TRUNK POSTURAL DEMANDS OF PHYSICAL OCCUPATIONAL ACTIVITIES FOR WOMEN IN BENIN

A study of the occupational activities of merchant pregnant women in Benin

and

The trunk postures for the specific task of carrying loads on the head for women in Benin

by

Erica Claire Beaucage-Gauvreau

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Abstract

Women in Benin commonly participate in physically demanding activities that involve the carriage of heavy loads on the head and back. These strenuous tasks combined with pregnancy can result in back pain that may persist after delivery in some cases. The objective of this study was to examine how the trunk postures of pregnant women in Benin were affected by their occupational activities. This study also examined trunk postures, as well as postures of the head relative to the trunk, in the specific task of carrying loads on the head. Finally, the instrument used in this study to measure trunk postures, the Virtual Corset™ (VC) (Microstrain, Williston, VT, USA), was validated against a system of potentiometers.

Questionnaires completed by 26 pregnant and 25 non-pregnant subjects revealed that 58% of pregnant women suffered from back pain since the start of pregnancy. An average of 328 instances of trunk flexion at angles larger than 60° were recorded during the workdays of 17 pregnant women, while 66 of those flexions events were held for more than four seconds. Furthermore, an average of 36% of the recorded workday was spent in trunk flexion at angles exceeding 20°. Trunk postural data, at C7 and S1, as well as sagittal positions of the head relative to the trunk were compared between pregnant and non-pregnant subjects and between unloaded and loaded walking conditions for the specific task of head load carriage. These comparisons showed that load on the head significantly increased upper trunk extension and lateral bending of the upper trunk towards the left during walking. Motion of the head relative to the trunk and motion of
the upper trunk significantly decreased in the loaded condition and was compensated by increased motion at the sacrum level.

In the validation study, the VC was moved at different speeds to observe the effects of accelerations on the angle measurements. Root mean square difference between the angles measured by the VC and the potentiometers were all below 5° and 6° for flexion-extension and lateral bending, respectively, with the exception of rapid movements where errors were slightly larger.
Co-Authorship

This thesis is the original work of Erica Beaucage-Gauvreau and was completed under the supervision of Dr. Geneviève A. Dumas and Dr. Mohamed Lawani. Field data were collected in Porto-Novo, Bénin under the supervision of Dr. Mohamed Lawani. Validation data were collected in Kingston, Ontario with the help of Romain Bigard, an undergraduate student, under the supervision of Dr. Geneviève A. Dumas. Data analysis was performed using custom software developed by the author, Erica Beaucage-Gauvreau. The interpretation of the results as well as the writing of this document were also completed by the author of this thesis.
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Chapter 1

1 General Introduction

Back pain is a common problem among pregnant women (MacEvilly & Buggy, 1996; Mantle et al., 1977; Fast et al., 1987; Ostgaard et al., 1991a). Studies on the subject in the last decades have been conducted mostly in affluent societies (Bjorklund & Bergstrom, 2000). Consequently, it has been suggested that this problem was more common to welfare societies than those with low income (Bjorklund & Bergstrom, 2000). Cultural beliefs of different populations is thought to be another factor that affects the attitude towards pain (Bjorklund & Bergstrom, 2000). In fact, a study on pregnant Taiwanese women in mountainous regions showed that 95% of the subjects in the study group ignored the pain symptoms and carried out their normal daily activities as the symptoms were considered to be part of pregnancy (Fung et al., 1993). Conversely, the high rate of sick leave related to back pain during pregnancy among Swedish women indicates that there is a change in attitude in this nation towards a new demand and expectation of health and well being during pregnancy (Sydsjo et al., 1998).

The resources available to alleviate pain in different societies may also influence the attitude towards pain because of the different expectations of pain endurance (Bjorklund & Bergstrom, 2000). For example, the use of epidural analgesia is common in affluent countries to relieve pregnant women during delivery. However, any form of analgesics during delivery is rare in poorer nations leaving the women in pain (Bjorklund & Bergstrom, 2000). The lack of access to proper care and medical facilities is further
evidenced by the high maternal mortality rate in these underdeveloped parts of the world (Bjorklund & Bergstrom, 2000). In spite of the differences in resources and expectations between rich and poor nations, it was found that European and African pregnant women had a similar prevalence rate of back pain with comparable intensities (Bjorklund & Bergstrom, 2000).

Back pain during pregnancy afflicts about half of all pregnant women in the world regardless of their ethnicity (MacEvilly & Buggy, 1996; Mantle et al., 1977; Fast et al., 1987; Ostgaard et al., 1991). Despite this high prevalence rate, its etiology still remains unclear (Bjorklund & Bergstrom, 2000). Mechanical, biological, hormonal, traumatic, degenerative, and occupational factors have been identified as possible causes for back pain during gestation (MacEvilly & Buggy, 1996; Bjorklund & Bergstrom, 2000; Cheng et al., 2009). This pain can affect women in their social life and may prevent them from working (Ostgaard et al., 1991). The repercussions of such an impairment can be costly for health insurers and employers as they must cover the sick leave pay, replace the worker, train a new one, etc. However, women in some developing parts of the world do not benefit from these social advantages and are afflicted by a loss of income in addition to the back pain from which they suffer. In fact, women in West Africa typically provide for themselves and their families by performing various commercial activities; a decrease in their capacity to carry out these tasks results in a direct diminution of revenue.

African women also typically perform a wide range of daily occupational activities that are more physically demanding than their counterparts living in more technologically advanced parts of the world. Tasks such as getting water, doing laundry, washing dishes
are generally executed manually by the women. The physical work involved in these occupational factors has been linked to back pain during pregnancy (Berg et al., 1988; Cheng et al., 2009). Trunk twisting and bending down as well as other tasks such as lifting heavy objects or sustaining posture are associated with increased risk of back pain during pregnancy (Cherry, 1987; Rungee, 1993; Endresen, 1995). The poverty and low level of education as well as the high gravidity are other factors that put these women at risk of experiencing back pain during pregnancy (Nagi et al., 1973; Carey et al., 1995; Toroptsova et al., 1995; Worku, 2003). Gravidity is defined as the number of times that a woman has been pregnant.

