the neck, shoulder, and mid back regions indicated greater pain with heavier backpack loads after walking. The neck and shoulder were the most frequently identified regions of pain, regardless of backpack weight. At the 10%BW load, subjects reported “no pain” and neck pain equally, with greater VAS pain scores at the neck than the shoulder. The presence of neck and shoulder pain continued with both the 15% and 20%BW loads, and mid back pain scores were reported for both the 15% and 20%BW loads.

The protocol excluded any child who reported pain during the initial questionnaire. The children in this study did not report pain prior to participating in data collection, and they all used backpacks on a daily basis. None of the children in this study reported pain during the initial interview; however, more than 51% of the children reporting pain after walking with the 10% load, 71% of the children reported pain after

walking with the 15%BW load and more than 81% of the children reporting pain after walking with the 20% load.

At the 10%BW load, the neck was prime location for pain across all backpack loads, with 32% of the children reporting the worst pain at the 10%BW load located in their neck, with an average VAS of 2.33 out of 10. Twenty-four percent of the children reported shoulder pain with an average pain score of 1.48. At the heavier backpack loads of 15% and 20%BW, the shoulders were the primary location for pain with 33% of the children reporting the worst pain at the 15%BW load located in their shoulders, with an average VAS of 2.60, and 50% of the children reporting the worst pain at the 20%BW load located in their shoulders, with an average VAS of their shoulders of 3.95. The neck was the second most frequently reported site of pain for the heavier loads of 15% and 20%BW. The VAS was 2.7 for the 15%BW load, and 3.67 for the 20%BW load.

The subjective complaints of neck pain increased with increasing backpack loads from 10% to 15% to 20%BW. At the 10%BW load, the neck pain score was 2.33. At the 15%BW load, the neck pain score had increased to 2.70. At the 20%BW load, the neck pain score had increased to 3.67, a significant change from both the 10% and 15%BW loads.

The shoulder pain scores increased significantly with increased backpack weights. At the same time, the forward trunk lean angle increased significantly with increased backpack weights. Increased backpack loads necessitate progressively larger forward trunk flexion to compensate for the external, posterior load. In typical student backpack design, the 70% of a backpack load is borne upon the shoulders and upperback,¹³⁹ where

it has been reported that the pressures from even a 7.2%BW backpack load may exceed the threshold for skin irritation, potentially affecting blood circulation.⁸⁵

It is possible that backpack loads of 10%, 15% and 20%BW may exceed the threshold for skin irritation and cause the children to report shoulder pain. Prolonged backpack carriage with maintained shoulder pressure may result in long term damage unless part of the load can be transferred to the hips.⁸⁵

Pain was also reported in the mid back region, with ratings of 1.65 and 1.56 after walking with the 15%BW and 20%BW loads respectively with significant differences from the 10%BW load for both. These scores were much lower than the pain scores for either the neck or shoulders at these loads, indicating that the mid back is not a primary source for acute subjective complaints after 6 minutes of walking.

Pain was reported in the low back region by 5% of the children after carrying the 10%BW load, and by just less 2% of those who carried the 15% and 20%BW loads. The average pain score for the low back ranged from 0.63 after the 15%BW load to 0.90 after the 10%BW load. As only 30% of a backpack load is carried on the back, regardless of load,¹³⁹ the reduced complaints of pain in the mid and low back are not improbable. Despite the literature reporting back pain from the use of backpacks in children, these results indicate that either the backpacks carried in this study were not heavy enough to cause back pain, the time spent walking was too short, the children were too young, or a combination of these.

The findings of this study suggest that loads of 10%BW and more should be avoided as significant increases in the majority of reported pain occurred with all

backpack loads tested, although the 10%BW load resulted in smaller pain scores than the heavier weights.

Research Question 4: Based on these results, what is the recommended weight limit for backpacks carried by elementary school children ages 8 to 11?

This study examined multiple aspects of backpack load carriage in an effort to identify their effects on children and use these results to identify and recommend a critical value for backpack weight limits. Carrying backpacks weighing 10% or more body weight potentially puts the pediatric backpack users at risk for multiple maladies, including neck and shoulder pain, headaches, increased lumbosacral compression forces,¹¹⁸ and restrictive lung function.²³¹ The presence of pain in childhood is a known predictor for pain in adulthood, which is very costly in the long run.

In this study, there were significant changes in the postural angle measures of CVA, FTL and TILT upon the initial donning of backpacks weighing 10% of body weight and greater. The postural angles were immediately responsive to the weights of the backpacks. The differences in these measurements increased after walking for 6 minutes. Based on the changes in the postural angles, the results presented here suggest that children should avoid carrying backpack weighing 10% or more of their body weight. There were significant differences occurred for all backpack loads tested, although the differences were the smallest for the 10%BW load.

In this study, there were significant differences in the measures of functional walking distance, perceived exertion/fatigue and pain ratings after walking with backpacks weighing 10% of body weight and greater. The changes in these measures

may impact daily functional activities of children, such as their ability to walk to school and the ability to move without pain or fatigue influencing their upright posture. Based on the changes in these measures, the results of this study suggest that children should avoid carrying backpacks weighing 10% or more of their body weight. While significant differences occurred at all backpack loads tested, they were the smallest for the 10%BW load.

