

**THE EFFECTS OF VARIOUS METHODS OF INFANT CARRYING  
ON THE HUMAN BODY AND LOCOMOTION**

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Bachelor of Arts in Anthropology with Distinction.

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## **ABSTRACT**

Although the causes of the evolution of bipedalism are unclear, one consequence is that the hands are freed from use in locomotion, making it possible to carry objects including tools, firewood, water, food, and dependent, helpless offspring. Carrying infants can be problematic because while the baby needs to nurse, the mother also needs to be able to work. Cross-culturally, there are many different methods and tools used by women to carry their babies throughout the day such as front wraps, back wraps, side slings, and carrying in-arms. In this study, I conducted motion analysis on 22 women carrying 7 and 20 lb weights using these four ways of carrying infants. In the biomechanical engineering lab, I observed women carrying two different loads while walking and standing, to look at the change in their posture and variation in gait. Approved by the Human Subjects Board at the University of Delaware, the protocol does not involve harmful or invasive procedures, and assures anonymity. The two main objectives of this research were to understand the effects of baby weight and baby carrying position on the hip flexion and extension angles and the lateral trunk and forward trunk angles. The results show that on the whole, carrying an increased weight exaggerates the effect of the load on the hip and trunk angles. Also, the front and back carrying positions cause a change in the gait of the carrier, while the back wrap and in arms carrying position cause a change in the



posture of the carrier. This study will lead to a better understanding of a universal cultural practice that affects the biology of the human body.



## **Chapter 1**

### **BACKGROUND**

The bipedal form of locomotion, walking upright on two legs, evolved in human ancestors 4-7 million years ago and brought with it both advantages and disadvantages (Hewes, 1964; Kramer, 2004; Lancaster, 1978; Lovejoy, 1981). While models of human origins suggest a variety of different hypotheses to account for the evolution of bipedalism, this remains a contentious area. The possible reasons for bipedalism include: tool use, thermal regulation, predator spotting, and food carrying. Regardless of the cause, one advantage of bipedalism is that it freed the hands from use in locomotion, allowing the biped to carry objects such as tools, water, firewood, dependent/helpless offspring, or food to share with other members of the group. “These tasks are cross-culturally ubiquitous and have an energetic price. Frequently, women bear the majority of transport tasks” (Kramer, 2004: 103).

Among the “objects” carried by humans on a daily basis, infants have usually been ignored by scholars of bipedalism. This is surprising, since women in most non-industrial societies carry their offspring with them for more than 50% of the day (Lozoff et al., 1979; Schön and Silvén, 2007). For example “the !Kung infant is held or carried 80 to 90% of the time during the early months and 60% of the time at nine months” (Lozoff et al., 1979: 481). “The Central African Aka, also a foraging people,

hold their infants about 96% of the time at the age of 3-4 months, and 87% of the time at 9-10 months. For the Kipsigis in Africa, the corresponding figure is 70% for infants under the age of 1 year” (Schön and Silvén, 2007: 146). The women of Bali tend to carry their babies for about a year (DeLoache et al., 2001), while the women of the Wodaabe in Niger usually carry their children until they are two-year-olds (Van Offelen, 1993). “Children are carried so often they seem a part of the mother’s dress” (Aryes, 1973). In many societies, children are carried until they are weaned, able to walk and keep up on their own, or the mother has another child (Aryes, 1973; Kramer, 1998; Schön and Silvén, 2007, Wall-Scheffler, 2007).

When a woman has a child who is still dependent on her for nutrition and mobility, there are several options available to her: she can take and leave the baby within her sight (Aryes, 1973; Falk, 2004), she can leave the baby with an older sibling, grandmother, or other relative (Aryes, 1973; Bernhard, 1996; DeLoache et al., 2001; Marlowe, 2005), or she can carry the baby with her during her daily activities (Bernhard, 1996; Brazelton, 1977; DeLoache et al., 2001; Ellison, 2001; Goldberg, 1977; Kramer, 1998; Marlowe, 2005; McElroy and Townsend, 1985; Wall-Scheffler et al., 2007; Watson et al., 2008). Cross-culturally, the most common form of infant care involves the mother carrying her own offspring throughout the day so that the infant has constant access to her breast for nursing. In addition to developing various methods to carry resources, societies around the world have also created different ways to carry their infants. Infants are usually carried in close body contact, using a sling, a flexible pouch, a wrap, or even no carrying device (Lozoff et al., 1979: 480).

“Modern hunter-gatherers most commonly utilize slings which can be moved to different locations on the torso and inside or out of the clothing” (Wall-Scheffler et al., 2007: 841). “Such devices are specifically used for carrying infants and they are designed to allow the mother to perform routine tasks while keeping the infant in close physical contact” (Aryes, 1973: 392). A woman is able to contribute to her family’s sustenance by working in the fields, foraging, or collecting water or firewood while still caring for her child.

### Modes of Infant Carrying

Four main methods for carrying babies have been developed: front wrap, back wrap, side sling, and no tools. Front wraps are found in Mayan society and among Westerners today in the form of front slings or pouch baby carriers (Bernhard, 1996: McMann, 2008). Front carriage is not very prevalent cross-culturally because if the mother is working or cooking while she is carrying the baby, the baby may get in the way or even get hurt. “The front position, while being less popular in combination with a carrier, is obviously a common choice when carrying a child in one’s arms or as a temporary position during breast feeding” (Schön and Silvén, 2007: 147). The front wrap position can be accomplished by using a single piece of cloth that wraps around the torso of the carrier and/or over his/her shoulders. Some contemporary Western carriers are also made out of cloth while others look like a backpack worn in the front ([www.sobebabies.com](http://www.sobebabies.com)).

Another method of carrying is the back wrap. “The back position seems most widespread in Africa, even though carrying cloths may also be tied in a way that makes it possible to bring the child around to the side, for example for nursing” (Schön and Silvén, 2007: 147). The back carrying position is also found in societies outside of Africa such as the Maya of Mexico (Brazelton, 1977) and Guatemala, the Quechua of the Andes, the Hmong in Thailand, and the Nepali of Nepal (Bernhard, 1996). Like the front wrap, the back wrap also requires the use of a single piece of cloth that is wrapped around the torso of the carrier. Other back wraps are supported by a belt around the mother’s waist (Aryes, 1973). The Inuit also carry their infants on the back, but in the hood of their parka (McElroy and Townsend, 1985). Carrying babies on the back is also common in industrial cultures using a carrier similar to a backpack (<http://www.ergobabycarrier.com/>).

The other mode of infant carrying used cross-culturally is the side sling in which the child is carried on the mother’s hip and is supported by a sling or shawl. The side sling is found in the Balinese (DeLoache et al., 2001), Yanomano of the Amazon, the !Kung in Botswana, the Mbuti in Central Africa (Bernhard, 1996), and the Lese in north east Zaire (Morbeck, 1997). As with the other carrying positions, they are not found solely in non-industrial societies. Westerners are also beginning to use the slide sling when carrying their infants.

While the first three modes of carrying are able to free the mother’s hands for work, the last carrying position is slightly more difficult. The fourth way to carry an infant is without the aid of a device or tool. The child is carried on the mother’s hip,

back, or even shoulders (Aryes, 1973). This type of carrying usually requires the use of the carrier's arms to help support and stabilize the baby, so it is harder for the carrier to do other work. In-arms carrying is found in the Americas, Africa, and Asia (Aryes, 1973).

Not all societies carry their infants throughout the day. "It appears that in the majority of North American societies (Pomo, Iriquois, Salish, Nootka, and Papago) and also in Greece, infants were carried to the field or woods in the cradle, which was then hung from a branch or placed in a hole, while the mother pursued her economic activities" (Ayres, 1973: 392). The babies were rarely held and lay swaddled in a cradle for most of the day. Infant carrying in Western and other industrialized societies has also dropped greatly in recent years probably due to industrialization and the rise of women re-entering the formal job force. Women are able to use substitutes for breast milk, so they are no longer required to be the primary caretaker (Lozoff et al., 1979). When most women go to work in a market economy, they do not bring their babies, but leave them in the care of someone else. In Western societies where people value independence, women have been told that constantly holding or soothing a child will cause him/her to become too dependent and attached to their parents, even though the research supports the opposite conclusion. In an effort to teach their child to be independent, parents sometimes do not respond immediately to their crying baby (Schön and Silvén, 2007). While Westerners believe they are doing what is best for their children, "a baby receiving high levels of maternal body contact by United

States' standards would be judged deprived among hunter-gatherers" (Lozoff et al., 1979: 482).

### Benefits of Infant Carrying

Since carrying infants is a worldwide form of infant care, there must be reasons for why infant carrying is beneficial. In "Natural Parenting-Back to Basics in Infant Care", Schön and Silvén discuss the numerous benefits to carrying babies. Having such close physical contact with its mother can lead to better overall health for the infant. The first advantage of infant carrying is that it allows the infant to breastfeed whenever it needs to. All the nutrition an infant needs can be found in his/her mother's breast milk, which happens to be cost-free and instantly available. "Human milk is low in fat and extremely low in protein, suggesting that the human infant is adapted to frequent feeding and extensive maternal contact" (Lozoff and Brittenham, 1979). Holding a baby close to the body allows him/her to be soothed by the carrier's heartbeat, a sound they heard while in the womb. "Research data supports the notion that young infants feel most comfortable in an environment approximating that before birth" (Schön and Silvén, 2007: 111). Babies who were exposed to a recording of a human heart beat were shown to cry less, to pacify easily, and to be generally healthier than babies who were not exposed to a regular heartbeat after birth (Schön and Silvén, 2007: 111). As well as having that comforting sound of the heartbeat, walking and working while carrying also provides a soothing rocking motion. "Infants sleep peacefully while the mother works, abandoning themselves completely to the



movements of the carrier” (Aryes, 1973: 393). Schön and Silvén also mention studies that have shown that touching and massaging are linked to a better immune system. Touching can stimulate glands in the skin, which are a part of the immunological process, to secrete certain hormones (Schön and Silvén, 2007: 116). Another benefit of carrying infants lies in thermal regulation. “The distribution of body fat of human infants suggests that ventral contact with the caregiver helps to guard young infants against excessive loss of body heat” (Schön and Silvén, 2007: 117). Finally, carrying an infant can be beneficial to his/her hip development. Because a newborn baby’s spine is more curved, rather than S-shaped like an adult human’s spine, their legs are usually in a position of flexion and abduction. “This anatomical feature does not support upright walking, but is ideal for lateral sitting on the caregiver’s hip” or in a carrier that supports this healthy posture (Schön and Silvén, 2007: 107). Carrying infants throughout the day also provides many chances for the child to learn and be stimulated by the world around them. The baby is able to see how the mother interacts with others and her surroundings. (Konner, 1977). Not only does carrying infants allow the mother to do other work while caring for her child, but it is also good for the health of the baby.