Various treatments are usually suggested in an attempt to prevent or reduce back pain. Physical exercises before and during pregnancy are recommended as they have been shown to result in a decreased incidence of musculoskeletal complaints (Ireland & Ott, 2000). Strengthening of the core muscles has also been suggested as pregnant women rely largely on these muscles to maintain stability (Poole, 1998; Ireland & Ott, 2000). Trunk postures are considered to be directly linked to the occurrence of back pain. Consequently, pregnant women should also modify their approach to everyday life activities to relieve low back pain. Postural education has been found to be an effective method to teach women how to work with their changing bodies (Sanya & Olajitan, 2001). Medication is another option to reduce pain although its use is not preferred because of the possible negative effects of pharmacological agents during pregnancy (MacEvilly & Buggy, 1996). A study by Bjorklund and Bergstrom (2000) showed that European women seemed to avoid the use of analgesics with only 2% of them opting for this remedy whereas the corresponding figure for African women was 45% when
including local drugs used for analgesia. This high rate may be related to the fact that African women generally carry out heavy physical labor, even throughout pregnancy (Bjorklund & Bergstrom, 2000).

In developing parts of the world, heavy loads are regularly carried by individuals over long distances as a necessary part of their daily routine. The most common method employed in Africa is a form of head-loading where loads are balanced on top of the head. This method is also used for commercial activities by women who carry on their heads a wide range of goods for retailing purposes. It is not uncommon to encounter women carrying on their heads loads of up to 70% of their body mass for long periods of time (Maloiy et al., 1986). This specific activity combined with pregnancy is believed to increase the risk of back pain, as it involves lifting and carrying of heavy loads. The physiological demands of such a practice have been examined (Maloiy et al., 1986; Heglund et al., 1995; Lloyd et al., 2010), but the biomechanics, such as trunk movements and trunk postures, of this particular technique of load carriage have not been studied.

Work-related trunk postures have been shown to be related to musculoskeletal health (Vieira & Kumar, 2004). Consequently, their measurements represent an important field of research as it allows the establishment of exposure limits to certain risk factors (Trask et al., 2007). Several methods for measuring postures have been used in musculoskeletal studies (Trask et al., 2007). The choice of exposure assessment techniques largely depends on the exposure of interest as well as the validity, reliability, and resolution of the instrument (Trask et al., 2007). The environment where data collection is performed will also influence the method chosen by the investigators. The Virtual Corset™
(Microstrain inc., VT, USA) represented a good option for this specific study as it is an inclinometer that continuously measures trunk postures in two planes (sagittal and frontal planes) with respect to the line of gravity. Its small size, light weight, and wireless feature are advantages for its use in the field; furthermore, data can be collected over long periods of time because of its on-board datalogger. This device has been used in several field studies to determine the orientation of the trunk (Trask et al., 2007; Slot et al., 2010) and shoulder (Amasay, 2008; Rempel et al., 2010; Hess et al., 2010).

Guidelines on maximum loads to be lifted and carried as well as postural recommendations for the execution of several daily tasks (ACOG, 2002) are available for pregnant women living in a contemporary society. However, these guidelines might not directly apply to pregnant West African women as little is known about their postures during their daily activities.

The purpose of this thesis was to document the trunk postures assumed by a small group of pregnant women from West Africa throughout the day to understand the physical demands of the occupational activities of this understudied group. A specific focus on head load carriage was also of interest as this task is commonly performed by West African pregnant women and considered as a risk factor for developing back pain. An increased knowledge of these topics will allow the possibility for development of postural modifications to reduce postural loading and decrease the likelihood of sustaining musculoskeletal injuries. The instrument used in this study, the Virtual Corset™, has been validated previously. However, the conditions in which it was tested were different than the ones of this thesis. Therefore, this study also intended to validate
the Virtual Corset™ against potentiometers in a series of movements more similar to those of the trunk during walking.

This thesis was written in the manuscript style format defined by the School of Graduate Studies. Chapter 2 is a review of the literature of pregnancy and back pain, head load carriage, and the different techniques used to measure postures. Chapter 3 presents the trunk postural demands of the occupational tasks of a small sample of merchant pregnant women in Benin. The trunk biomechanics of head load carriage are discussed in Chapter 4. The validation of the instrument chosen for this study is presented in Chapter 5. Chapter 6 discusses the limitations associated with the studies in this thesis and suggests recommendations for future work. Chapter 7 summarizes the results obtained in this thesis.
1.1 References


Chapter 2

2 Literature Review

2.1 Introduction

The relevant literature surrounding back pain in pregnant women, its possible causes and solutions as well as the physical and biomechanical changes linked to pregnancy is summarized in this chapter. A specific section on back pain in African pregnant women is also included to describe the problem in this particular setting. However, this topic is not covered extensively in the literature, and as a result, the information available on the subject is limited. The effects of load carriage on human gait and energy expenditure, with a specific focus on the head load carriage method are also reviewed, followed by a description of its effect on the human spine. Again, the existing documentation on head load carriage is slender as only a limited number of studies have examined this specific topic. Finally, a brief review of the current methods used to measure human posture is presented.

2.2 Back Pain and Pregnancy

Back pain is a common problem among pregnant women. In fact, it is so frequent that it is often considered to be part of normal pregnancy (MacEvilly & Buggy, 1996). It was found to have a prevalence ranging from 48 to 56% depending on the study (Mantle et al., 1977; Fast et al., 1987; Ostgaard et al., 1991). Back pain can significantly decrease
the quality of life of pregnant women as it was reported to interfere with normal daily life activities and work in more than a third of them (Ostgaard et al., 1991). The pregnancy stage at which back pain starts to be experienced varies across studies: Ostgaard et al. (1991) found that pain symptoms often started before the 12th week of pregnancy, while Fast et al. (1986) found that most complaints of backache began between the fifth and seventh months of pregnancy. On the other hand, it is also believed that the most intense back pain occurs during labor (MacEvilly & Buggy, 1996).