Ideally, children should carry little to no weight on their backs. The altered biomechanics required to carry loaded backpacks on a daily basis may influence the normal musculoskeletal developmental growth.⁹⁵ Of the backpack weights tested in this study, the 10%BW load created the least changes, similar to Hong et al.⁹⁵ However, these results also demonstrate that even a “light” load of 10%BW is not innocuous, as it resulted in significant changes in postural angles and subjective complaints. Children carrying a backpack weighing 10%BW reported pain and demonstrated significant changes in their postures. As discussed earlier, a prior history of pain predicts pain in adulthood. Therefore, these children may potentially anticipate backpain as they mature into adults.

Blinding and Randomization

Randomization for the weight conditions was established through a Random Integer Generator.¹⁷⁷ This study was designed to limit bias as much as possible. Subjects could not be blinded to the study purpose of examining the effects of backpacks on children. They were blinded to the weight being tested and the actual postural angles that

the researcher was measuring. The researcher who placed the markers, instructed the subjects and took the photographs was also blinded to the load being carried. Only the research assistant who measured the subject's daily weight and loaded the backpack with the percentage of weight assigned knew the amount of weight carried each day. Each research assistant was assigned to one aspect of data collection. The photographs were analyzed by an independent researcher who was blinded to the purpose of the measurements.

Limitations

This study had a number of limitations that should be considered. Although the initial questionnaire asked if the subject had any pain at that moment, a post-walk survey was not conducted after the unloaded 6MWT, so a full comparison of VAS pain scores against the unloaded condition was not possible. Blinding, as mentioned above, was a limitation.

The 6MWT data may have been influenced by two opposing factors. The subjects may have been influenced by occasional encouragements provided by family members to the children while they were walking. Consistency in the instructions and cues for the 6MWT were attempted, though family members would periodically encourage the participant to "walk faster". Additionally, while the children were blinded about the testing conditions, they were not blinded about the overall purpose of the study to investigate the effects of walking with loaded backpacks which may have predisposed them to alter their walking speed.

The post walk pain survey did not originally contain a question about pain in the shoulders, but as the subjects reported the location of their “worst pain” as their shoulders, we verbally added “shoulders” as a location, and asked the subjects to rate the pain using the same VAS scale. The data obtained was included in the analysis and results. Only the primary researcher administered the post walk pain survey, improving consistency of administration. This study took place over three weekends, which required a significant time commitment by the subjects. This was done to minimize the effects of fatigue and error, which might have been present if the study had been designed for repeated trials on one day.

Clinical Relevance

To identify the relevance of this research, one must consider the magnitude of backpack use across the world and the variety of effects on children due to the backpack loads. Children are not little adults. Their bodies are still growing and developing and are not as tolerant as adult bodies are to external forces such as backpack loads. Various government agencies in the United States, as well as other countries, have recognized that there are limits to what adults may carry before they are at risk of injury. However, as of this writing, children do not have that umbrella of protection, only recommendations from various professional organizations that don’t carry any clout. This research was designed in an effort to contribute to the body of knowledge that could be used to establish backpack weight limits for children.

The pediatric spine is different from the spinal structures of adults¹² and may be vulnerable to developing low back pain from carrying heavy backpacks during the most

critical period of spinal development from 12-14 years,¹⁹ as the spinal ligaments and muscles are not fully developed until after 16 years of age.¹⁰ Backpacks that are repetitively worn incorrectly, or loaded heavily may result in kinematic, physiological and histological changes, as well as an early onset of back pain complaints.^{12,13,93} The external forces provided by heavy backpacks may affect the development of normal skeletal alignment,¹² resulting in musculoskeletal complaints, vertebral abnormalities¹⁰⁵ and compensatory strategies that alter postures and structures.⁴ Adolescent posture may be affected by both internal and external influences, making adolescents more susceptible to injury.¹²

A history back pain complaints in childhood is the strongest predictor of having musculoskeletal discomfort and back pain as an adult.^{12,13,93} Extrapolation of this information supports the theory that prolonged use of excessively heavy school bags contributes to the development of early musculoskeletal disorders, as well as establishes a vulnerability to developing a musculoskeletal disorder later in life.

NIOSH took the initiative to recognize the risk of youth for musculoskeletal injuries while working in agricultural settings.¹⁶⁷ However, only 2 million youth work in agricultural settings,¹⁶⁷ as opposed to more than 40 million children and youth who carry backpacks on a daily basis.^{2,3}

Children are being placed at risk for developing pain and musculoskeletal discomfort at young ages due to excessive backpack loads. Entering the cycle of pain, injury and treatment at a young age adds children into the list of MSD statistics and inflates all indirect and direct costs to both patient and provider.

So now what? The present cost of low back injuries is immense, with more than \$164 billion in annual direct & indirect costs in 2005⁸¹ and potentially as much as \$600 billion per year for indirect, direct costs and all other associated costs.¹⁶¹

Physical therapists, as healthcare providers, are qualified to address this issue. Physical therapists are skilled clinicians who are trained through entry level physical therapy curriculums to treat musculoskeletal symptoms and injuries in adults and children. Additional post-professional training can augment skills in manual therapy and other orthopaedic realms. However, physical therapists need to be able to do more than provide interventions for injuries. As a doctoring profession with a goal of autonomous practice,²³² physical therapist needs to focus on preventative aspects of patient care, as well as diagnosis and intervention.