### Evolution and Infant Carrying

While access to feeding and mother-child bonding are a few reasons that babies are carried, there are three main characteristics of the human body that have evolved and ensured that the babies must be carried or at least heavily cared for in

order to survive: increased brain size, fur reduction, and upright walking. The first evolutionary reason, encephalization, is the increase of brain size in relation to body size. By having a larger brain, human babies must be delivered/born early in their development so that they are able to pass through the birth canal (Rosenberg and Trevathan, 1999). Because of the human body structure, the infant cranium fits snugly inside the birth canal in comparison to other primates, making the birthing process more difficult, painful, and most important, risky. “The exceptionally immature state in which humans infants are born indicates that gestation is not complete with birth but needs to be completed outside the womb as a form of extero-gestation - the development takes place outside the mother’s uterus” (Schön and Silvén, 2007: 110). Being born at an earlier developmental stage means that the baby is very dependent on others for survival. “Humans are in a more immature state at birth, and continue to be dependent on their parents’ care for a longer period than practically any other mammal” (Schön and Silvén, 2007: 110). In other primates, the mother only carries her infant for the first few weeks, until the infant is strong enough to cling to her body hair (Lancaster, 1978). A human infant is unable to hold up his head, let alone support his own body weight. Our infants are unable to cling to their mothers, requiring that the mother actively carry the infant during locomotion.

Even if human babies had the strength to support themselves and cling to their mothers, their mothers do not have anything for them to cling to. The second characteristic of the human body that requires human infants to be carried is hair loss. Other primates’ bodies are covered in fur that provides their infant something to grip

onto when the mother is moving from place to place (Altmann et al., 1992; Lancaster, 1978). While there are humans who are “hairy”, we are no longer covered in dense body fur like other primates (Schön and Silvén, 2007: 106).

Finally, even if human infants were strong enough support their own weight and their mothers had fur for them to hold onto, the morphology of their feet and gravity would inhibit them. The last characteristic of modern humans that contributes to the fact that babies must be carried lies in our bipedal locomotion. As part of the change in locomotion from quadredpedalism to bipedalism, the human foot was selected to be a more stable platform with all of the toes in-line with each other. Humans no longer have opposable first toes, and our feet are unable to grasp in the way that other primates can (Schön and Silvén, 2007; Wall-Scheffler, 2007). Because we no longer have grasping feet, it would be difficult or even impossible for human infants to cling to a parent using only their upper body strength, rather than being able to use their feet as other primates are able to do. Also, bipedal humans are traveling upright, rather than on all fours like many other primates. When the infants of non-human primates cling to the fur of their mother’s back, they are on a slight slope of their caregiver's horizontal back. While most quadrupedal monkeys have arms and legs that are the same length so that their backs provide a flat area for the baby to ride on, other primates do not. Chimpanzees have slightly longer arms than their legs, there is a slight slope of the backs when they are knuckle-walking. Gorillas have even longer arms, so that there is an even greater slope. With bipedalism however, the infant would be on a completely vertical slope, and it would be difficult for it to hang

on without falling (Wall-Scheffler et al., 2007). “Bipedality is clearly incompatible with the usual clinging and mounting pattern of infant carrying” (Amaral, 2008: 281).

### The Costs of Infant Carrying

As stated previously, there are many reasons why infant carrying is beneficial for humans, especially to the infant. However, infant carrying comes at a heavy price for the mother. Infant carrying in primates is one of the most costly forms of infant care for the mother, second only to lactation (Altmann and Samuels, 1992; Kramer, 1998; Wall-Scheffler et al., 2007, Watson et al., 2008). A few studies have been done to better determine the energetics of infant carrying and their effects on human evolution. One such study was conducted by Kramer (Kramer, 1998). “Since maternal energy is a finite resource, the “decision” the carry a child or force it walk independently is especially important” (Kramer, 1998: 71). One issue that she addressed was the energetic cost of locomotion for children. She found that the younger the child, the more energetically costly it is for them to walk independently at increasing speeds. Therefore it is always in the child’s best interest to be carried so that they can use their energy towards other tasks, such as growing. By also taking into consideration how dependent the child was on the mother for nutrition, the weight of the mother, and speed at which she walked, Kramer examined when a mother should force her child to walk independently. If the child receives the majority of his/her nutritional intake from external sources, it is best energetically for a mother who weighs less than 45 kg not to carry her child. “In all cases, as the contribution of

the mother to the child's nutritional support, and hence energetic budget, decreases, the critical velocity increases and the age at which she would force her child to walk independently decreases. In other words, increased nutritional support of offspring by external agencies reduces the mother's need to carry her child" (Kramer, 1998: 83). However, at high velocities, it can be to the mother and child's benefit for the mother to carry the child, no matter her size.

Another important study on the cost of infant carrying was done by Wall-Scheffler et al who examined the energetic costs of infant carrying and its role in tool development (Wall-Scheffler et al., 2007). Since infant carrying is such a costly form of infant care, Wall-Scheffler et al. wanted to determine if it is energetically beneficial for the mother to use a tool to aid in infant carrying. For their methods, they had 6 women walk on a treadmill under four conditions: carrying a weight with arm swing, carrying a weight without arm swing, carrying an infant dummy using a sling, and carrying an infant dummy in arms. They found that carrying an infant using a sling is far more economical and requires fewer calories than carrying an infant in arms and without the use of a tool. Since our human ancestors would have also needed to carry their offspring, "this research has suggested that the cost of carrying an infant in one's arms would have been meaningful enough to reward the development of carrying tools rapidly following the advent of bipedalism" (Wall-Scheffler et al., 2007). While there is little archeological evidence of infant carrying tools before 15,000 years ago because of the biodegradable nature of the material, it is reasonable to assume that infant carrying tools were among the first tools to be created.

Finally, Watson et al., examined the role of infant carrying in the evolution of bipedalism (Watson et al., 2008). The importance of carrying efficiency was central to one of the hypotheses about why bipedalism evolved in human. Watson et al. measured the energy cost of carrying a load in different positions that would have been available to our human ancestors. One of the weights was made to represent a toddler and was carried asymmetrically on the hip by the research subjects. The results showed that carrying a weight asymmetrically was significantly more energetically costly than carrying an evenly distributed weight. Since the cost of carrying an infant on the hip while walking is so high, they concluded that it was unlikely that infant carrying was a precursor to bipedalism.

All three studies show that the energetic cost to the mother of infant carrying is very high. By studying the energetic costs of infant carrying, researchers are not only able to look at the effect of infant carrying on people today, but they are also able to hypothesize about its role in human evolution. Because the costs of carrying a child for a long period of time is so difficult, it is unlikely that it was a reason for the evolution of bipedalism, but a result. Also, while babies are carried for large portion of their early life, there comes a time when it is in the mother's best interest to stop carrying her child. This point is dependent on the main source of the child's nutrition and the weights of the mother and child. Finally, the high cost of infant carrying without a tool can lead us to the conclusion that the use of a sling (which greatly reduced these costs) was probably developed and utilized by our human ancestors.

### Biomechanical effects of carrying

Since there is very little information about the effects of infant carrying on the biomechanics of human posture and walking, I had to draw my hypotheses about the effect of the different carrying positions from research on other topics. To study the effect of front carrying, I focused on the effects of pregnancy. For back carrying, I reviewed research done on children and soldiers with backpacks. For side sling and in-arms carrying, I used studies focusing on the effect of asymmetrical loading and hand lifting during work. I also looked at the health issues for the carrier associated with all of the carrying methods. While most of these studies do not address the effect of carrying babies, their results are directly relevant to my own research.

#### Front Carrying:

As stated previously, carrying babies in a front wrap can be compared loosely to pregnancy. “A decrease in perceived stability combined with an increase in mass might result in pregnant subjects displaying similar gait adaptations as those found in obese and load-carrying people” (Lymbery, 2005: 247). In addition to changes in gait, there are health concerns during pregnancy that are associated with the positioning of the extra load.

Numerous studies have looked at gait changes during pregnancy. Some researchers found that there is a significant change in gait because of the shift in the center of mass (COM) while others did not find a significant difference. Lymbery and Gilleard found that there was a change in gait pattern when women were pregnant.

They tested 13 women's gait patterns and ground force reactions during and after pregnancy. There was a wider step width and the ground force reaction increased in a medial direction during pregnancy. "The alterations in gait pattern seen in late pregnancy compared with after birth were consistent with a need to promote stability" (Lymberry and Gilleard, 2005: 249).

While some studies show that pregnancy and the shifting in the COM anteriorly causes a change in gait pattern, other research refutes this idea. Foti et al. conducted a study that included 15 women in the second half of their third trimester, and then again at one year post partum. In order to examine gait, they calculated and analyzed the lower-extremity joint angles, net joint moments, and net joint powers during the gait cycle. Foti et al. found that "despite major anatomical changes associated with pregnancy, the kinematics of gait during pregnancy was found to be remarkably unchanged." (Foti et al., 2000: 632). While there were small deviations in pelvic tilt and hip flexion, extension, and adduction, it was not enough to change the walking velocity, stride length, or cadence, the number of steps per unit of time. These data suggest that pregnant women are able to maintain their normal walking pattern by changing their body posture slightly to compensate for the extra weight in front.

In addition to a possible change in gait, pregnancy may also physically alter the mother's stance and her joint angles during standing. In her dissertation, Whitcome tried to better understand the biomechanical change of pregnancy, specifically looking at the change in center of mass (COM) and spinal loading



patterns. She included 25 pregnant women in her research and conducted a motion analysis of their posture and gait at different points throughout their pregnancy. Whitcome found that an increase in the curve of the lower back and the pelvic tilt during human pregnancy provides a biomechanical solution to the shift in the maternal COM (Whitcome, 2006). The larger the fetus gets, the greater the effect on the mother's lumbar lordosis and pelvic tilt.