2.2.1 Physical and biomechanical changes during pregnancy

Women go through several corporal changes during pregnancy. These changes may induce mechanical and structural changes in the spine contributing to gestational and postpartum back pain (MacEvilly & Buggy, 1996). Relaxin, a hormone secreted by the corpus luteum throughout pregnancy, creates greater mobility of the pelvic joints and intervertebral joints, thus making them more vulnerable to stress (Poole, 1998). In addition, the higher body fluid retention due to pregnancy may also increases laxity around the vertebral column and pelvis (MacEvilly & Buggy, 1996). Furthermore, women experience a weight gain of approximately 11-16kg (McNitt-Gray, 1991) characterized by a small gain rate in the first trimester, followed by a higher and more linear rate during the second and third trimesters with a higher weight gain rate in the second trimester (Carmichael et al., 1997). Moreover, as the foetus develops, the uterus expands into the abdominal cavity in an anterior and superior direction resulting in a shift of the center of gravity and an increase in the torque caused by the upper body at the hip joint (Poole, 1998; Whitcome et al., 2007). It has been shown that in order to prevent a
forward fall, some pregnant women increase their lumbar lordosis by tilting the pelvis anteriorly and rotating the pelvis on the femur (Poole, 1998; Whitcome et al., 2007). The anteroposterior translation of the center of mass occurs over a narrow range of less than 0.3 ± 0.7 cm by term and maintains a relatively stable position throughout pregnancy (Whitcome et al., 2007). However, if the center of mass was found to remain relatively stable, the lumbar lordosis of pregnant females was found to increase by nearly 60% from a mean angle of 32° ± 12° in early pregnancy to 50° ± 12° at term (Whitcome et al., 2007). Furthermore, it has been suggested that the cervical spine flexes and protracts over the scapula in order to compensate for the increased lordosis (Poole, 1998).

2.2.2 Causes

Despite its high occurrence, knowledge of the pathogenesis, physiology, and management of back pain during pregnancy is far from complete although several biological, social, and biomechanical factors have been identified to contribute to the problem (MacEvilly & Buggy, 1996; Cheng et al., 2009). The physical changes occurring during pregnancy such as weight gain, secretion of relaxin, and laxity of ligaments of the pelvis ensued by postural changes are believed to be a cause of the problem (Mantle et al., 1977; Fast et al., 1987)). However, since the pain does not usually increase throughout the duration of the pregnancy, the biomechanical factors from weight gain are not the only sources of pain (Poole, 1998). In fact, Fast et al. (1987) found that weight gain, from the foetus and/or mother, was not related to gestational back pain. On the other hand, it is suggested that the rapidity of weight gain during the second and third trimester could exceed the adaptive capability of certain individuals (MacEvilly & Buggy, 1996) as the
overstretched abdominals and the shortened back muscles are put at a mechanical
disadvantage (Poole, 1998). These muscles might not be able to withstand the demands
imposed by postural changes and excessive loads, thus ultimately leading to strain of the
pelvis ligaments and possible damage (Mens et al., 1996; Poole, 1998). Therefore, this
strain of the ligaments in the pelvis and lower spine combined with the joint laxity and
additional demand on the muscles is hypothesized to be another cause for back pain.
Furthermore, history of back pain or back pain in previous pregnancies is associated with
pregnancy-related back pain (MacEvilly & Buggy, 1996; Poole, 1998). High gravidity
(number of births plus abortions) was also considered to be a factor contributing to back
pain (Worku, 2003). Consequently, the occurrence of low back pain among older women
is strongly related to multiparity (Worku, 2003). Conversely, it was also found that
younger age is another risk factor possibly due to higher sensitivity to hormonal changes
(Fast et al., 1987; Bookhout & Boissonaul, 1988). Physical work and occupational
factors are also linked to back pain during pregnancy (Berg et al., 1988; Cheng et al.,
2009). Twisting and bending several times an hour (Endresen, 1995) as well as strenuous
physical work such as lifting and sustained posture were reported to be associated with
increased risk of developing low back pain (Cherry, 1987; Rungee, 1993). On the other
hand, confined area and restricted space were also identified as occupational factors
positively correlated with severity of back pain during late pregnancy for women working
in a less physically demanding environment (Cheng et al., 2009).
2.2.3 Postpartum Back Pain

Although pregnancy is temporary, back pain may persist up to 18 months after delivery (Poole, 1998). To and Wong (2003) even observed persistent back pain up to 24 months post-partum in older patients while Noren et al. (2002) documented females with back pain 3 years post partum. The incidence of postpartum back pain has been reported to be in the 30-45% range (Breen et al., 1994). Furthermore, it has been estimated that 35% of pregnant women who experience low back pain during pregnancy go on to develop chronic low back pain and/or disc injuries (Svensson et al., 1990). However, postpartum pain was found to be mild and intermittent (To & Wong, 2003).

Although its role is still controversial based on findings from various studies (MacArthur et al., 1990; Breen et al., 1994), the use of the epidural anesthesia during labor has been identified as a possible cause for postpartum back pain (Russel et al., 1993; MacArthur et al., 1995). MacArthur et al. (1995) found that epidural anesthesia was a strong predictive factor for the development of new long-term back pain, but Breen et al. (1994) and To and Wong (2003) found contradictory results. Back pain associated with epidural anesthesia is thought to be initiated by the loss of reflexes due to the anesthesia as well as poor posture and stressed positions during labor (MacEvilly & Buggy, 1996). Age of the patient appears to be another controversial factor as some studies showed that younger maternal age was a factor for postpartum back pain (Breen et al., 1994) whereas To and Wong (2003) showed that older patients were more likely to have persistent pain at 2 years.
Previous history of back pain was found to be one of the most important factors associated with persistent back pain after delivery (To & Wong, 2003). Here, previous back pain symptoms refer to ache experienced either during pregnancy or in the non-pregnant state. Higher postpartum weight gain and weight retention have also been found to increase the incidence of persistent pain symptoms after delivery (To & Wong, 2003). Several work factors such as heaviness of the work, frequency of twisting and bending forward, as well as psychological factors were also found to contribute to postpartum back pain (MacEvilly & Buggy, 1996). On the other hand, education, parity, height/weight/body mass index, delivery mode, or length of breast feeding were not reported to have any effect on persistent back pain (To & Wong, 2003).