According to the APTA, current physical therapy education curriculum includes topics of biology/anatomy, cellular histology, physiology, exercise physiology, biomechanics, kinesiology, neuroscience, pharmacology, pathology, behavioral sciences, communication, ethics/values, management sciences, finance, sociology, clinical reasoning, evidence-based practice, cardiovascular and pulmonary, endocrine and metabolic, and musculoskeletal.²³³ These topics focus primarily on diagnosis and intervention rather than prevention.

One U.S. college with an entry level physical therapy program offers a graduate degree in Health Promotion and Disease Prevention Program²³⁴ completely separate from the PT program. Another entry level physical therapy program possesses a dedicated Health Promotion Research Laboratory, though its primary focus is addressing health through movement intervention with obese subjects.²³⁵ An examination of curriculum

and course listings of physical therapy programs through the internet reveal that there may be a class listed as “prevention and wellness” or “Health Promotion and Disease Prevention” which is described as an overview of the “role of physical therapists in health promotion and disease preventions.”²³⁶

During the entry level Physical Therapy curriculum, students may be educated in proper positioning for neck and back pain patients as a component of therapeutic intervention in a spine management class. An ergonomics lecture may be provided to entry level students during their coursework as a preventative measure to protect them from injury, or it may be offered as a continuing education class. It is imperative that physical therapists be exposed to health promotion, education and wellness of all patient populations throughout the entry level curriculum, rather than as a seminar taken to fill continuing education requirements for licensure.

Physical therapy research should also embrace prevention; identifying components of patient’s lives that present an increased risk of injury and work towards the prevention of that injury. Research into the effects of backpacks on children falls into the realm of prevention-focused research; aimed at identifying and minimizing the risk of injury to children today before they become our injured patients of tomorrow. The results of this study will contribute to the body of knowledge to be used to establish backpack weight limits for children. The establishment of mandated weight limit guidelines for children may ultimately be facilitated through “prevention-focused” research such as this study.

Despite the recent development and proliferation of electronic devices containing textbooks information, the issue of backpack weight limits remains important. These

devices may serve to reduce the quantity of textbooks carried, but students will likely be required to carry electronic book readers, laptops and traditional lined notebooks for note taking. The contents of the backpacks may change, but the weight will still be an important issue. Backpack design also plays an important role, as hiking backpacks offer different support than standard student backpacks. The most important clinical implication is prevention. Educating health providers, students, workforce users, recreational backpackers and military users on the importance of backpack loading, lifting and carrying techniques as well as core strengthening will help prevent future backpack related injuries.

Future Research

Further research may identify additional risk factors for pain or injury due to backpacks, or even strategies to reduce risk. Future research should further investigate the relationships among pain, postural changes, and fatigue differences and use the results towards the development of a clinically accessible measure to identify children at risk for developing pain due to carrying heavy backpacks. Future research should examine the self-reported pain history of the subjects and the postural and subjective responses to backpack weights to identify relationships and potential risk indicators. Future research needs to examine the spinal compression and shear forces due to backpack loads through modeling and software. In order to make a case for backpack weight limits due to the forces and risks, there needs to be clear, objective measurements in parallel with the research that exists for adults. Future investigations should include obese subjects and novice youth backpack users. As the obesity epidemic of American youth grows, obesity may influence posture without a backpack, let alone the biomechanical adjustments

required to carry a backpack without a loss of balance. Future studies should examine muscle activation patterns according to backpack load weights and location on the back (high versus low). A strengthening program may be developed to train those muscles which are most active during backpack use. Based on past studies that have examined effectiveness of backpack use strategies²³⁷ and the differences between novice and experienced backpack users, the development of a program to “train” youth on core strengthening for backpack use would have merit in its endeavor to decrease complaints of pain in school-age backpack users.

Conclusions

The children who carry heavy backpacks today may become our patients tomorrow if they develop back and neck pain, headaches and other problems from early and excessive backpack use. The changes in postural angles, 6MWT distance, VAS pain scores, fatigue and perceived exertion scores indicate that children are sensitive to backpacks weighing 10%, 15% and 20% body weight. The findings of this study suggest that children should avoid carrying backpack weighing 10%BW or more as significant changes in postural angles and subjective complaints resulted from carrying backpack loads weighing more than 10%BW. Of the backpack weights tested in this study, the 10%BW load resulted in smaller, although still statistically significant changes. These results indicate that while the changes are smaller than those exhibited due to heavier weights, a 10%BW backpack load is not innocuous. Children should carry backpacks weighing less than 10%BW whenever possible to minimize postural changes and subjective complaints.

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APPENDIX I – FLYER



University of Miami

Elementary School Children wanted for a Research Study
to examine the effects of backpacks on posture

“Effect of Backpack Load Carriage on Posture and Subjective Complaints in Primary Schoolchildren”

This study has been designed by a local physical therapist and mother to examine the effects of backpacks on the posture and subjective complaints of children.

Various professional organizations suggest a weight limit of 10-15% of body weight as the maximum a child should carry in a backpack. On a daily basis, our children are carrying much more.

Through scientific research of this study and later studies, we wish to examine the effects of various loaded backpacks weighing up to 20% of body weight on the posture of children. These backpack weights are about the same or less than the amount your child may carry *every day* at school.

We are seeking schoolchildren, ages 8 to 11 (3rd through 5th grade students) who carry backpacks to school, and are overall healthy without any illnesses or recent back pain that may interfere with carrying a backpack.