The change in gait and body angles due to the change in COM may be the cause of health concerns for pregnant women and load carriers. "Incidence of back pain during pregnancy has been reported to range from 47 to 82%" (Franklin, 1998: 133). "Many of the common musculoskeletal problems associated with pregnancy may be due, in part, to musculoskeletal overuse injuries incurred as a consequence of secondary gait deviations that compensate for changes in body mass and distribution" (Foti et al., 2000: 625). Changes in body posture that neutralize the effects of the increased and shifted weight may cause additional stress to the lower back muscles. Noren et al. found that 20% of women who experienced back pain during pregnancy also had pain 3 years later. Most of the pain was in the lumbar the sacral regions (Noren et al., 2002). These data may also be predictive of the pain and injuries felt by women who carry their babies throughout the day. Since the body is subjected to similar forces, it will also probably have similar consequences as carrying an extra load.

However, not everyone agrees that the change in posture is a direct cause of back pain during pregnancy. The results of other studies have shown that there is no

correlation between posture changes and back pain. Franklin and Conner-Kerr conclude that “from the first to the third trimester of pregnancy lumbar lordosis, posterior head position, lumbar angle, and pelvic tilt increases; however, the magnitude and the changes of these posture variables are not related to back pain” (Franklin and Conner-Kerr, 1998: 136). They suggested that posture-correcting clinical exercise regimens should be investigated and considered as a cause of back pain in pregnant women.

#### Back Carrying:

While carrying babies on the back has not been studied extensively, a large amount of research has been done on back carrying in general. The use of backpacks is most commonly used in schools, the military, and in recreation. The research focuses on ergonomics and the way the backpack affects the body. While carrying a baby in the back wrap position is not the same as carrying 40% of body mass in military equipment, the results and conclusions of backpack carrying can be used to better understand the effect of back wrap on posture and locomotion.

One of the most common areas of research in back carrying involves school children. In many countries, children are carrying increasingly heavy loads in their backpacks. Researchers and parents are concerned with health issues that arise from young children and adolescents continually carrying heavy loads (Chow et al., 2006; Forjuoh et al., 2004; Hong and Cheung, 2003, 2008; Pascoe et al., 1997; Seven et al., 2008; Singh and Koh., 2009).

In 2003, Hong and Cheung looked at the effect of carrying different weights in the backpack position in 9-10 year old boys. By looking at stride length and trunk lean angles, they concluded that for young children, the average weight of a backpack should not exceed 15% of body weight. “The results showed that the 20% body weight load induced significant forward lean of the trunk” (Hong and Cheung, 2003: 32). In order for the body to maintain stability, the child leaned his trunk forward to compensate for the weight on the back. This forward lean may cause musculoskeletal strain of the lower back in young school children. In a recent study of backpack loads in school children, Singh and Koh also reported higher trunk lean when walking with a backpack (2009). They concluded that “during load carriage, the forward inclination of the trunk counters the posterior shift of the combined COM of the body and backpack system” (Singh and Koh, 2009: 52). In order to look at the change in gait with use of a backpack, Chow et al. analyzed pelvic motion and hip flexion and extension. They found that there was a decrease in speed, stride length, and pelvic motion, and a greater degree of hip flexion-extension. Overall, “load-bearing placed increased demands on gait” (Chow et al., 2006: 430).

Carrying heavy loads is especially dangerous in young children and adolescents because “heavy backpacks can put pressure on the growing joints and ligaments” (Forjuoh, 2004: 532). Pascoe found that the most common symptoms associated with overweight backpacks were muscle soreness, back pain, numbness, and shoulder pain (Pascoe, 1997: 638). The straps of the backpacks put pressure on the nerves in the shoulders affecting the shoulders and the arms. While the back

carrying position included in my research does not involve the use of straps, it does displace the center of mass in the same direction. Also, it is important to note there is a physical difference between children and adults. The effects of a backpack may be more exaggerated and amplified in a child compared to an adult because they are still growing and therefore their bodies are more susceptible to change.

The military is another group that conducts research on the effects of carrying heavy loads. “Foot soldiers often carry extremely heavy backpack loads and walk longer distances than most of their civilian counterparts” (Knapik et al., 1996: 207). The research has been used to argue for improving the load-bearing performance of infantry and trying to reduce the adverse effects of carrying a heavy load for a long period of time (Birrell et al., 2007; Dziados et al., 1987; Harman et al., 2000; Knapik et al., 1996; LaFiandra et al., 2003; Schiffman et al., 2006; Tilbury-Davis et al., 1999). Another area of backpack use that has been studied extensively is its use in recreational activities. Hikers normally carry heavy loads using backpacks (Bloom et al., 1987; Kinoshita, 1985; Knapik et al., 1996). The research in this field has been geared toward calculating the optimal amount of weight that can be carried safely over long distances, and toward better understanding of the injuries that can occur because of the extra weight. The weight carried by soldiers and hikers are usually higher than the weight of a baby, but by looking at a heavier weight, we can gain insight into the effect of back loads on the body and locomotion.

Multiple studies of backpack carrying have analyzed the effect of the weight and its position on the forward trunk angle (Bloom et al., 1987; Harman et al., 2000;

Kinoshita, 1985; Knapik et al., 1996; Martin et al., 1986). In a review of load carriage, Knapik et al., showed that the forward trunk lean of a backpack carrier may increase with three factors: increasing fatigue, increasing load, and increased need for stabilization. “Forward inclination of the trunk increases significantly with load, which helps to keep the body-plus-pack center of mass over the feet (Knapik et al., 1996: 210). Harman et al. also found that the forward incline of the trunk was meant to put the center of mass over the feet, however “the adjustment did not bring the center of mass as far forward over the foot as without a load” (Harman et al., 2000: 1). Another study also found an increase in forward trunk tilt, but only with heavier weights carried in a rucksack. The heavier the weight, the more the carrier leaned forward (Martin et al., 1986: 1197). “An examination of the mean data indicated that the average forward lean of the trunk while carrying the heavy load (40% of body weight) reached approximately 11 degrees” (Kinoshita, 1985: 1358). Even with different locations of the weight in the backpack, the carrier still leans forward. When investigating different backpack types, Bloom and Woodhull-McNeal found that while the trunk tilts forward with any type of backpack, wearing the bulk of the weight lower and closer to the trunk requires more compensation by the body to maintain balance (Bloom et al., 1987: 1429). In addition to trunk tilt, the effect of backpacks on postural sway has also been studied to better understand how the body maintains stability. Schiffman et al. included fourteen male soldiers in their research and used three different weights. “It appears from the findings of this study that increasing the

mass of an external load on the body changes balance control without muscle activity” (Schiffman et al., 2006: 613).

The effect that backpack carrying has on gait has also been investigated in multiple studies. There are two criteria that must be met in order to assume that a gait pattern is successful: forward propulsion and maintenance of balance (Hsiang et al., 2002: 650). A failure in gait can lead to falling and injuries. To better understand how the body maintains balance when carrying, one study looked at four different ways of carrying (back pack, front/back pack, front pack, and “two hands carrying”) at multiple speeds (Hsiang et al., 2002). By looking at the ground reaction forces, they found that “some loading positions and higher speed reduce the reliability of the execution of gait patterns while other positions may actually increase the reliability” (Hsiang et al., 2002: 639). The “two hands carrying” and front loading conditions produce the highest weight acceptance most likely because of the forward shift in the center of gravity, thus changing the gait pattern. Focusing solely on the effect of backpacks on the gait pattern, another study looked at walking speed and the coordination of trunk movements in both men and women (LaFiandra et al., 2003). The results supported their hypothesis that carrying a backpack containing 40% of body mass would decrease pelvic rotation and therefore decrease stride length and increase stride frequency.

While carrying heavy loads on the back can be harmful because the extra weight on the back can cause the carrier to be unstable and therefore increase their chances of falling, there is also the possibility of a permanent change in body posture

because of the continuous load. The permanent effects may especially be seen in adults who carried heavy loads while they were young and still growing. Smith et al. completed their study of 30 women college students and analyzed the influence of backpacks on pelvic tilt and rotation. “Range of motion for pelvic obliquity and rotation was significantly decreased when walking with a backpack. These results suggest that backpack carriage could cause permanent posture deviations in young female college students” (Smith et al., 2006: 263). Carrying a backpack increases the forward trunk lean which “may lead to increases lordosis causing compression of the lumbar vertebral bodies and facet joints, increased interdiscal pressure, and narrowing of the intervertebral foramina resulting in chronic lumbar pain disorders” (Smith et al., 2006: 266).

#### Asymmetric Carrying:

To better understand the effect of carrying an infant in the side sling position, I looked at studies done on single strap backpacks. Not only are single strap backpacks used by school children, but they also used by many workers such as those in the U.S. postal service. Fowler et al. examined the effect of asymmetrical loading on trunk orientation (2006). “Carrying an asymmetric load caused the participants to increase the side flexion of the trunk in comparison to the unloaded condition in all periods of the gait cycle in a direction opposite to that in which the bag was held” (Fowler et al., 2006: 137). They also noted an increased forward trunk flexion with the heavier loads.

While Fowler et al. focused on the effects on the upper body posture, other studies have focused on lower limb coordination during gait. Matsuo et al. compared asymmetric loading between young and elderly women (2008). They also found that “asymmetrical load-carrying was associated with increased trunk flexion toward the contralateral side and the amplitude of the trunk lateral flexion increases with the load weight” (Matsuo et al., 2008: 518). In terms of the lower limbs, their results show that the “lower limb coordination was not affected by different load conditions” (Matsuo et al., 2008: 518).



## **Chapter 2**

### **AIMS & HYPOTHESES**

In my research, I chose to examine different styles of infant carrying that occur frequently around the world. My aim was to understand whether different cultural practices are associated with different biological consequences on the human body and to understand the range of how walking might be affected by different types of carrying. In my study, I looked at two different loads (Cathy - 7 lb.; Timmy 20 lb.) and four different carrying patterns as well as an unloaded condition.

First, I will examine the effect of the increasing weight of the baby on the trunk and hip angles during each carrying position. Second, I will examine the effect of the carrying position on the trunk and hip angles with each baby. The hip angles that I looked at are the hip flexion angle and hip extension angle, the trunk angles are the lateral trunk angle and the forward trunk angle.

#### **1. The effect of baby weight on hip and trunk angles with the same carrying position**

1.1. The effect of increasing baby weight on hip and trunk angles during the front carrying position compared to the control.

##### **Hypotheses:**

1.1.1. As the weight of the load increases from 0 to 7 to 20 lbs., the hip flexion angle at heel strike will increase and the peak hip

extension will decrease. Since the center of mass is anteriorly placed, the carrier will take a larger step forward and extend her leg less posteriorly with the increasing weight.