2.2.4 Pain characteristics

Back pain episodes during pregnancy are usually described as intermittent in nature and mild in the majority of cases (To & Wong, 2003). Wu et al. (2004) reported similar results with mild or bearable reported pain in about half of back pain episodes and serious pain in approximately 25%. It was also shown that backache tended to worsen in the evenings and to be common in bed at night (Mantle et al., 1977). Back pain during pregnancy can be categorized in three groups based on the site of pain (Ostgaard et al., 1991; Noren et al., 1997): high back pain in the thoracic region, low back pain in the lumbar region, and pelvic pain when referring to sacroiliac joint and symphysis problems (Mens et al., 1996; Ayanniyi et al., 2006). “ Burning”, “dull ache”, and “stabbing” were the descriptors used to portray pain in the thoracic spine, lower back and pelvic area, respectively (Sturesson et al., 1997). Diagnostic differentiation between the three back
pain categories is important because the treatment administered to the patient will differ depending on the pain characteristics (Ostgaard et al., 1994). High back pain has been reported to be the least common type of backache for pregnant subjects with an occurrence of approximately 10% in various studies (Ostgaard et al., 1991; Noren et al., 1997; Ayanniyi et al., 2006). There are conflicting findings on whether low back pain or posterior pelvic pain is the more common type. The disparity between the results suggests that there is a certain level of diagnostic confusion between these two types of back pain (Albert et al., 2000). Several methods have been used in the attempt to establish a classification of symptoms from the lower back and pelvic girdle, but the lack of consensus on terminology and the different areas included to describe the pelvic region show that the classification and localization of pain are intricate (Albert et al., 2000). Furthermore, about one-sixth of women were reported to experience both types of pain, thus increasing the difficulty when attempting to discern the symptoms between those two types of back pain. Despite these contradicting results, there is an agreement across studies showing that back pain has a high incidence rate among pregnant women and that it deserves serious attention from the medical and scientific communities (Wu et al., 2004).

2.2.5 Postural Stability

The localized weight gain and increased joint laxity during the development of the foetus may contribute to the perception of increasing postural instability throughout pregnancy and may lead to a higher incidence of falls (Dunning et al., 2003; Jang et al., 2008). In those studies, good static postural control is defined as a small sway path (path length)
and small sway excursion of the center of foot pressure movements (Toupet et al., 1992). Butler et al. (2006) found that postural stability declined during pregnancy and remained diminished until 6 to 8 weeks after delivery. This increased instability was found to be directed mainly along the anterior-posterior direction during pregnancy while lateral sway was found to be predominant after delivery (Jang et al., 2008). The steady medial-lateral balance measured throughout pregnancy could be explained by the increasing stance width adopted by pregnant women (Jang et al., 2008) as it has been shown that increasing stance width reduces postural sway, especially lateral sway (Kirby et al., 1987; Day et al., 1993). On the other hand, the increase in postpartum lateral sway suggests that there is a potential residual effect of stance-width reduction, and this increase in postpartum lateral sway may also explain the reduced sense of balance observed after delivery (Jang et al., 2008). However, no association between postural balance and change in weight was found, thus suggesting that additional factors such as laxity of the pelvic ligaments also influence postural stability during pregnancy (Butler et al., 2006). An increased reliance on vision to maintain balance was also reported for pregnant women (Butler et al., 2006). The combination of these two factors, diminished static postural equilibrium and increased reliance on visual cues for balance, can explain the high incidence of falls among pregnant women (Dunning et al., 2003). In fact, Butler et al. (2006) found that 25% of the pregnant women group sustained a fall, compared to none in the control group. Similar fall rates were reported by Dunning et al. (2003) for a larger cohort of pregnant women. Consequently, clinical recommendations based on those findings are to use a comfortable wide and slightly staggered foot placement while standing to increase the lateral and anterior-posterior base of support (Jang et al., 2008).
2.2.6 Possible treatments and solutions

Since back pain is a very common problem during and after pregnancy, various treatments are usually suggested to try and reduce the burden of this condition. Physical exercise and fitness before and during the pregnancy have been shown to result in a decreased incidence of musculoskeletal complaints (Ireland & Ott, 2000). Strengthening of the abdominal and lumbar musculature is particularly important as pregnant women rely largely on the muscles and ligaments of the core to maintain stability (Poole, 1998; Ireland & Ott, 2000). Postural education is another effective and cheap solution to relieve low back pain during pregnancy (Sanya & Olajitan, 2001). Frequent postural changes such as pelvic tilt were also found to ease the symptoms of back pain (Ayanniyi et al., 2006). The use of mechanical supports like the wedgeshaped pillow or trochanteric belt also proved to be useful during pregnancy (MacEvilly & Buggy, 1996). Low dose aspirin is yet another option although it is not preferred due to the disadvantages of pharmacological agents during pregnancy (MacEvilly & Buggy, 1996). Physiotherapy was also identified as an approach to manage back pain symptoms but was mostly used in serious cases of backache (MacEvilly & Buggy, 1996). Finally, higher autonomy over the work pace and work space appeared to have beneficial effects on low back pain during pregnancy (Cheng et al., 2009). In summary, education about the emergence of back pain in pregnancy should be an integral part of pre-natal courses as it affects a large number of women (MacEvilly & Buggy, 1996).
2.2.7 Back pain for African women

In a more specific African context, the presence of severe back pain was found to be affected by the intensive farm work and heavy weight lifting (Worku, 2003). It has also been reported that the prevalence of low back pain complaints was significantly higher in people from low socioeconomic classes and with low education levels (Nagi et al., 1973; Toroptsova et al., 1995; Carey et al., 1995). Women living in poverty in rural parts of Africa have traditionally been given little to no access to basic health services and education (Worku, 2003). This author reported that, in fact, rural mothers were more vulnerable to back pain than their urban counterpart because they lived in poverty with low levels of education and performed strenuous farm work. On the other hand, ethnicity was found to have no effect on the prevalence of low back pain (Nagi et al., 1973; Reisbord & Greenland, 1985). Bjorklund and Bergstrom (2000) found that prevalence of back pain during pregnancy was not affected by geography when comparing pregnant women from two different cities in Africa and Scandanavia, regardless of the socio-economic status of each of the four studied countries. Similarly, Mijiyawa (1993) found that low back pain among the black population of West and Southern Africa was as common as in Europe.

2.3 Load carriage

In some parts of the world, loads are mainly carried by individuals using a range of methods. More precisely, African women are known for carrying heavy loads as high as 70% of their body weight balanced on top of their heads (Heglund et al., 1995). The methods of transporting loads on the head can be categorized into two groups: heavy
loads for short time and over short distances or lighter loads over long distances and for many hours (Echarri & Forriol, 2005). The human gait, energetic cost, and effects on the spine of such a practice will be discussed.