Subjects will wear a backpack and we will take their picture from the side before and after a short walk. Data collection will take about 20-25 minutes on each of 3 consecutive Saturdays (~75 minutes total) at Physical Therapy Institute, a physical therapy clinic at Linton Blvd and Military Trail in Delray Beach

After each of the first 2 sessions, the subjects will receive a cool No. 2 pencil, and they may keep the reflective stickers used during the study. After completing the third and final data session, each child will be given a packet of Silly Animal Bracelets or a Kooky Klicker Pen as a thank you. Girl & Boy Scouts may be able to apply participation towards a health or community service badge.



This research is conducted under the direction of Dr. Ira Fiebert,
Department of Physical Therapy at the University of Miami, (305) 284-4535

To learn more about this research, call Fran Kistner, MSPT at 561-866-4994

APPENDIX II – PARENTAL INFORMED CONSENT

ePost ID: 20080286
Version:
Approved

Approval Date: 4/19/2010
Exp. Date: 4/18/2011

Effect of Backpack Load Carriage on Posture and Subjective Complaints in Primary Schoolchildren

University of Miami
CONSENT TO PARTICIPATE IN A RESEARCH STUDY
Effect of Backpack Load Carriage on Posture and Subjective Complaints in Primary
Schoolchildren

The following information describes the research study in which your child is being asked to participate. Please read the information carefully. At the end, you and your child will be asked to sign if you both agree to allow your child to participate.

PURPOSE OF STUDY:

The purpose of this study is to examine the effects of loaded backpacks weighing up to 20% of body weight on the posture of children. This backpack weight is about the same or less than the one your child may carry every day at school. Your child is being asked to be in the study because he/she already carries school books and homework to and from school every day using a backpack. We wish to identify when a child's posture changes because of a backpack load, and we will examine the relationships between backpack weights, subjective complaints, postural changes, and child body height & weight.

PROCEDURES:

This study involves 3 sessions scheduled over three consecutive Saturdays. Each session will last roughly 20-25 minutes for a total participation time of about 75 minutes. During the first session, your child will be asked questions about how they carry their backpack, how often they carry their backpack, if they have any discomfort from their backpack and what their general physical activity level is during and after school. We will weigh your child's backpack that they carried home from school. Your child's height, weight, trunk, hip and ankle strength will be measured. Your child will be sitting or laying while we test the strength of your child's trunk, hip and ankle muscles using a hand held device that measures muscle strength while they move their foot, knee, and trunk. This is similar to being asked to "make a muscle and hold it". Your child will walk without a backpack for 6 minutes for a comparison to walking with a backpack in Part 2 (below). All three sessions will include 3 parts:

- **Part 1:** Reflective stickers will be placed on your child's left ankle, side of their left knee, left hip joint, left shoulder, neck and in front of their left ear. Your child will need to be dressed in shorts and a sleeveless shirt so these reflective stickers may be applied and visible to the investigator. A slight reddening of the skin under the stickers is normal, and disappears shortly after the sticker is removed. Photographs will be taken from the left side of your child as your child stands with their toes lined up on a taped line on the floor.
- **Part 2:** Your child will be asked to put on a backpack with one of three possible backpack weights. The backpack weights will be 10, 15 or 20% of your child's body weight. These backpack weights are about the same or less than the one your child may carry every day at school. The percentage of body weight selected for each session will be determined by chance. Over the 3 testing sessions, your child will be tested using each of the possible back pack weights. After putting on the weighted backpack your child will again be photographed from the left side. Your child will then walk around the room for 6 minutes wearing the backpack. After 6 minutes, another photograph will be taken of your child standing while wearing the weighted backpack.
- **Part 3:** Your child will be asked to fill out a brief 12-question survey that will ask how they feel after walking with the backpack, if they feel any discomfort, and any comments.

ID _____

Page 1 of 3

ePost ID: 20080286
 Version:
 Approved

Approval Date: 4/19/2010
 Exp. Date: 4/18/2011

Effect of Backpack Load Carriage on Posture and Subjective Complaints in Primary Schoolchildren

All testing will take place at Physical Therapy Institute, Inc, a physical therapy clinic located at 4800 Linton Blvd. Suite 116 F, Delray Beach, FL 33445.

RISKS AND/OR DISCOMFORTS:

Because the backpack weights we are using are about the same or less than the one your child may carry every day at school, this study involves no risk beyond what your child encounters in his or her normal daily life. Your child's posture may temporarily change while carrying the backpack as it does when he or she carries a backpack to and from school. These changes in posture are normal responses to carrying a backpack.

When the stickers are removed, you/your child will feel the removal of the stickers. Some individuals may develop a mild skin redness or slight rash from the reflective stickers, but it should fade away quickly. Every effort will be made to ensure you/your child's comfort and safety throughout this study period. Supervision from the investigators will be readily available during all trials. Your child should report any problems to the researcher. If your child wishes to stop at anytime, he/she may do so. We will be taking photographs from the side. If your child feels uncomfortable being photographed, we will stop testing and he/she will be free to go.

BENEFITS:

There is no direct benefit to you or your child from participating in this study. This study is expected to contribute to our understanding of how backpack loads effect children's posture.

ALTERNATIVES:

Participation is not mandatory. Your child has the right not to participate in this study.