1.1.2. As the weight of the load increases from 0 to 7 to 20 lbs., the trunk lateral angle will remain unchanged. Even with an increasing weight, the carrier will not lean to either side because the load is placed toward her mid-line.

1.1.3 As the weight of the load increases from 0 to 7 to 20 lbs., the trunk forward angle will decrease. Because the center of mass is shifted in front of the carrier, she will lean increasingly backwards with the increasing weight.

1.2. The effect of the increasing baby weight on hip and trunk angles during the back carrying position compared to the control

Hypotheses:

1.2.1. As the weight of the load increases from 0 to 7 to 20 lbs., the hip flexion angle at heel strike will decrease and the peak hip extension will increase. As the load increases in the back of the carrier, she will take smaller steps forward and extend her leg further behind her.

1.2.2. As the weight of the load increases from 0 to 7 to 20 lbs., the trunk lateral angle will remain unchanged. Even with an

increasing weight, the carrier will not lean to either side because the load is placed toward her mid-line.

1.2.3. As the weight of the load increases from 0 to 7 to 20 lbs., the trunk forward angle will increase. As the carrier has more weight to carry on her back, she will lean forward to compensate for the weight.

1.3. The effect of the increasing baby weight on hip and trunk angles during the side carrying position

Hypotheses:

1.3.1. As the weight of the load increases from 0 to 7 to 20 lbs., the hip flexion angle at heel strike and the peak hip extension will decrease on the side with the weight. The load on the side of the subject will obstruct their gait on that side causing the carrier to take a smaller step with the leg that is on the side supporting the load.

1.3.2. As the weight of the load increases from 0 to 7 to 20 lbs., the trunk lateral angle will increase, tilting away from the side with the load. Since the weight is located laterally, the carrier will tilt away from the load to maintain their balance.

1.3.3 As the weight of the load increases from 0 to 7 to 20 lbs., the trunk forward angle will remain unchanged. Since the

weight is not posterior or anterior to the carrier, they will not have to lean forward or backward to compensate for the load.

#### 1.4. The effect of the increasing baby weight on hip and trunk angles during the “in arms” carrying position

##### Hypotheses:

1.4.1. As the weight of the load increases from 0 to 7 to 20 lbs., the hip flexion angle at heel strike and the peak hip extension will decrease on the side with the weight. The load on the side of the subject will slightly obstruct their gait on that side, causing the carrier to take a smaller step with the leg that is on the side supporting the load.

1.4.2. As the weight of the load increases from 0 to 7 to 20 lbs., the trunk lateral angle will increase, tilting away from the side with the load. Since the weight is located laterally, the carrier will tilt away from the load to make sure that they are secure while walking.

1.4.3 As the weight of the load increases from 0 to 7 to 20 lbs., the trunk forward angle will increase. Since the weight is not posterior or anterior to the carrier, they will not have to lean forward or backward to compensate for the load.

#### 2. The effects of the carrying position on hip and trunk angles with the same baby weight.

2.1. The effect different carrying positions on hip and trunk angles while carrying 7 lb.

Hypotheses:

2.1.1. The largest increase in hip flexion at heel strike will occur using the front wrap, and a decrease in the back, side, and in arms carrying positions. The largest increase in the peak hip extension will occur using the back carrying, and decrease in the front, side, and in arms carrying positions. Carrying the weight anteriorly will cause the carrier to take a larger step forward, while carrying in the other positions will cause the carrier to take a smaller step forward. Carrying the weight posteriorly will cause the carrier to extend their leg further back, while the other carrying positions will do the opposite.

2.1.2. The largest increase in lateral trunk lean away from the carrying side will occur using the side sling and in arms carrying. There will be no change during the front and back carrying. Placing the load laterally will cause the carrier to tilt to the side to compensate for the lateral shift in center of mass.

2.1.3. The largest increase in forward trunk angle will occur using back carrying, no change in side and in arms carrying, and a decrease in front carrying. Carrying the weight posteriorly will cause the carrier to lean forward, while carrying the weight

anteriorly will cause the carrier to lean back. The other carrying positions will not affect the forward angle because they are positioned laterally.

## 2.2. The effect of different carrying positions on hip and trunk angles while carrying 20 lbs.

### Hypotheses:

2.2.1. The largest increase in hip flexion at heel strike will occur using the front wrap, and a decrease in the side, in arms, and back. The largest increase in the peak hip extension will occur using the back carrying, and decrease in the side, in arms, and front carrying. Carrying the weight anteriorly will cause the carrier to take a larger step forward, while carrying in the other positions will cause the carrier to take a smaller step forward. Carrying the weight posteriorly will cause the carrier to extend their leg further back, while the other carrying positions will do the opposite

2.2.2. The largest increase in lateral trunk lean away from the carrying side will occur using the side sling and in arms carrying. There will be no change using the front and back carrying. Placing the load laterally will cause the carrier to tilt to the side to compensate for the lateral shift in center of mass.

2.2.3. The largest increase in forward trunk angle will occur using back carrying, no change in side and in arms carrying, and a decrease in front carrying. Carrying the weight posteriorly will cause the carrier to lean forward, while carrying the weight anteriorly will cause the carrier to lean back. The other carrying positions will not affect the forward angle because they are positioned laterally.

## **Chapter 3**

### **METHODS**

#### Human Subjects Review Board

Before contacting potential subjects, I submitted my research proposal, protocol (see Appendix A), and informed consent form (see Appendix B) to the University of Delaware's Human Subjects Review Board as required by the Undergraduate Research Department. My research was approved to include women from the ages of 18 to 40 years in a noninvasive study. Originally, I planned to include 15 women, but I was able to increase my subject pool to 22 women. Before I began the experiment, each subject signed an informed consent form. Anonymity of the subject is ensured. With the subjects' consent, pictures and video taken during each experiment are used only for comparison with the motion data and/or educational presentations. If used in presentations, the subjects' faces are blocked out in the pictures and videos so that they cannot be identified.

#### Finding participants

In order to find interested participants for my research, I contacted members of student groups and academic organizations of which I am a member. These groups included Anthropology Club, Delaware Kamaal (Indian-fusion dance team), Summer



Scholars, and McNair Scholars. My professors in the anthropology department also told students in their classes about my research in class and through email. Potential participants were given a summary of the topic of my research and the protocol I would be following. They were told that they would be asked to wear shorts and t-shirt. They would have to walk at their self-selected speed on a treadmill carrying weighted dummies (7 and 20 lb.) in 4 different positions. The entire experiment would last a maximum of 2 1/2 hours, and with their consent, pictures and videos would be recorded. While I had about 30 women who were interested, because of time issues and the difficulty of coordinating schedules, I was only able to include 22 women in my study.

#### Conditions for Participation

My sample included healthy women from the University of Delaware, students and faculty, between the ages of 18 and 40 years. They were not currently pregnant, nor had they had a muscle, bone, or nervous system disorder. The average weight of my subjects was 130 lb.  $\pm$  20 lb. and their average height was 64 in.  $\pm$  2 in.

#### Collecting Data

When a subject was recruited for my research, we scheduled a date when they were free for a time block of 2 1/2 hours. They were asked to prepare for the experiment by bringing shorts, a t-shirt, and sneakers.

Before the subject arrived on the day of the experiment, I prepared the lab (Biomechanics treadmill lab, room 203 in Spencer Lab at the University of Delaware). For the weights that would represent the two babies, I bought water rescue mannequins (Mass Group Inc. Miami, FL; <http://www.drmass.com/>): Rescue Timmy 3-Year Old - Child (water filled weight 20 lb.. Size: 34" x 11" x 7") and Rescue Cathy - Newborn (water filled weight 7 lb.. Size: 26" x 8" x 8"). I filled the mannequins with water in the bathroom sink by attaching one end of the tube provided to the valve on the mannequin's foot and the other to the tap. They were filled until water came out of the valve on the other foot as instructed by the manual. The lab was calibrated by using Cortex 1.0.0. (Motion Analysis, Santa Rosa, CA; sampling rate 60 Hz) and the force plates on the split belt treadmill (Bertec Corp. Columbus, OH; sampling rate 1080 Hz) were tarred. The weight of the mannequins were recorded on a single belt of the treadmill.

When the subjects arrived, they read and signed the informed consent form, and any questions they had were answered. To measure the self-selected speed at which they would be walking during the experiment, the subjects were asked to walk up and down the hallway at their normal speed. The time it took them to walk 10 meters was recorded twice using a stopwatch and then averaged to find their self-selected speed. This average was then converted to mm/s so that it could be entered into the treadmill controls. In addition to weighing the subject on the scale in the lab, I recorded their weight on the treadmill by having them stand on a single belt. This was done to ensure that the correct weight was recorded.

Twenty-seven retro-reflective markers were then attached to the subject using Velcro dots in the Helen Hayes placement protocol (Davis et al., 1991; Zeni and Higginson, 2009). The markers were placed on the head of the second toe, the heel, the inside and outside ankle, the shin, the side of the knees, the thigh, the anterior superior iliac spine, the sacrum, the sternum, shoulders, elbows, and wrists (Seven et al. 2008). A cloth band was attached around their hips to keep the subject's shirt close to her body and to attach the pelvic markers. The subjects were then wrapped using one of the four styles of baby carrying. The subjects first carried Cathy, and then carried Timmy in the same position. Each trial consisted of a single baby in one carrying position. At the beginning of each trial, a Static was recorded when the subject was asked to stand still with a foot on either belt while carrying the mannequin. Before they began walking on the treadmill, the markers on the medial side of their legs were removed to allow them to walk as normally as possible without worrying about the markers rubbing against each other.

Before they began the dynamic portion, the subjects were told to keep each foot on its treadmill belt during walking and to avoid stepping in the middle. They were also told that they had the option of hitting a red button on the treadmill to stop it at anytime if they felt it was going too fast. Using the treadmill controls at the computer, I was able to start and stop the treadmill. I eased the subjects up to their self selected walking speed, and once they were walking on the treadmill comfortably for a few seconds, I began recording the data. The markers were tracked in Cortex 1.0.0. Each recording lasted 30 seconds, and multiple recordings were taken to ensure

that at least one recording had tracked all of the markers for most of the time. Problems arose when some of the markers would become unstuck from the subject and fall off, or a marker would become hidden from the motion analysis cameras by part of the wrap, the subjects' clothing, or the mannequin. The markers were reattached if they fell off during a trial and repositioned if they moved from their original position or became blocked by the cloth or mannequin. The markers for the sacrum and the sternum had to be placed on the mannequin if the mannequin was blocking the spot where the marker should have been. The sternum's marker was placed on Timmy's head when in the front carrying position. The sacrum marker was placed on Timmy's, and occasionally Cathy's back, when in the back wrap position because the mannequin blocked the carrier's lower back.