2.3.1 Human Gait

The human walking gait is characterized by cyclic fluctuations in the height and forward velocity of the center of mass of the body (Heglund et al., 1995). Consequently, the potential and kinetic energy of the center of mass of the body oscillates between maximum and minimum values during each step of walking (Cavagna et al., 2002). Active movements of humans are assumed to be powered by positive and negative work of the muscles in order to sustain the mechanical energy changes of the center of mass (Cavagna et al., 2002). During walking, the work done by the muscles is reduced due to the pendular transduction of potential energy into kinetic energy and vice-versa (Cavagna et al., 2002). Unfortunately, humans are not frictionless pendulums, and thus, only part of the energy is conserved during the transfer (Heglund et al., 1995). The recovery of mechanical energy for humans was found to attain a maximum of 65% in normal unloaded walking at the self-selected or optimal speed (Heglund et al., 1995). This optimal speed corresponds to the speed at which the mechanical energy changes of the center of mass between kinetic and potential energy are minimized (Maloiy et al., 1986). In other words, this speed is the most efficient and requires less work by the individual. However, carriage of light or heavy loads has been shown to significantly change the normal pattern of walking (Martin & Nelson, 1986).
2.3.2 Load carriage and energy expenditure

It has been demonstrated across a range of animal species and in humans that the increase in energy expenditure associated with a given load carried on the back is directly proportional to the relative increase in mass (Taylor et al., 1980; Rorke, 1990; Quesada et al., 2000). For instance, an additional load of 10% body mass leads to a 10% increase in energy expenditure when loads are carried on the back. The rate of energy expenditure is obtained from a conversion of the rate of oxygen consumption calculated by analysis of the oxygen content of an air mask worn by the subjects during walking (Taylor et al., 1980; Maloiy et al., 1986; Heglund et al., 1995; Rorke, 1990; Quesada et al., 2000; Lloyd et al., 2010). It has also been shown that energy expenditure significantly decreases when loads are placed close to the trunk (Soule & Goldman, 1969) but only small or no physiological advantages between different loading methods involving trunk loading were reported (Holewijn, 1990; Kirk & Schneider, 1992). Conversely, it was reported that loads carried high on the back have a significant advantage over loads carried in a low position (Stuempfle et al., 2004) showing a lower metabolic cost. It has also been argued that the head-loading method represented a particular economical technique as African women were found to be able to carry loads of up to 20% of body weight with no additional energy expenditure with a linear relationship thereafter (i.e., load of 30% of body mass required a 10% increase in energy expenditure) (Heglund et al., 1995). Similarly, Maloiy et al. (1986) found that African women could carry loads of up to 20% for “free” without any energetic cost (Maloiy et al., 1986). These results are impressive as even trained individuals such as army recruits were not able to carry small loads without any metabolic cost (Maloiy et al., 1986). The mechanisms for this energy
economy is uncertain but it was hypothesized that anatomical changes had occurred as a result of carrying loads since childhood (Maloiy et al., 1986; Heglund et al., 1995). The latter also suggested that African women, when loaded, had a greater capability of conserving mechanical energy, thus resulting in a decrease in work or energy expenditure. In fact, African women showed a better transfer between their potential and kinetic energy than the control group when walking in loaded conditions (Heglund et al., 1995). However, Lloyd et al. (2010) revisited the matter more recently and obtained contradicting results, showing little support for the “free-ride hypothesis”. Lloyd et al. (2010) justified these opposing results with the small sample sizes (less than six) of the two previous studies; they argued that these small sample sizes were unable to illustrate the inter-subject variability. Although they found some evidence of energy-saving mechanisms, their results suggest that load carriage economy may be specific to each individual. Their data also revealed significant variation in load-carrying economy, regardless of method, proposing that there may be several factors interacting differently on individuals rather than a single set of factors that influence load carriage economy. The disagreement between the different studies demonstrates the need for future work to establish the nature of the factors influencing load carriage and their interactions in individuals.

2.3.3 Effect of axial load on the upright human spine

Long-term head load carriage inevitably has an impact on the spine of the carriers. Meakin et al. (2008) studied the effects of load carriage on the human spine in vivo using a positional MRI scanner where subjects could be scanned in upright postures. The study
showed that the average-shaped spine straightened slightly under loaded conditions (Meakin et al., 2008). However, the effect of load systematically varied between individuals; unloaded spines with a large, mainly lordotic curvature curved even more under load, whereas spines with a smaller lordotic curvature straightened under load (Meakin et al., 2008). Straightening of the spine had previously been found experimentally by means of external measurements of the back (Shirazi-Adl & Parnianpour, 1999; El-Rich et al., 2004). This variation in the spinal curve as well as the different behaviors under load indicated that there is possibly a considerable inter-subject variability in the forces experienced by the spine (Meakin et al., 2008).

2.3.4 Cervical Spine

The cervical spine is the most mobile part of the spine because it has the greatest ratio between the height of the body and the intervertebral disc (Echarri & Forriol, 2005). It has a natural lordosis to increase the resistance to axial compression generally caused by the single weight of the head (Echarri & Forriol, 2005). The cervical discs experience larger pressures than discs in other sections of the spine due to their smaller surface area (Echarri & Forriol, 2005). The discs provide for shock absorption and distribute the weight over the surface of the vertebral bodies. The pressure borne by these intervertebral cervical discs increases when an additional load is placed on top of the head.

Disc degeneration is very common in the general population and is generally linked to the ageing process while the effect of gender is still controversial across studies (Jager et al., 1997). In fact, all of the cervical spines for patients over 70 years old in the study demonstrated degenerative changes. However, the results showed that these changes
occurred at an earlier age and with greater severity for individuals carrying loads on their heads. Degenerative changes were observed in two or more cervical segments for 74.3% of the carriers compared to 11.4% of the non-carriers. Similarly, Echarri & Forriol (2005) found that 88.6% of carriers had degenerative changes in the cervical spine compared with 22.9% in the control group. Degenerative changes correspond to a simultaneous degeneration of the discs, vertebral bodies, ligamentous structures, and facet joints (Jager et al., 1997). Degeneration usually starts by disc height loss followed by the apparition of osteophytes at the superior and inferior attachments along the periphery of the discs (Jager et al., 1997). Both studies reported the highest degeneration changes occurring at C5/C6 (Echarri & Forriol, 2005; Jager et al., 1997). Although there was radiographic evidence of severe degeneration on the cervical neck of the carriers, several individuals were completely asymptomatic (Jager et al., 1997). The weight of the load carried on the head also seemed to have an impact on the development of osteophytes as the light-load bearers were less affected than the heavy-load bearers (Echarri & Forriol, 2005).