CONFIDENTIALITY:

The investigators will consider all records confidential to the extent permitted by law. These records and results will be coded so that only an ID number is used during the study. We will not identify you or your child individually in any presentation or publication without your written consent. The results of the research study may be published, but your child's name will not be used at any time. The records will be stored in a locked cabinet in the principal investigator's office at the University of Miami in Coral Gables, Florida. Access to these records will be limited to the researchers.

Any photographs that may be used in a research presentation or publication will be touched up to cover the face and any identifiable features. Photographs, both printed or on digital media, will also remain secured in the locked cabinet and will be retained for 5 years, and then destroyed.

By signing this consent, you authorize the Investigators(s) and his/her/their staff to access your child's records as may be necessary for purposes of this study.

COSTS:

There are no costs associated to you or your child for participation in this study. Although injury is unlikely, if injury should occur, treatment will in most cases be available. If injury occurs, treatment will in most cases be available. If your child has insurance, your insurance may or may not pay the costs. If you do not have insurance, or if your insurance refuses to pay, you will be expected to pay. Funds to compensate for pain, expenses, lost wages or other damages caused by injury are not routinely available.

eProst ID: 20080286
 Version:
 Approved

Approval Date: 4/19/2010
 Exp. Date: 4/18/2011

Effect of Backpack Load Carriage on Posture and Subjective Complaints in Primary Schoolchildren

COMPENSATION:

Boy and Girls Scouts may be able to receive credit or a patch for participation. Your child will receive a cool (No. 2) pencil after each of the first 2 data sessions, and a packet of Silly Animal Bracelets or a Kooky Klicker Pen will be given to him/her after participating in all three data collection sessions and completing the study.

RIGHT TO DECLINE OR WITHDRAW:

Your child's participation in this study is voluntary. Your child is free to refuse to participate in the study or withdraw his/her consent at any time during the study. The investigator reserves the right to remove your child from the study without your child's consult at such time that they feels it is in your child's best interest. If you choose not to have your child participate or to withdraw your child from the study at any time, there will be no penalty of any kind. If you are an employee or student at the University of Miami, your desire not to participate in this study or request to withdraw will not adversely affect your status as an employee or grades at the University of Miami.

CONTACT INFORMATION:

You may ask any questions concerning this study and the investigators will answer you/your questions. Dr. Ira Fiebert or Fran Kistner, PT may be reached at the numbers below, and will gladly answer any questions you may have concerning the purpose, procedures, and outcome of this project. If you have questions about your child's rights as a research subject you may contact the Human Subjects Research Office at the University of Miami, at (305) 243-3195.

PARTICIPANT AGREEMENT:

I have read the information in this consent form and agree to allow my child to participate in this study. I have had the chance to ask any questions I have about this study, and they have been answered for me. I am entitled to a copy of this form after it has been read and signed.

Signature of Parent/Guardian

Date

Signature of person obtaining consent

Date

Investigators:

Ira Fiebert, Ph.D., P.T.
 (305) 284-4535 (office)
 (561) 479-0727 (night)

Fran Kistner, M.S.P.T.
 (305) 284-4535 (office)
 (561) 866-4994 (night)

Photography

[] By signing this section you give consent for your child to be to be photographed during this study.

Signature of Parent/Guardian

Date

Signature of person obtaining informed consent

Date

ID _____

Page 3 of 3

UNIVERSITY OF MIAMI STANDARD PATIENT PHOTO RELEASE

Please send completed form along with completed Attachment 46 to the Office of HIPAA Privacy & Security



AUTHORIZATION/RELEASE FOR PHOTOGRAPHY OR AUDIO/VIDEO RECORDINGS

Print Patient Name _____ N/A _____ Social Security Number _____ IDX Number _____

Address _____ Phone Number _____

I, _____, authorize the University of Miami, Department of _____ Physical Therapy _____, to take still photographs, audio recordings, and/or video recordings of me/ (my child), and I authorize the release and publication of any protected health information or other identifying information in connection with such activity (as applicable), for use in any manner, as indicated below (*please read and check box and describe activity or list the publication in the space next to the appropriate permission statement*):

Publication(s) or other broadcast, promotional, advertising or commercial purposes:

Medical Training, teaching, education, scientific meetings and scientific publications, including professional journals or medical books: _____

Other: _____

I hereby release all claims, rights, and interests that I might have in such photography or audio or video recordings or use thereof. I agree that the University of Miami, its Trustees, officers, employees, students, faculty and agents will not be responsible for any claims arising in any way out of the taking and use as described above of such photographs and/or audio or video recordings, and that I will not receive any benefit from the use of such photographs and/or recordings. I understand that I will not have an opportunity to inspect and approve such photographs or recordings prior to their use, and that the University of Miami will be the owner of such photographs and/or recordings. I confirm that these photographs and/or recordings were taken with my knowledge and consent.

_____Physical Therapy Institute, Delray Beach, FL_____ /2010 _____
Location of Activity _____ Activity Date _____

Description of photographs or audio/video recordings, for identification purposes _____

Signature of Patient _____ Print Name _____ Date _____

Witnessed by _____ Print name _____ Date _____

Patient Representative/Relationship _____ Print Name _____ Date _____

Patient Date of Birth (*If less than 18 years of age or otherwise lacks legal capacity*)

Fran Kistner, PT _____ UM Dept of Physical Therapy _____ 305-284-4535 _____
Name of Department Representative _____ Department _____ Dept. Phone Number _____

University of Miami Office of HIPAA Privacy and Security • PO Box 019132 (M879) Miami, FL 33101
Phone: 305-243-5000 • Fax: 305-243-7487 • hipaa@med.miami.edu



Form
D3900055E

Revised
03/20/06

Patient Name: _____

IDX #: _____

Patient SS#: _____

Department Name: _____

UNIVERSITY OF MIAMI STANDARD PATIENT HIPAA RELEASE

Date Completed if Records Sent: _____ (FOR OFFICE USE ONLY.)