The subjects were asked to carry the two mannequins in four different ways: front wrap, back wrap, side sling, and "in arms". I wrapped all of the subjects into all of the loading positions and loaded them with the mannequins. If the subject was uncomfortable with the positioning or felt that the mannequin was slipping, I re-wrapped them until they felt secure enough to walk on the treadmill. For the wraps, I used pieces of cloth that I already owned that I cut into the right dimensions or a piece of cloth on loan to me from Dr. Katherine Dettwyler. This piece of cloth was from Mali and used to carry babies in the back wrap position. Cloth dimensions: front wrap (22 in. x 210 in.), back wrap (45.5 in. x 62.5 in.), and side sling (22 in. x 80 in.).

The front wrap was done by using a single long piece of cloth. The cloth was first placed horizontally across the stomach with the ends towards the back. The ends

were then crossed in the back and brought over the shoulders. The ends were then draped down the front, but tucked under the first section that is across the stomach. I then placed the baby underneath the waist band of the wrap and the subject held the baby in position against her chest while I continued to secure the wrap. I crossed the ends of the wrap in between the legs of the mannequin and around the back of the subject. The ends were brought to the front of the subject after crossing again in the back, and then I knotted it in front of the subject. The straps over the subject were adjusted for comfort by spreading them across the shoulders but not covering the marker. The band over the baby was pulled up to cover its back so that it would not tip forward. The smaller mannequin, Cathy, was carried facing the subject and the larger mannequin, Timmy, was carried facing away from the subject. Timmy's legs were tucked up and into the front of the wrap because when his legs hung down, they blocked the camera's view of the thigh markers.

In order to allow me to tie the back wrap, the subject stood bending forward at the waist for most of the time. Leaning forward helped to balance the mannequin on her back while the cloth was being tied. I placed the mannequin on the subject's back and laid the rectangular piece of cloth over the baby and the subject with the upper edge across the baby's shoulder blades. The subject secured the upper edge of the cloth in front of themselves by overlapping the ends above their chest and rolling the cloth outward as if they were wearing a bath towel. While they were doing this, they were still in the forward leaning position and I was holding the baby against their back. When the top was rolled tight enough for the subject's comfort, I tied the

bottom half by double knotting the two lower corners of the cloth in front of the subject and around her waist. Both mannequins were carried with their face towards the subjects' backs. When tying Timmy, his legs were put on either side of the subject's waist to simulate the way in which a child of that size would wrap their legs around their mother while being carried.

Before I tied the side sling, the subject held the mannequin to either side to choose which side they found more comfortable. After choosing, they held the mannequin to the preferred hip, and I tied the cloth by first putting the middle around the mannequin's bottom and then draping it across the body and up to the other shoulder. The ends were knotted over the shoulder and made tight enough for the subject's preference. The excess cloth was tucked in under the sling to avoid discomfort or blocking the markers.

When carrying the mannequins in their arms without the use of any slings, the subjects were asked to carry the mannequins in the way that they would carry an infant and a one-year-old child. Most subjects chose to carry Cathy in a front cradle position using two arms. Most of the subjects carried Timmy on the same hip they used for the side sling position using two arms or in the upright front carrying position.

For my control, I recorded the subjects walking without carrying any weight at all.

Throughout the experiment, I took pictures and recorded the subjects walking with the different weights. I would take a picture or record a 10 second clip of the subject after they completed the trials.

After the experiment, the subject was free to leave. After they left, I shut down the treadmill and closed the computer applications. I emptied the mannequins in the bathroom sink and pumped air back into them. All of the supplies (the mannequins and wraps) were stored in the lab. While the data were collected in the software Cortex, they were processed using another software, Orthotrack.

#### Points chosen for analysis:

At the beginning of my research, I was interested in looking at the effect of the different carrying positions on lower back. After reading Katherine Whitcome's dissertation on the effect of pregnancy on lumbar lordosis, I wanted to see how carrying the baby after birth would affect the mother's body. In many cultures, the burden on the mother of carrying a child does not end with pregnancy, but continues until the child is a few years old. Since there are many different ways to carry a child, I originally wanted to see how these positions would also affect the lower back.

However, while putting together my protocol in the biomechanical engineering lab, I realized that studying the lower back would be very difficult if not impossible. In order to track the motion of the lower back, I would have to place the reflective markers directly on the subject's back. Unfortunately, the back carrying position places the weight on the back of the subject, blocks the markers from view of the motion analysis cameras. While I could track the lower back in the other carrying positions, the back wrap meant that I could not observe the lower back.

To compromise, I was able to try to analyze the affect on the lower back by looking at the body segments around it. I chose to track the trunk angles and the hip angles because they were closest to the lower back and would probably also be affected by the weight and carrying position. I did not want to look at the change in pelvic tilt during load carriage because as was the case with the lower back, the back wrap blocked the location of the sacral marker. Because of the inconsistent placement of the sacral marker, I was not able to specifically analyze the pelvic tilt.



## **Chapter 4**

### **RESULTS**

For all of the graphs pertaining to the effect of weight in a single carrying position on the angles: the unweighted control is a solid blue line, Cathy (7 lb..) is a red dotted line, and Timmy (20 lb..) is a dashed green line. For all of the graphs pertaining to the effect of the carrying position with a constant weight on the angles: Front Wrap is a red dotted line, Back Wrap is a blue dashed line, Side Sling is a purple long-dashed line, and In Arms is a green dotted/dashed line. After giving a brief overview of the gait cycle and how to read the graphs, I will present my results. First, I will discuss the effect of the increasing weight in the front wrap, back wrap, side sling, and in arms carrying position on the hip and trunk angles. Second, I will discuss the effect of the different wrap position while carrying Cathy and then Timmy on the hip and trunk angles.

Unfortunately, of the 22 women who participated, only 19 produced usable data. Two of the subjects only felt comfortable walking if they were able to hold onto the railing of the treadmill. Since this is known to change someone's gait, I was unable to include them while analyzing my results. Another subject was dropped because the data points were not consistently recorded, so I was unable to use her data. Some of the data points are not recorded at certain points during the gait because the

cameras are unable to see certain markers if they are being blocked by the railing on the treadmill. This generally happens for the hip and wrist markers. While the software can average the points in space where the marker was before and after it disappeared from view of the camera, this can sometimes skew the data. If the marker is blocked for a long period of time or consistently disappears from view throughout the walking trial, then there are too many points missing for the software to accurately predict and estimate where the location of the marker. In total, I was able to analyze the results of 19 women; and all of the graphs represent an average of these 19 women.

#### Understanding the Gait Cycle:

The gait cycle is calculated by tracking one leg and can be split into two phases: stance and swing. The beginning of the gait cycle starts with the stance phase and begins when the foot first touches the ground at heel strike. The stance phase is approximately 60% of gait cycle. Towards the middle of the cycle, the body weight moves from behind the foot and comes forward. This phase ends when the body weight has moved so much forward that it cause the heel to rise off the ground. The swing phase, the final 40% of the gait cycle, begins when the foot is lifted off the ground and brought to the front so that the body is propelled forward. The heel striking the ground again marks the beginning of another cycle. In the line graphs that I will use, the x-axis is the percent gait cycle. Heel strike is the start of the cycle, so it is  $x = 0$  and  $x = 100$ . (Winter, 1991).

**Figure 1. Percent Gait Cycle. The "stance" phase is 60% of the cycle while the "swing" phase is 40%. Heel strike is at the beginning of the "stance" phase**  
**(<http://me.queensu.ca/people/deluzio/GaitAnalysis.php>).**

#### Understanding Hip Flexion and Extension Line Graphs

The x-axis is percent gait cycle and the y-axis is the angle (degrees). To create the percent gait cycle, five gait cycles for each subject was averaged. The graph tracks the cycle of the leg on the preferred carrying side. Subjects were allowed to carry the

baby on the side they found most comfortable and I found variation in side preference. Twelve of the twenty-two women preferred to carry the weight on the right side. If the subject preferred to carry the baby on the right for the Side Sling, the right leg was used in the results. Although, for back and front carrying, there was not an issue about side; the preferred leg in Side carrying was also used to be consistent. Heel strike occurs at  $x = 0$  and is also a peak of hip flexion. Hip flexion and extension refers to the angle at which the leg is positioned either in front of or behind the body. When  $y$  is positive, the hip is in flexion, meaning the leg is forward and in front of the subject. When  $y = 0$ , the hip flexion angle is zero. The leg is perpendicular to the plane created by the pelvis and is in full weight bearing. When  $y$  is negative, the hip is in extension, so the leg is behind the subject and the subject is stepping forward with the other leg. The point at which the angle is most negative is when the leg is most extended behind the body.

### Understanding Hip Flexion, Hip Extension, and Forward Trunk Angle

#### Histograms

The y-axis is the angle (degrees). The graphs show the average hip flexion angle at heel strike with one standard deviation indicated for each mean. The graphs for average hip extension angle show the maximum hip extension with one standard deviation, which occurs at the minimum value of  $y$ . The graphs for the forward trunk angle show the average angle at heel strike with one standard deviation. The p-value

is provided for angles with a significant difference according to an ANOVA in which different methods of carrying and weights of the babies are being compared.

### Understanding Lateral Trunk Angle Line Graphs

The lateral trunk angle is the side to side tilt of the trunk in the frontal (coronal) plane. When tracking the trunk on the subject during data collection, the markers on the shoulders, sternum, and back are used. The x-axis is percent gait cycle and the y-axis is the angle (degrees). When y is positive, the trunk is leaning toward the preferred side of carrying. When  $y = 0$ , the trunk is perpendicular to the plane created by the pelvis. When y is negative, the trunk is leaning away from the carrying side. When comparing the results, the lateral trunk angle is analyzed at heel strike,  $x = 0$ .