2.4 Measuring posture

There is evidence in the literature that working postures are related to musculoskeletal health (Vieira & Kumar, 2004). Consequently, measurement of trunk postures and movements is an important area of research in the bioengineering, rehabilitation, and ergonomic fields (Wong et al., 2007). Various methods are available to assess trunk posture and trunk motion in the field and laboratory settings. These methods can be broadly classified in three different categories: self-reports by workers, observations by a trained individual, and direct measurements (Trask et al., 2007); these three methods of
exposure assessment are in order of increasing precision (Winkel & Mathiassen, 1994; Burdorf, 1999). All of these methods have their respective limitations (Hansson et al., 2001), therefore the choice of assessment method for a particular study will depend on the tasks monitored and the objectives of the study as well as the budget available (Trask et al., 2007).

2.4.1 Self-reports by workers

Self-reports can take several forms such as interviews, questionnaires, or worker diaries (David, 2005). These reports are used to collect data on workplace exposure to physical and psychosocial factors as well as information on demographic variables, pain and postural discomfort, and levels of subjective exertion (David, 2005). Post-shift interviews can also be conducted to assess self-reported exposures of the work shift and obtain estimations on the durations of the work postures from drawings of representative postures (Trask et al., 2007) and the number of high trunk flexions (Andrews et al., 1998). These methods are straightforward, applicable to a wide range of situations, and relatively low cost (David, 2005). However, subjectivity is a major problem associated with these methods as it has been shown that individuals with symptoms reported higher durations or frequencies of physical load when compared to pain-free workers (Viikari-Juntura et al., 1996; Pope et al., 1996). Literacy, question comprehension, or question interpretation are other issues related to self-reports (Spieholz et al., 2001). Furthermore, the presence of researchers or other people during interviews may influence the outcomes of self-reports, thus affecting the validity of this method (Trask et al., 2007). Although the precision and quantification of exposure level are unreliable (Pope et al., 1996; Trask
et al., 2007), these methods can identify groups at higher risk to determine which occupational groups require a more detailed analysis (Burdorf, 1999).

2.4.2 Observational methods

A number of observational techniques have been developed to systematically record workplace exposure by a trained observer (David, 2005). The number of exposure factors included in the assessment varies across the different techniques but the majority assess several critical physical exposure factors such as trunk and head inclination, elevation of the arms, angle at elbow, etc. (David, 2005). Observational methods are more suited for the assessment of static or repetitive tasks (Van der Beek & Frings-Dresen, 1998) as it has been shown that trained observers are capable of estimating body angles of static postures to a high level of accuracy and precision (Douwes & Dul, 1991; Van der Beek et al., 1992; Genaidy et al., 1993) but that the validity is unsatisfactory for dynamic tasks (De Looze et al., 1994). Observation of dynamic work is very labour intensive and can challenge the observer to stay aware of the workplace hazards surrounding the tasks performed (Trask et al., 2007).

Dynamic activities generally require video observation or direct measurements (Van der Beek & Frings-Dressen, 1998) to be able to view all working postures. However, video recordings are not without their limitations either. Drawbacks of videos are the possible perspective errors when a worker rotates from the optimal viewing angle or when the worker disappears from sight when moving around. (Veltink et al., 1996). Nevertheless, video recordings generally provide more information than simple observational
techniques because they allow for review of certain postures and offer the possibility for digitization (Van der Beek & Frings-Dressen, 1998).

A major disadvantage of both observational techniques, direct or video recordings, is that they are subjected to intra- and inter-observer variability as they are subjective methods (Li & Buckle, 1999; David, 2005). Despite these limitations, observational methods and video recordings have the advantage of being inexpensive and practical for observing workers in a field setting without disruption (David, 2005).

2.4.3 Direct measurements

A number of methods using sensors or markers attached directly to the subject have been developed for the measurement of posture and exposure variables at work (David, 2005). A wide range of lightweight sensors are used to provide continuous recordings of human movement while minimally interfering with the task studied (David, 2005). Large quantities of highly accurate and objective data can be generated by these systems. However, the high cost of the equipment, the need for highly trained technical staff, the time required for set-up, and the high maintenance of the equipment, can render direct measurement unsuitable in some environments (Li & Buckle, 1999). Motion capture systems, electrogoniometers, electromagnetic tracking systems, accelerometers, gyroscopes, and inertial measurement units are the methods reviewed in this section.

2.4.3.1 Motion capture systems

Motion analysis systems have become an increasingly popular tool for accurate measurement of human motion and posture (States & Pappas, 2006). Motion capture
systems use either light-reflective markers or light-emitting diodes that are fixed to the human body (Wong et al., 2007). The three-dimensional positions of these markers are captured by cameras, and through data processing, the orientation of body segments, position of body parts, and joint angles can be determined (States & Pappas, 2006). However, the measurement volume is small and markers must be visible at all times by the cameras. Due to these constraints, motion capture systems are usually restrained to a laboratory setting where no equipment, personnel, or machinery can obstruct the camera’s view. Furthermore, the high cost and the time-consuming calibration are other disadvantages associated with motion capture systems for workplace applications (Marras et al., 1992). Nevertheless, these systems provide high precision, accuracy, and reliability that result in minimal measurement error (States & Pappas, 2006).