Attachment 46
Authorization for 3rd Party Disclosures - Short Form

I authorize the use or disclosure of health information about me as described below.

1. Person(s) or class of persons authorized to use or disclose the information (Note: e.g., medical records department, physician):

 University of Miami, Department of Physical Therapy

2. Person(s) or class of persons authorized to receive the information (Note: e.g., family member, attorney, employer, researcher):

If you would like your records to be sent to a third party, please provide address or fax where you would like us to send the information.

Name: _____ Phone: _____
 Address: _____ Fax: _____

3. Description of information that may be used or disclosed (Note: e.g., all information related to a specific type of treatment):

 Photographs

4. The information will be used or disclosed for the following purposes: (Note: if a patient initiates the request, the statement "at the request of the patient" is sufficient)

5. I understand that if the person or entity that receives the information is not a health care provider or health plan covered by federal privacy regulations, the information described above may be rediscovered and no longer protected by these regulations.

6. [If applicable] The disclosure of my information for marketing purposes is expected to result in a direct or indirect financial benefit to _____
 _____ [insert the name of the disclosing covered entity].

7. I understand that I may refuse to sign this authorization and that my refusal to sign will not affect my ability to obtain treatment or payment, enrollment, or my eligibility for benefits.

8. I understand that I may revoke this authorization at any time by sending a written request to the University of Miami privacy officer, except to the extent that action has been taken in reliance on this authorization.

9. This authorization expires _____ [insert a date or describe an event or activity related to the patient or purpose of the authorization]. If not completed, this authorization will expire one year from date signed.

Signature of Patient or Representative _____

Date _____

Patient's Name _____

Patient Address _____

Patient Contact Phone Number _____

Social Security Number _____

Date of Birth _____

Name of Personal Representative (if applicable) _____

Relationship to Patient _____

(A copy of this signed form will be provided to the patient)

University of Miami - Office of HIPAA Privacy and Security
 PO BOX 019132 (M879)
 Miami, FL 33101
 hipaa@med.miami.edu
 (305) 243-5000

AUTHORIZATION FOR 3rd PARTY DISCLOSURES –
 SHORT FORM

Form
 D3900052E
 Revised
 08/01/05



NAME: _____

MRN: _____ IDX SMS

SS: _____

AGE: _____ DOB: _____ / _____ / _____

DATE OF SERVICE: _____ / _____ / _____

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Page 1 of 1

APPENDIX III – MINOR ASSENT

eProst ID: 20080286
Version:
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Approval Date: 4/19/2010
Exp. Date: 4/18/2011

MINOR ASSENT DOCUMENT

Project Title: *Effect of Backpack Load Carriage on Posture and Subjective Complaints in Primary Schoolchildren*

Investigator: Fran Kistner, MSPT, CEAS, Ira Fiebert, PhD, PT

We are doing a research study about how carrying a backpack changes your posture. A research study is a way to learn more about people. If you decide you want to be part of this study, you will be asked to wear a backpack three different while a picture is taken from the side.

There are some things about this study you should know. We will need to see you on three Saturdays for about 20-25 minutes. We will test your back, belly, hip and ankle strength on the first day. You will wear a backpack carrying three different amounts of school books. These backpacks weigh about the same or less than the one you use every day at school. We will put some stickers on one of your shoulders, one leg, hip, and by your ear. These stickers help us take better pictures of your posture. We will take three pictures of you, one before you put on a backpack, another after you put on the backpack and then one more after you have walked around for 6 minutes. We need you to come back next weekend, and the weekend after for about 20-25 minutes total each day.

Not everyone who takes part in this study will benefit. A benefit means that something good happens to you. Some children might be able to use this experience towards volunteer time or a badge for Scouting. We will give you cool pencil after each of the first 2 days, and either a packet of Silly Animal Bracelets or a Kooky Klicker pen after we finish the third session as a thank you.

When we are finished with this study we will write a report about what was learned. This report will not include your name or that you were in the study. Any pictures that might be used will be blurred so no one can tell who is in the picture.

You do not have to be in this study if you do not want to be. If you decide to stop after we begin, that's okay too. No one will be mad at you if you decide not to do this study. You may ask questions about the study at any time.

Do you have any questions?

If you decide you want to be in this study, please sign your name.