### Understanding Forward Trunk Angle Line Graphs

The forward trunk angle is the change in upper body's tilt in the sagittal plane compared to the point created by the pelvis. The markers for the pelvis are the placed on the anterior superior iliac spine and the sacrum. These points are then averaged to find a point in the center that is then used to create a perpendicular line that the change in the trunk angles are compared to. When tracking the trunk on the subject during data collection, the markers on the shoulders, sternum, and back are used. The x-axis is percent gait cycle and the y-axis is the angle (degrees). When y is positive, the

trunk is leaning toward the front. When  $y$  is negative, the trunk is leaning toward the back.

### Determining a Significant Difference

To determine if there is a significant difference between the increasing weight of the baby and the different positions, I used one-way analysis of variance (ANOVA) tests. The level for statistical significance was set at  $p = 0.05$ .

### Effect of increasing weight in a single carrying position on the hip and trunk angles.

#### Front Wrap

The increasing weight in the front wrap position significantly increased the hip flexion angle at heel strike and decreased the maximum hip extension angle. This means that the carriers took a larger step forward and then did not extend their leg behind them as much. There were no significant changes in lateral or forward trunk angles. There was a slight tendency for the carrier to lean forward while carrying Cathy, the lighter baby, but this was not significant.

**Figure 2.1. The effect of weight in the front wrap position on the hip flexion and extension angles. There is a significant difference between the different weights in the hip flexion angle at heel strike (p-value < 0.001) during the front wrap carrying position. As the weight of the child increased, the hip flexion angle at heel strike increased. There was also a significant difference in the hip extension angle (p-value = 0.002). As the weight of the child increased, the hip extension angle increased.**

**Figure 2.2. The effect of weight in the front wrap position on the hip flexion angle at heel strike. The error bars represent one standard deviation. The p-value < 0.001 using ANOVA shows that there is a significant difference between the weights.**



**Figure 2.3. The effect of weight in the front wrap position on the hip extension angle. The p-value = 0.002 found using ANOVA shows that there is a significant difference between the weights.**

**Figure 2.4. The effect of weight in the front wrap position on the lateral trunk angle. No significant difference between the different weights was found using ANOVA (p-value = 0.68) meaning that lateral trunk angle does not change with increasing weight of load.**

**Figure 2.5. The effect of weight in the front wrap position on the forward trunk angle. No significant difference between the different weights was found using ANOVA (p-value = 0.12)**

#### Back Wrap

With an increase in weight in the back wrap position, there was a significant increase in the hip flexion angle, but no significant change in the hip extension angle. While the average hip flexion angle at heel strike during the unweighted walking was 17 degrees, the angle was 20 degrees while carrying Cathy, and 25 degrees while carrying Timmy. There was no significant change in the lateral trunk angle while carrying an increasing load in the back wrap position. There was a significant increase

in forward trunk angle at heel strike with increasing weight in the back wrap position. While Cathy only increased the angle 1 degree from the unweighted position of -3 degrees, carrying Timmy increased the angle by 7 degrees.

**Figure 3.1. The effect of weight in the back wrap position on hip flexion and extension. There is a significant difference between the different weights in the hip flexion angle at heel strike (p-value = 0.03) during the back wrap carrying position. As the weight of the child carried increased, the hip flexion angle at heel strike increased. There was no significant difference in the hip extension angle (p-value = 0.93).**

**Figure 3.2. The effect of weight in the back wrap position on the hip flexion angle at heel strike. The p-value = 0.03 found using ANOVA shows that there was a significant difference between the weights.**

**Figure 3.3. The effect of weight in the back wrap position on the lateral trunk angle. No significant difference between the different weights was found using ANOVA (p-value = 0.29)**

**Figure 3.4. The effect of weight in the back wrap position on the forward trunk angle. There is a significant difference between the different weights in the forward trunk angle between the different weights at heel strike (p-value < 0.001) during the back wrap carrying position. As the weight of the child carried increased, the forward trunk angle at heel strike increased.**

**Figure 3.5. The effect of weight in the back wrap position on the forward trunk angle at heel strike. The p-value < 0.001 found using ANOVA shows that there is a significant difference between the weights.**

#### Side Sling

There were no significant changes in the hip and trunk angles in the side sling position with increasing load. While it looks as if there is a great difference in the lateral trunk tilt, the p-value found using ANOVA was .35. There was less than 1.5 degree change in the lateral trunk angle at heel strike when carrying Cathy and Timmy.



**Figure 4.1. The effect of weight in the side sling position on the hip flexion and extension angles. No significant differences between the different weights was found using ANOVA (flexion: p-value = 0.09, extension: p-value = 0.44)**

**Figure 4.2. The effect of weight in the side sling position on the lateral trunk angle. No significant difference between the different weights was found using ANOVA (p-value = 0.35)**

**Figure 4.3. The effect of weight in the side sling position on the forward trunk angle. No significant difference between the different weights was found using ANOVA (p-value = 0.82)**

#### In Arms

There was no significant difference on the hip flexion and extension angles or the lateral trunk angle with increasing weight when the load was carried in arms. There was however, a significant difference in the forward trunk angle. Whereas an increasing load in the back wrap position caused the carrier to lean forward while walking, carrying and increasing load without the use of a tool/wrap caused the

subject to lean increasingly backwards. The average forward trunk angle in the unweighted position at heel strike was -3 degrees while Cathy was -4 degrees and Timmy was -6 degrees.

**Figure 5.1. The effect of weight in the in arms position on the hip flexion and extension angles. No significant difference between the different weights was found using ANOVA (flexion: p-value = 0.06, extension: p-value = .36)**

**Figure 5.2. The effect of weight in the in arms position on the lateral trunk angle.**

**No significant difference was found between the different weights  
using ANOVA (p-value = 0.97)**

**Figure 5.3. The effect of weight in the in arms position on the forward trunk angle. There is a significant difference between the different weights in the forward trunk angle at heel strike (p-value = 0.01) during the in arms carrying position. As the weight of the child carried increased, the forward trunk angle at heel strike decreased.**

**Figure 5.4. The effect of weight in the in arms position on the forward trunk angle at heel strike. The p-value = 0.01 found using ANOVA shows that there is a significant difference between the weights.**

The effect of the carrying position with a constant weight on the hip and trunk angles.

Cathy

I analyzed the differences in hip flexion angle, hip extension angle, lateral trunk angle, and forward trunk angle between carrying positions while carrying Cathy, the 7 lb. mannequin. Compared to the angles during the unweighted walking, carrying

Cathy in any of the positions did not have a significant effect on the hip flexion angle at heel strike, the maximum hip extension angle, or the lateral trunk angle. However, carrying Cathy in both the front and back wrap positions significantly increased the forward trunk angle. The in arms position also significantly changed the forward trunk angle. In the in arms position, the forward trunk angle decreased, meaning the subjects tended to lean backwards with the extra load.

**Figure 6.1. The effect of the carrying position with Cathy (7 lbs.) on the hip flexion and extension angles. No significant difference was found between the different carrying positions using ANOVA (flexion: p-value = 0.15, extension: p-value = 0.10)**



**Figure 6.2. The effect of the carrying position with Cathy (7 lbs.) on the lateral trunk angle. No significant difference was found between the different carrying positions using ANOVA (p-value = 0.71)**

**Figure 6.3. The effect of the carrying position with Cathy (7 lbs.) on the forward trunk angle. There is a significant difference between the different carrying positions in the forward trunk angle at heel strike (p-value = 0.007) while carrying Cathy. While all of the carrying positions are in the negative, comparatively, carrying Cathy in the front and back positions increased the forward trunk angle. In arms carrying decreased the forward trunk angle the most.**

**Figure 6.4. The effect of the carrying position with Cathy (7 lbs.) on the forward trunk angle at heel strike. The p-value = 0.007 found using ANOVA shows that there is a significant difference between the carrying postions.**

#### Timmy

I also analyzed the differences in hip flexion angle, hip extension angle, lateral trunk angle, and forward trunk angle between carrying positions while carrying Timmy, the 20 lb. mannequin. While all of the carrying positions affected the hip flexion and extension angles compared to the unweighted condition, there was a significant increase in hip flexion and decrease in hip extension when Timmy was

carried in the front wrap position. Carrying Timmy in the back wrap position also significantly increased the hip flexion angle. There was no significant difference found in the lateral trunk angle for any of the carrying positions even though there was a trend for the trunk to lean toward the preferred carrying side while using the side sling. The back wrap significantly increased the forward trunk angle at heel strike, meaning the carrier was leaning forward, away from the baby. In arms carrying significantly decreased the forward trunk angle more than any other carrying position, so that the carrier was tilted backwards.

**Figure 7.1. The effect of the carrying position with Timmy (20 lbs.) on the hip flexion and extension angles. There is a significant difference between the different carrying positions in the hip flexion and extension angles at heel strike (flexion: p-value = 0.04, extension: p-value = .003) while carrying Timmy. While the pattern of change in the hip flexion and extension angles remains the same throughout the gait cycle for all carrying positions, the front wrap significantly increases the hip flexion angle at heel strike and decreases the hip extension angle compared to other forms of carrying.**

**Figure 7.2. The effect of the carrying position with Timmy (20 lbs.) on the hip flexion angle at heel strike. The p-value = 0.04 found using ANOVA shows that there is a significant difference between the carrying postitons.**

**Figure 7.3. The effect of the carrying positions with Timmy (20 lb) on the maximum hip extension angle. The p-value = .003 found using ANOVA shows that there is a significant difference between the carrying postitons.**

**Figure 7.4. The effect of the carrying position with Timmy (20 lb.) on the lateral trunk angle. Although the side sling carrying position increases lateral trunk angle throughout the cycle, there was no statistically significant difference among the five conditions using ANOVA (p-value = 0.69).**

**Figure 7.5. The effect of the carrying position with Timmy (20 lb) on the forward trunk angle. There is a significant difference between the carrying positions in the forward trunk angle at heel strike (p-value < 0.001) while carrying Timmy. Carrying Timmy in the back wrap position significantly increased the forward trunk angle at heel strike compared to all of the other carrying positions. The in arms carrying position decreased the angle more than any other carrying position. Carrying Timmy in the front wrap and side sling positions similarly effected the forward trunk tilt angle.**



**Figure 7.6. The effect of the carrying position with Timmy (20 lb) on the forward trunk angle at heel strike. The p-value < 0.001 found using ANOVA shows that there is a significant difference between the carrying postitons.**

## **Chapter 5**

### **DISCUSSION**

#### Effect of hip angles on gait and posture

An increase in hip flexion corresponds with an increase in stride length.