2.4.3.2 Electrogoniometers

An electrogoniometer is a flexible angular sensor that uses strain gauges to measure angles between two adjacent body segments (Nicol, 1987; Wong et al., 2007). The device consists of two lightweight plastic end-blocks connected by a flexible spring that protects a strip of steel foil (Boocock & Jackson, 1994). The angle of one end-block with respect to the other is measured by strain gauges fitted to the surface of the steel foil and enclosed in the end-blocks (Boocock & Jackson, 1994). The linear relationship between electrical output from the strain gauges and the angle between the encapsulated ends is used to measure body segment movements in two principal planes; usually sagittal and coronal (Wong et al., 2007). These devices are usually attached directly on the skin of the subject with the end-blocks parallel to the long axis of the adjacent segments being monitored.
The telescopic arrangement of one of the end-blocks allows the relative distance between the two ends to change during movement thus preventing over-stretching or buckling of the steel foil (Boocock & Jackson, 1994). However, the linear displacements of certain joints may exceed the distance permitted by the telescopic arrangement of the device thus limiting the measurement range of motion (Boocock & Jackson, 1994). It was shown that the measurements of spinal motion by electrogoniometers were comparable to those measured by a fluid-filled inclinometer or a flexicurve (Boocock & Jackson, 1994) but not comparable with radiographic data in the lumbar range of motion (Thoumie et al., 1998). Despite this lack of precision and accuracy in the measurements, the device was recommended for use in occupational environments to provide quantitative information of lumbar sagittal motion (Boocock & Jackson, 1994). Electrogoniometers have the advantage of being light, but they also have the disadvantage of being relatively expensive and fragile.

2.4.3.3 Electromagnetic tracking system

Human posture and movement analysis can also be measured by an electromagnetic tracking system (Wong et al., 2007). These systems generally consist of a transmitter and several receivers attached on body segments; the transmitter generates a low-frequency magnetic field that is detected by the receivers (Wong et al., 2007). The three-dimensional positions and orientations of the different receivers, and therefore of the body segments, relative to the transmitter can then be determined by the system processor (Wong et al., 2007). Electromagnetic tracking systems provide high resolution accuracy and repeatability in spinal motion analysis with reported errors of less than 1° and 2°,
respectively (Pearcy & Hindle, 1989). However, the accuracy of measurement is affected by the distance between the transmitter and receivers. Consequently, the measurement volume of this system is very limited as it has only a small optimal operational zone limiting the types of activities that can be analyzed (Bull & McGregor, 2000). Furthermore, the accuracy of the system is also affected by the presence of metallic objects in the surroundings. In fact, metallic interference occurs when metal is placed within 100 mm of the transmitter or receiver (Lou et al., 2000). Therefore, this type of system is not suitable for patients with metallic implants or prostheses as they would interfere with the signal. These limitations, in addition to the wires necessary for the receivers, restrict the use of electromagnetic tracking systems to a laboratory setting where the environment is controlled.

2.4.3.4 Accelerometers

An accelerometer is a transducer that measures acceleration along its sensitive axis or axes (Veltink et al., 1996; Luinge & Veltink, 2004). Accelerometers are frequently used to monitor human movement as they are small, robust, relatively inexpensive, have low power requirements, and can easily be attached to a human body segment (Luinge & Veltink, 2004). The output of an accelerometer fixed to a body segment can be divided into four main components: 1) acceleration due to movement of the segment; 2) gravitational acceleration; 3) external vibrations not produced by the body itself (e.g. vehicles); 4) accelerations due to bouncing of the sensor against other objects or jolting of the sensor on the body due to loose attachment, resulting in mechanical resonance (Bouten et al., 1997). The external vibrations as well as the mechanical resonance add
noise to the accelerometer output, but those components can be attenuated with filtering and proper attachment of the sensor to the body segment (Bouten et al., 1997). Only the first two components of the accelerometer signal are directly related to the movement of the body segment (Bouten et al., 1997). The acceleration component is often referred to as the kinetic component and depends on the activities performed by the individual wearing the accelerometer (Bouten et al., 1997). If this kinetic component is small compared to gravity, accelerometers can be used as an inclinometer to determine the orientation of a body segment relative to the line of gravity (Kemp et al., 1998). When doing so, the sensitive axis of the accelerometer should be placed perpendicular to the line of gravity as it is the most sensitive to tilt (Accelerometer datasheet, Appendix A).

As a result of these properties, accelerometers have been a common approach in recent years for measuring posture by using a set of two or three accelerometers mounted orthogonally (Veltink et al., 1996; Foerster et al., 1999; Mathie et al., 2003; Luinge & Veltink, 2004).

The combination of two or three accelerometers oriented perpendicular to one another allows the monitoring of a body segment in two planes (Accelerometer datasheet, Appendix A). However, the inability to assess the rotation around the line of gravity remains a fundamental limitation of inclinometry (Hansson et al., 2001). Another drawback of the accelerometer is the poor quality of inclination estimates for movements with large accelerations (Luinge & Veltink, 2004). Large dynamic accelerations can partially be dealt with by using a low pass filter to remove signals above a cut-off frequency chosen based on the human movements performed during data collection.
Despite these shortcomings, accelerometers remain the only suitable sensors for long term ambulatory recording of human body movements (Luinge & Veltink, 2004).

2.4.3.4.1 The Virtual Corset™

The Virtual Corset™ (VC) (Microstrain Inc., Williston, VT, USA) uses the accelerometer properties and principles described above to monitor trunk angles in the frontal and sagittal planes. Acceleration data are measured by the VC and transformed using an algorithm to output the resulting data in degrees. The manufacturer’s specifications state that lateral bending angles can be measured accurately within the range of ±70° with respect to the vertical whereas flexion and extension angles can be measured accurately throughout the full 360° range. The Virtual Corset™ is composed of two bi-axial accelerometers mounted orthogonally combined with a datalogger enclosed in a pagersized plastic cover (Figure 2.1). The device is wireless, battery-powered, and possesses 1MB of non-volatile memory. A press button is also included in the device to identify specific events during data collection. The manufacturer reports an accuracy of ± 0.5° for the angles measured by the device. The user can choose between a linear or bin logging mode. The bin mode logs inclination data in 1° increment in the form of histograms at a sampling rate chosen by the user. On the other hand, the linear mode records the actual angle of inclination in a continuous stream from beginning to end of a session at a fixed sampling rate of 7.5 Hz for approximately 10 hours. Inclination angles can be downloaded to a computer using the Virtual Corset Software for further processing. The Virtual Corset™ represents a low cost method that is easy to use and not restrained to a laboratory setting to measure trunk postures in two directions for long periods of time. Its
small size, low weight, and wireless feature also minimize its interference with the movements of daily activities.

![Image](image.png)

**Figure 2.1.** Picture of the VC with dimensions 67 mm long x 50 mm wide x 20 mm thick. A) Front view of the Virtual Corset with the battery (in pink) contained in the hard plastic pager-type enclosure and the push button (in black) in the left corner; B) Back view of the Virtual Corset with the spring-loaded belt clip.