I agree _____ I do not agree _____ to participate in this study which I have read or which has been explained to me by _____

(Sign your name here)

(Date)

(Signature of Person Obtaining Assent)

(Date)

ID _____

Backpack Assent

APPENDIX IV – INITIAL QUESTIONNAIRE

ePost ID: 20080286
Version:
Approved

Approval Date: 4/19/2010

ID Number: _____

Initial Survey

Today's date: _____ Birthday: _____ Grade: _____ Gender: Boy Girl

1. Which hand do you prefer to write with? Right Left
2. Do you go to school? Yes No
3. What sort of bag do you use to carry your school books? (check the one you use the most)
 None Backpack Rolling backpack Computer shoulder bag Athletic bag
4. How old is it? New this school year New last school year Older than last year
5. Please check which of the following features are on your backpack:
 Waist belt Padded shoulder straps Padded back support
 Chest strap Adjustable shoulder straps Metal framing
6. How often do you use:
the waist belt? Never sometimes always don't have it
the chest strap? Never sometimes always don't have it
7. Where do you carry your bag?
 High up on your back? In the middle? Low on your buttocks?
8. How do you go to school?
 Walk bicycle car bus Other _____
9. How do you go home from school?
 Walk bicycle car bus Other _____
10. How long do you normally spend carrying your bag on the way to school? (check one)
 less than 5 min 5-10min 11-20min 21-30min more than 30 min
11. How long do you normally spend carrying your bag on the way home from school? (check one)
 less than 5 min 5-10min 11-20min 21-30min more than 30 min
12. How long do you normally spend carrying your bag during the school day? (check one)
 less than 5 min 5-10min 11-20min 21-30min more than 30 min

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ID Number: _____

13. How do you normally carry your bag **to** school?

Both shoulders right shoulder left shoulder right hand left hand

14. How do you normally carry your bag home from school?

Both shoulders right shoulder left shoulder right hand left hand

15. Do you carry your bag during the school day? Yes No

16. If yes, how do you normally carry your bag during the school day?

Both shoulders right shoulder left shoulder right hand left hand

17. Do you carry anything else to school besides your school bag?

Yes No What?

18. Most of the time, the weight of my school bag is:

light medium heavy

19. Do you experience pain in your neck, shoulder or back when carrying your school bag?

Yes No If yes, where? _____

20. Where does it hurt the most?

21. Over the past 8 months, how many times have you experienced pain during or after carrying your backpack? During: _____ After: _____

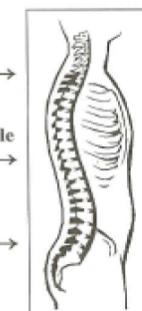
22. Do you have any pain right now? yes No If yes, please stop and tell the researcher.

23. When do you have discomfort or pain?

It is always present while carrying your bag after taking off your bag

24. Did you have pain after wearing your backpack yesterday? Yes No

25. Did it bother you? Yes No



26. Do you have *neck pain* only? Yes No



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ID Number: _____

28. Have you missed school because of *neck pain*?

Yes No

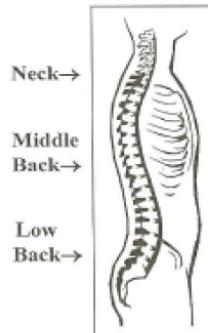
29. Have you ever had to rest or not play in outdoor activities because of *neck pain*?

Yes No

30. Have you ever seen a doctor/school nurse/physical therapist because of *neck pain*?

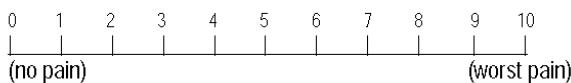
Yes No

31. Do you have *middle back pain* only? Yes No



32. How bad is your *middle back pain* on a scale of 1 to 10?

(0=no pain, 10=the worst pain)



33. Have you missed school because of *middle back pain*?

Yes No

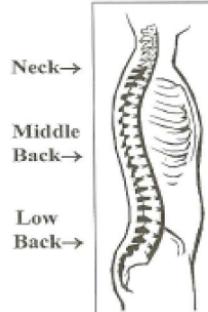
34. Have you ever had to rest or not play in outdoor activities because of *middle back pain*?

Yes No

35. Have you ever seen a doctor/school nurse/physical therapist because of *middle back pain*?

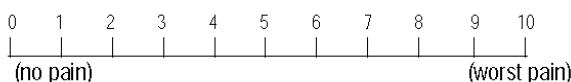
Yes No

36. Do you have *low back pain* only? Yes No



37. How bad is your *low back pain* on a scale of 1 to 10?

(0=no pain, 10=the worst pain)



38. Have you missed school because of *low back pain*?

Yes No

39. Have you ever had to rest or not play in outdoor activities because of *low back pain*?

Yes No

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ID Number: _____

40. Have you ever seen a doctor/school nurse/physical therapist because of *low back pain*?

Yes No

41. Do you have any injuries that affect you right now?

Yes No If yes, please describe: _____

42. Do you have any medical conditions? Asthma, scoliosis, other?

Yes No If yes, please describe: _____

43. Check the sentence that best describes what you do most of the time for fun after school and on weekends:

I spend most of my time playing outdoors and do things like play sports and ride my bicycle.

I spend most of my time playing indoors and do things like watch TV, using the computer, playing with handheld electronic games, video games or board games.