Research that examined the difference between walking and running, has shown that increasing hip flexion is followed by an increase in stride length, and therefore the forward step that the subject is taking (Hamill and Knutzen, 2003). Also hip flexion and extension can be related to the lumbar lordosis through the pelvis tilt. When the hip is flexed, the pelvis is tilted posteriorly, and when the hip is extended, the pelvis is tilted anteriorly (Crosbie and Vachalathiti, 1997, Crosbie et al., 1997, Franz, 2009). “A significant positive correlation was found between hip extension and anterior pelvic tilt during both walking and running, indicating that anterior pelvic tilt was greater in subjects that displayed reduced utilized peak hip extension” (Franz, 2009: 494). As the hip flexion angle is increased, so is the amount of posterior pelvis tilt, and the same applies for the hip extension and anterior pelvis tilt. When investigating the relationship between the pelvis and the trunk, Crosbie found that there is “apparent consequential trunk motion following pelvic displacements suggesting that the spinal movements associated with walking are linked to the primary motions of the pelvis and the lower limbs” (Cosbie, 1994: 6). Some studies have reported a strong correlation between increased anterior pelvic tilt and increased lumbar lordosis (Franz,

2009). While I have not come across research showing a specific link between the two, it can be assumed from other research that the hip angles may influence the lumbar lordosis.

#### Effect of increasing weight in front wrap position

The results on the effects of increasing weight during the front wrap carrying position on the hip and trunk angles mostly support my hypotheses. I found that carrying an increasing load in the front wrap position significantly increased the hip flexion angle at heel strike and decreased the maximum hip extension angle. The same trend was found in other studies of changes in gait during pregnancy. For example, Foti et al. found that during pregnancy, hip flexion increased while hip extension decreased (Foti et al., 2000: 627). They concluded that “only small deviations in pelvic tilt and hip flexion, extension, and adduction were observed during pregnancy, therefore, gait during pregnancy is remarkably unchanged” (Foti et al., 2000: 629). Another study also found that even though there were changes in pelvic and trunk rotations, gait during pregnancy did not differ significantly from non-pregnant gait (Wu et al., 2004). However, when hip flexion is increased, it is likely to also cause an increase in the step length, therefore carrying and increasing weight in the front wrap position causes the carrier to take a larger step forward.

Contrary to what I expected to find, there was not a significant decrease in the forward trunk angle with increasing weight in the front wrap position. In fact, the subjects tended to lean forward, increasing their forward trunk angle, when they were

carrying Cathy. Because there was a slight shift in the center of mass by carrying the lighter baby, the subject leaned forward slightly while walking. It is possible that Cathy was not heavy enough to cause the carriers to lean back to compensate for the extra weight. They still felt stable enough while walking to lean forward with the extra load.

Even when carrying the heavier weight in the front wrap position, the subjects did not lean backward compared to unweighted walking. While the carrier can lean forward a lot and still remain steady while standing and walking, a person can only lean back a little and retain the same sense of stability. Also, tilting backward to compensate for the anterior load puts an increasing strain on the lower back. One of the main complaints of pain during pregnancy is lower back pain (Franklin et al., 1998; Gutke et al., 2008; Noren et al., 2002; Orvieto et al., 1994; Wang et al., 2004). Whitcome found that during pregnancy, lumbar lordosis, the lower curve of the spine, increases to neutralize the shift in the center of mass (Whitcome, 2006: 57). Lower back pain can be due to anatomical changes and an increase in stress on the back muscles (Gutke et al., 2008; Noren et al., 2002; Orvieto et al., 1994; Wang et al., 2004). Many researchers founded that these changes and stress lead to lower back pain. Since the weight is located in similar places during pregnancy and front carrying, there should be similarities between the changes to counteract the shift in center of mass and back pain.

### Effect of increasing weight in back wrap position

The results for the effect of increasing weight in the back wrap position on the hip and trunk angles only supported my hypotheses about the change in the trunk angles. While I thought that the increasing weight on the back would cause the carrier to flex her leg less and take a smaller step forward and extend her leg further back, this was not supported by my results. I thought that since carrying a load in the front of the body would cause it to react one way, then carrying the same load behind the body would cause it to react in the opposite way. Contrary to what I expected, the results showed that there was actually a significant increase in the hip flexion at heel strike. This may be because as the weight of the baby causes the carrier to lean forward, she must take a greater step forward to stabilize her gait and stop herself from falling forward. Devroey et al., found that there was an increase in hip flexion to help maintain balance while carrying a backpack (Devroey et al., 2007). Also, the results showed that the subjects did not significantly alter their hip extension angle with the increasing load. Supporting my results, a study done with children and backpacks also showed that there was an increase in hip flexion and a decrease in hip extension while carrying a backpack (Chow et al., 2006). The maximum and minimum range of motion (degrees) allowed in the hip flexion and extension angles are 140 and 30, while the range used in walking is 30 and 15 (Stewart et al., 2006: 24). Therefore, it is easier and more feasible for the body to increase flexion rather than increase extension because there is a greater range of hip flexion.

While the hypotheses about the hip angles were refuted, the hypotheses pertaining to the trunk angles were supported. As expected, there was no significant change in the lateral trunk angle with an increasing weight when the load is carried in the back wrap position. Because the weight was located along the midline of the carrier, there was no need for her to tilt to either side to compensate for the extra load. Also, there was a significant increase in the forward trunk angle as seen in other studies (Devroey et al., 2007; Kinoshita, 1985; Knapik et al., 1996; Martin et al., 1986). “Increased trunk flexion with increasing load has been identified as an adaptation to bring the centre of gravity of the body and backpack further forward to maintain balance” (Devroey et al., 2007: 739). By using weights that were 20% and 40 % of the carrier’s body weight, Kinoshita found that the average trunk inclination increased significantly as the load became heavier (Kinoshita, 1985).

Back pain has long been associated with back carriage (Chow et al., 2006; Devroey et al., 2007; Forjuoh et al., 2004; Hong and Cheung 2003; Kinoshita, 1985; Martin et al., 1986; Schiffman et al., 2006). Some studies have suggested that it is best not to carry a load that exceeds 10-15% of the carrier’s body weight (Devroey et al., 2007; Hong and Cheung, 2003). “Low-back pain commonly occurs as a result of prolonged postural strain normally caused by the trunk being greatly displaced from its normal position” (Kinoshita, 1985). Also, “the forward flexion of the thoracic area can be a predisposing factor that may contribute to the development of postural problems” (Fowler et al., 2006: 137). Since women carry their children with them

throughout the day, it is expected that they will also experience back pain from extended carrying.

#### Effect of increasing weight in side sling position

The results for the effect of increasing weight in the side sling position on the hip and trunk angles did not support most of my hypotheses. I hypothesized that the increasing weight of the side sling would cause the carrier to decrease both her hip flexion and extension angles on the preferred carrying side, because the weight on one side would cause that leg to take a smaller step in general. Even though there was a slight change in the hip flexion and extension angles, the results shows that it was not significantly different from walking unloaded.

Surprisingly, there was not a significant difference in the lateral trunk angle when the load is carried in the side sling position. Even though my graph shows that there is a trend for the subject to lean to side while carrying an increasing weight, there is actually less than 2 degrees change and the p-value was 0.35. Other studies have shown a difference in the trunk angle when carrying a load on the side. While looking at the effect of different carrying methods on gait and posture, Pascoe found that one-strap bag carriage on the right shoulder “caused a right shoulder elevation and a leftward curvature of the spine away from the weight of the book bag” (Pascoe et al., 1997: 634). Other studies have also shown that carrying a weight unilaterally causes “lateral spinal bending and shoulder elevation” (Smith et al., 2006: 266). One reason that my results were not consistent with other research may be because the weights

that I used were not heavy enough to cause such a change. When looking at the effects of side carriage on postal workers, the maximum weight used by Smith was 17.5% of the carrier's body mass (Fowler et al., 2006). The average weight of my subjects was 130 lb., and the average weight of Timmy throughout the trials was 20.2 lbs. This means that Timmy only weighed 15% of the subject's body mass on average. The second reason that my results may differ from that of other studies is the age of the participants. Pascoe's subjects were 11-13 year olds, while most of my subjects were attending college.

The only results that supported one of my hypotheses for the effect of increasing weight on in the side sling position was that there was no significant difference in the forward trunk angle. Since the weight of the baby was not located anteriorly or posteriorly to the carrier, she did not have to compensate for the extra load by leaning forward or backward.

Even though my results did not show a significant change in the hip or trunk angles, there are clinical implications for carrying a load on the side. "Lateral bending of the trunk to counteract the asymmetric placement of the load has been suggested as an important risk factor for a number of low-back disorders" (Fowler et al., 2006: 133). While carrying a load is generally physically demanding and requires extra energy expenditure, "increased energy expenditure and more rapid fatigue occur when the backpack is worn over one shoulder because of the possibility of out of phase transfer from the load to the trunk" (Smith et al., 2006: 266). Other studies have even



recommended back carriage “over asymmetrical modes of carriage, which are likely to be associated with increased risk of back pain” (Whittfield et al., 2001: 822).

#### Effect of increasing weight with in arms position

Along with the side sling carrying position, my results showed that there was no significant change in the hip flexion and extension angles. While I hypothesized that there was going to be a decrease in the hip flexion and hip extension, the slight change in both was not seen as significant.

Also, in the side sling position, there was no significant change in the lateral trunk angle. I expected the trunk to tilt away from the side with the weight, but there was no significant change. In studies where there was an increase in trunk lateral flexion, the weight was carried in a different position. Even though the weights used in the study by Matsuo et al. were not carried using any tools, they were not carried on the hip. In their study, the weight was in a hand held bag, while in my research, it was held closer to the body. They found that “asymmetric load-carrying was associated with increased trunk flexion towards the contralateral side and the amplitude of the trunk lateral flexion increased with the load weight” (Matsuo et al., 2008: 518). The reason that there is a difference in the lateral trunk angle in their study in contrast to mine may be due to the fact that the load in their study is further away from the center of mass than mine. The further away the weight is from the center, the more force and energy must be put into stabilizing the system.