44. Do you play organized sports regularly?

Yes No If yes, what do you do/play? _____

45. How many hours a week do you play sports?

0-2hrs/week 2-4 hours 4-6 hours 6-10 hours more than 10hrs/week

46. Do you exercise or go outside to play regularly?

Yes No

47. How many hours total **each week** do you exercise or go outside to play?

0-2hrs/week 2-4 hours 4-6 hours 6-10 hours more than 10hrs/week

48. Do you play on a computer? (not including in-school computer use)

Yes No

49. How many hours total **each day** do you play on a computer? (not including in-school use)

0-1/2 hr/day 1/2-1 hr/day 1-2hrs/day 2-4 hrs/day more than 4 hrs/day

50. Do you play a handheld videogame or TV-based video game (ie, Nintendo DS, or Xbox)?

Yes No

51. How many hours total **each day** do you play on videogames (handheld or through the TV)?

0-1/2 hr/day 1/2-1 hr/day 1-2hrs/day 2-4 hrs/day more than 4 hrs/day

Self-Administered Physical Activity Checklist (SAPAC)

A.1 Comments about data recorded? NO YES

This is a physical activity checklist. We want to know what physical activities children your age do, so I am going to ask you questions about what you did on your most recent day of school.

A2. What was the most recent day you went to school?

1 - Monday 2 - Tuesday 3 - Wednesday 4 - Thursday 5 - Friday

Is this within the 3-day SAPAC Window? NO _0 YES _1

If NO, check SAPAC TERMINATED here ____ and do not administer the SAPAC.

A3. Did you participate in physical education (gym) class [Yesterday] or [Day]? NO_0 YES_1

A4. If yes, how many minutes long was physical education class? _____ Minutes PE Class

A5. Did you participate in a recess or break [Yesterday] or [_____Day]? NO__0 YES__1

A6. If yes, how many minutes of recess or break did you have? _____ Minutes 1st Recess/Break
_____ Minutes 2nd Recess/Break

I am going to read a list of physical activities to see if you participated in any of them [yesterday] or [day].

If you tell me yes, that you did participate in any of the activities I read, I will ask you if you did the activity Before School, During School, or After School. I will then ask you how long you did the activity. It is important to determine as close as possible the total amount of time you ACTUALLY DID THE ACTIVITY.

We do not have enough space to write down everything you did [yesterday] or [day], so we will only record activities that you did for at least 5 minutes at a time. If you have trouble figuring out how long you did an activity, I will help you.

As we complete this form, I want you to know there are no right or wrong answers. We just want to know the physical activities you actually did [yesterday] or [] day]. It is important to be very honest.

Okay? Let's go.

SECTION B. ACTIVITIES

	Activity	Before School	During School	After School
1	Bicycling			
2	Swimming Laps			
3	Gymnastics: bars, beam, tumbling trampoline			
4	Exercise: push-ups, sit-ups, jumping rope			
5	Weight lifting			
6	Basketball			
7	Baseball/Softball			
8	Football			
9	Soccer			
10	Volleyball			
11	Skating: ice, roller, roller blade			
12	Hockey: ice, floor, field			
13	Racket Sports: badminton, tennis, paddleball			
14	Ball Playing: four square, dodge ball, kickball			
15	Active Games: chase, tag, hopscotch			
16	Outdoor Play: climbing trees, hide and seek			
17	Water Play: (in pool, ocean or lake)			
18	Combatives: judo, karate, competitive wrestling			
19	Dance			
20	Outdoor Chores: mowing, raking, gardening			
21	Indoor Chores: mopping, vacuuming, sweeping			
22	Skateboarding/Scootering (non-motorized):			
<p>* We walk and/or run many times throughout the day, often for less than 5 minutes at a time. A good example of this is going from class to lunch. Sometimes we do a combination of walking and running, where we walk some and run some. We call this mixed walking and running. *</p>				
23	Mixed Walking/Running			
24	Walking			
25	Running			
26	Other, Name of Activity:			
27	Other, Name of Activity:			

Now I want you to think about any TV, videos, or DVD you watched, or video or computer games you played...

	BEFORE SCHOOL		AFTER SCHOOL	
	hours plus	minutes	hours plus	minutes
T.V./Video/DVD				
Video Games & Computer Games				

APPENDIX V – POST WALK PAIN SURVEY

Post BP Survey Date: _____ Subject/ID: _____ BP Wt: _____

1. After walking with the backpack on for several minutes, how do you feel?

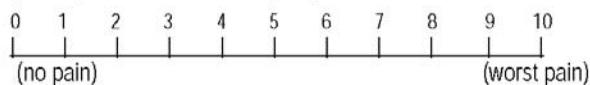
2. Do you have pain or discomfort after wearing the backpack? Yes No

3. Is this pain OK? Yes No

Do you have:

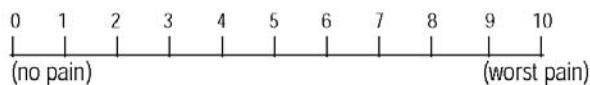
4. Neck pain only? Yes No

5. How bad is your back pain on a scale of 1 to 10?
(0=no pain, 10=the worst pain)



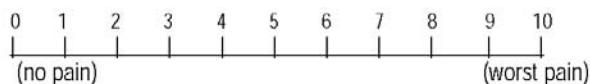
6. Middle back pain only? Yes No

7. How bad is your back pain on a scale of 1 to 10?
(0=no pain, 10=the worst pain)



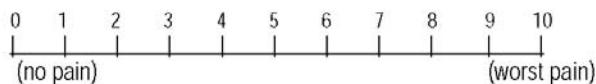
8. Low back pain only? Yes No

9. How bad is your back pain on a scale of 1 to 10?
(0=no pain, 10=the worst pain)



10. Where does it hurt the most?

11. How bad is the pain on a scale of 1 to 10?
(0=no pain, 10=the worst pain)



12. Is there anything you want to tell us about your comfort while wearing the backpack?