Unexpectedly, the results showed that there was a significant decrease in the forward trunk flexion with increasing weight in the in arms position. With the in arms carrying, the subjects were allowed to carry the babies in any position they felt most comfortable. Most of the women carried Cathy in a two-arms cradle hold while they carried Timmy in front, but to the side. Because the weight was positioned in front of the carrier, they tended to lean back to compensate for the shift in weight with both babies. It may seem contradictory that the front wrap position did not decrease the forward trunk angle like the in arms position. However the main difference between the two is the fact that the carrier was allowed the use of her arms in locomotion when she used a carrying tool, while the in-arms position did not. Carrying the weight in the in arms position may not have felt as secure as when using a wrap, so the carrier may have leaned backward to help stabilize herself. Also, it has been shown that arm swing during locomotion is important for balance (Park, 2008). While it is not necessary to use the arms while walking, Park's study shows that arm swing is an active part of walking and that walking without use the use of arm swing increases energy expenditure. Therefore, the subjects may have also changed their posture through the forward trunk angle to help balance themselves while walking.

#### Effect of position with Cathy

While I originally thought that carrying Cathy in different positions would affect the hip and trunk angles, in retrospect it does make sense that there was not a significant change in most of the angles. The average weight of my subjects was 130

lb., and the average weight of Cathy throughout the trials was 6.3 lbs. This means that Cathy only weighed 5% of the subject's body mass on average. Cathy's actual range of percent body mass was 3-6%. Most of the studies on the effect of increasing weights only found a significant difference while using a heavier load (Chow et al., 2006; Devroey et al., 2007; Hong and Cheung, 2003). Carrying a lighter weight did not significantly affect the hip flexion and extension angles or the lateral trunk angle.

However, carrying Cathy in the different positions did affect the forward trunk angle. As hypothesized, the back wrap caused the subject to lean forward compared to the unweighted trial. Unlike what I hypothesized, carrying Cathy in the front wrap position also increased the forward trunk angle so that the carrier had almost the same posture as when they were in the back wrap position. Since the weight of the baby was not very high, the carrier felt comfortable and stable enough to lean forward slightly in the direction of the load while walking. As expected the side sling did not cause the subject to lean forward, increasing their forward trunk angle, because the weight was positioned on the side. While I expected the in arms carrying to be similar to the side sling, it was not. I expected my subjects to carry Cathy upright and to the side, but the majority of my subjects carried Cathy by cradling her in front of them using two arms. Since the weight was in the front, it would then be expected that the in arms carrying would affect the body similarly to the front wrap position. However, the in arms position caused the carriers to lean back, possibly because they wanted to get into a more stable and secure position.

### Effect of position with Timmy

Carrying Timmy in the different positions significantly affects all of the angles except the lateral trunk angle. I hypothesized that only the front wrap would increase the hip flexion angle while all of the other carrying positions would decrease the angle. However, my results show that all of the carrying positions increased the hip flexion angle. While the side sling and in arms carrying increased the angle slightly, both the back wrap and the front wrap significantly increased the hip flexion angle at heel strike. Even though my results show that the front wrap position increases hip flexion more than the back wrap position, other studies have shown the opposite. Fiolkowski et al. compared a backpack and a front pack using two different loads (Fiolkowski et al., 2006). They found that a heavy backpack of 15% body mass significantly increased the hip flexion angle while a heavy front pack of 15% body mass significantly decreased the hip flexion angle. They concluded that “the increase hip flexion corresponded with an increased forward head position, demonstrating substantial postural adjustments to the load placement” (Fiolkowski et al., 2006: 891). My results also show that carrying Timmy in the front wrap position significantly decreased the hip extension angle. On the other hand, Fiolkowski et al. found that the hip extension angle during the front pack carriage decreased.

As for the trunk angles, carrying Timmy in the different positions did not have a significant affect on the lateral trunk angle. None of the carrying positions caused the carrier to change her lateral trunk angle to compensate for a lateral shift in weight. Even though the side sling position does move the center of mass to the side, the

subject may make an effort to keep a straight posture while walking. Finally, there was a significant difference in the forward trunk lean based on the location of the load with Timmy. While I expected and found an increase in the forward trunk angle with the back wrap position due to the weight compensation, I did not expect the results of the other carrying positions. I thought that the front wrap would cause a decrease in the angle because the carrier would want to lean backwards to counteract the weight in the anterior position of the weight. However, the front wrap did not cause the carrier to change the angle, but the in arms position did. Where I expected the front wrap to decrease the angle, the in arms carrying position actually caused a significant decrease. As stated previously, this may be due to the fact that the carrier is not able to use her hands in balancing and walking.

## **Chapter 6**

### **CONCLUSIONS**

Overall, maintaining stability during gait is the main factor to consider when carrying any type of load. The body has to exaggerate its compensation when carrying an increasing load in most of the carrying positions. First, I will discuss the effect of increasing weight on gait and posture. Then I will discuss the effect of the different wrap positions on gait and posture.

In term of changes in gait with increasing weight, only the back wrap and front wrap positions showed a change. Increasing weight increased hip flexion in both the front wrap and back wrap positions, supporting the idea that the carriers were taking a larger step forward to help compensate for the weight. Only an increasing weight in the front wrap position decreased hip extension, and there was no significant increase in the hip extension. Therefore the carriers did not extend their leg as far back when using the front wrap as they would have done when walking without a load. Based on the angles that I studied at, there was no change in gait with increasing load in the side sling or in arms positions.

As for a change in posture, carrying an increasing weight significantly affected the posture of the carriers only when using the back wrap and in arms carrying positions. As seen in research done on backpack carrying, the heavier the weight on

the back, the more forward lean is recorded. Carrying an increasing weight in the in arms position caused the carrier to tilt backwards. Both carrying styles are possible causes of lower back pain. There were no significant changes in lateral trunk tilt with increasing weight. While this is expected in the front and back wrap, this is a surprise for the side sling position. I predicted that the increasing weight would affect the posture of the carrier when using the side sling, but this was not supported by the data. This may be due to the location of the baby, and the fact that the weight was only carried for a short period of time. Also, the literature shows that an increase in hip extension will increase anterior pelvic tilt and therefore increase lumbar lordosis. Since there were no significant increases in hip extension, only decreases, I am unable to draw any conclusion as to the effect of increasing weights on lumbar lordosis. My results do not show that there is a possible increase in the lumbar lordosis, but a more direct study of those angles would be a better way to test the hypothesis.

When examining the effect of the different wrap positions, I used both Cathy and Timmy. However, since carrying Cathy in the different wrap positions did not significantly affect gait, I will focus on Timmy's results for the changes in gait. While all of the carrying positions increased hip flexion angle, only the front wrap and back wrap significantly increased flexion. Carrying in both the front and the back wrap positions caused the carriers to take a large step forward to help maintain their balance.

When looking at the change in posture, the carrier showed changes when carrying both Cathy and Timmy in the different wrap position. Overall, carrying a

weight in the back wrap position increases the forward trunk tilt, and therefore causes the carrier to lean forward while walking. Carrying a lighter weight in the front wrap position causes the carrier to lean forward, while carrying a heavier weight does not change the posture significantly from the unweighted carrying position. As with the increasing weight, there was no lateral tilt found in any of the carrying positions, and I am unable to conclude if there was an increase in lumbar lordosis based on change in hip extension from the different carrying positions.

It appears that various carrying positions affect the body and gait in different ways. When using the front wrap, the carrier may try to compensate for the displacement of her center of mass by taking a larger step forward and not extending their leg fully behind them. For the back wrap, the caretaker may try to maintain their balance by leaning forward to stabilize the load on their back. The side sling does not significantly affect any of the angles, but as one might expect, it does appear to cause the caretaker to lean to one side, because it displaces the center of mass laterally to the opposite side. Finally, carrying in arms, without the use of tools, causes the caretaker to lean backwards while walking. This may be due to the fact that the carrier no longer has her arms to use in walking and she is positioning the extra weight anteriorly.

While I am studying the immediate effects of carrying a load on the human body and walking, there is the possibility of long term effects during the individual's lifetime. There are some cases in which women who experienced lower back pain during pregnancy also felt the effects up to three years later (Noren et al., 2002). They



may not experience the pain unless they are participating in certain activities such as housework, shopping, walking for an extended period of time, or exercise. Not only would carrying regularly effect the body, but so might the amount of time it is carried. “It would seem reasonable to postulate that changes of even greater magnitude would be evident if the loads were carried for a longer period of time in field situations” (Kinoshita, 1985: 1357). Fatigue might affect the trunk angles more than changes in the hip angles. As the person is walking for an extended period of time with a weight, their upper body, which is supporting the weight, may become more hunched over. It would be very interesting for further research to look into the effects of fatigue on the carrier’s gait and posture.

As shown in other studies, carrying loads is very taxing on the body and gait. Infant carrying is one of the most expensive forms of child care for the mother. While it is always in the best interest of the child to be carried, there comes a point when it no longer makes sense energetically for the mother to carry her child. It is probable that the effects we see today were also relevant to our human ancestors who would have also needed to carry their offspring. By looking at the different forms of infant carrying and the different weights of babies being carried, I am able to contribute to a better understanding of how infant carrying affects the mother/carrier. As expected, carrying a heavier baby is more strenuous and has a greater impact on the carrier’s body and gait. Even though using the back wrap seems to have the most effect on posture and gait, it is prevalent in many societies. The side sling does not seem to have any significant effects on posture or gait and is also found all around the world.

While not commonly used, the front wrap affects both posture and gait. Carrying without the use of a tool has been shown to be the most costly energetically, but based on my results it only seems to affect the carrier's posture. To truly make a conclusion as to which carrying position is best, I would have to take into account many factors outside of the ones that I focused on in my research. There are other kinematic and kinetic factors that can be used to study gait and posture, as well as the culture differences with infant carrying that can be added onto this topic. Because infant carrying is so beneficial to the infant's health and therefore influential on the infant mortality rate, it is important to study the ways in which we care for our children.

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## APPENDIX A

### HUMAN SUBJECTS PROTOCOL University of Delaware

Protocol title: The effect of various methods of infant carrying on the human body and locomotion

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Type of review:

Exempt

Expedited

Full board

Exemption Category: 1 2 3 4 5 6

Minimal Risk: / yes \_\_\_\_\_ no

Submission Date:

HSRB Approval Signature	Approval Date
<i>Elizabeth Duggan Peluso</i>	8/4/08
HS Number	Approval Next Expires
HS 09-516	8/3/09

Investigator Assurance:

By submitting this protocol, I acknowledge that this project will be conducted in strict accordance with the procedures described. I will not make any modifications to this protocol without prior approval by the HSRB. Should any unanticipated problems involving risk to subjects, including breaches of guaranteed confidentiality occur during this project, I will report such events to the Chair, Human Subjects Review Board immediately.

Signature of Investigator: \_\_\_\_\_

Date: \_\_\_\_\_









## **APPENDIX B**