### 2.4.3.5 Gyroscopes

A gyroscope is another type of sensor used for measurement of human posture and movement (Wong et al., 2007) that recently showed its validity in measuring trunk tilt (Najafi et al., 2000). It is an angular velocity sensor based on the concept of measuring the Coriolis force that arises in the rotating frame of vibrating devices (Senturia, 2001). The Coriolis force is proportional to the angular rate of rotation, and the angular orientation of a body segment can be obtained from integration of the signal (Senturia, 2001). The device can be attached on any part of a body segment with its axis parallel to the measured axis as the angular rotation is the same along the segment. It has the advantages of being small and portable and thus, it is not limited to a laboratory setting. However, gyroscopes also have some drawbacks such as power consumption, high price,
drift of the signal, and a high sensitivity to shock (Aminian & Najafi, 2004). Gyroscopes have often been combined with accelerometers in recent years to form a measuring system capable of simultaneously collecting more information such as inclination with respect to gravity, linear acceleration, and angular velocity (Wong et al., 2007). This successful fusion between different types of sensors is a recommendation in designing future systems for human movement and posture analysis (Wong et al., 2007).

### 2.4.3.6 Inertial Measurement Unit

Inertial measurement units (IMU) are composed of a three-axial accelerometer and a three-axial gyroscope mounted approximately at the same point (Luinge, 2002). The introduction of Micro Electro Mechanical Systems (MEMS) technology has rendered the use of these inertial sensors suitable for human movement analysis as their small sizes allow their attachments to a body segment (Schepers, 2009). A calibrated IMU can measure three-dimensional angular velocity and three-dimensional acceleration to estimate change of position and orientation of a body segment (Schepers, 2009). The change in orientation can be obtained by integration of the angular velocity measured by the gyroscope, while the change in position can be obtained by double integration of the acceleration signals after removal of the gravitational acceleration (Schepers, 2009). These signals are expressed in the rotating coordinate frame of the sensor (Luinge et al., 2007). In order to express the signals in the coordinate frame of a body segment, the orientation of the IMU with respect to the segment must be obtained through calibration (Luinge et al., 2007). These inertial sensors are typically self-contained and can therefore be used to monitor ambulatory motions in a wide range of environments (Schepers,
However, they are vulnerable to integration drift caused by noise and a fluctuating offset (Schepers, 2009). Fusion of inertial sensors with other sensing technologies as well as the use of Kalman filters to eliminate the drift problems have been suggested to overcome the weaknesses of inertial sensors.

2.5 Conclusion

Back pain is a common and sometimes disabling problem among pregnant women. This back pain has also been found to persist for several years after delivery in some cases. Consequently, this predicament represents a serious problem that afflicts pregnant women, and it can have an important impact on the life of the sufferers. Strenuous physical work and sustained postures have been found to increase the risk of back pain during pregnancy. Previous studies have examined the effects of different tasks performed in typical North-American work environments on back pain during pregnancy. However, only a limited number of studies have focused on the same topic for West African women. Postures adopted by these women during their daily occupational tasks would provide valuable information on their exposure to high risk factors such as sustained postures, trunk flexion, and lifting. An instrument capable of measuring trunk postures in the field setting was preferred for this pioneer study.


2.6 References


Chapter 3

3 Trunk postural demands of occupational activities of merchant pregnant women in Benin, West Africa

3.1 Introduction

Back pain during pregnancy is such a frequent problem that it is sometimes looked upon as a part of normal pregnancy for women across the world (Nagi et al., 1973; Reisbord & Greenland, 1985; Fast et al., 1987). This back pain can be very severe in some cases and limit the pregnant women in their ability to work and perform daily activities (Ostgaard et al., 1991). Although back pain during pregnancy is common, its causes still remain unclear. However, several biological, social, biomechanical, and occupational factors have been found to contribute to the problem (Cheng et al., 2009). Of these factors, strenuous physical work including frequent lifting and sustained postures were identified to be associated with increased risk of developing low back pain during pregnancy (Rungee et al., 1993; Cherry, 1987; Heliovaara, 1989; Fung et al., 1993). Similarly, Endresen et al. (1995) reported that twisting or bending several times an hour during the workday were the occupational factors associated with the greatest risk for pelvic and/or lower back pain. Although these studies mainly focused on pregnant women in industry, these risk factors are also likely valid for women in other parts of the world who perform physically demanding work outside an industrial setting. More precisely, women in West
Africa participate in laborious daily occupational activities. Those daily duties include a variety of tasks ranging from farm work, drawing water from wells, and carrying the water to errands around the house such as doing laundry, washing dishes, and sweeping the floor. West African women also frequently take part in commercial activities that require the carriage of heavy loads on their heads for long periods of time with repetitive bending and lifting motions.

Additionally, high gravidity is another factor associated with increased risk of developing back pain during pregnancy (Worku, 2003). West African women typically have a higher number of pregnancies than women in Europe and North America, thus increasing the possibility of experiencing back pain. This high pregnancy rate combined with physical tasks and sustained trunk postures expose West African women to a great risk of musculoskeletal disorders, especially back pain. However, the characteristics of their daily occupational and head load carriage tasks are not well documented in the literature. Furthermore, to the author’s best knowledge, no posture analysis on this specific population has been performed to define the trunk postures assumed at various points throughout the day.

Consequently, the objectives of this investigation were to 1) identify the principal daily occupational tasks performed by pregnant women in Benin, West Africa; 2) gain descriptive information on the specific task of head load carriage; 3) describe bodily pain associated with this specific task; 4) compare the results from the first three objectives between pregnant women and a control group of non-pregnant women; and 5) measure trunk postures of pregnant women during their occupational activities in a field setting in
Benin. This descriptive information on the daily occupational tasks and postures assumed by these pregnant women will allow a better understanding of the physical demands of this understudied population.

3.2 Methods

3.2.1 Participants

Twenty-five non-pregnant women (age 26 ±7 years) and 26 pregnant women (age 26 ± 5 years) with past or present experience of head load carriage were recruited in Porto-Novo, Benin to participate in this study. Women unable to lift and carry a mass corresponding to approximately 20% of their body mass or unable to carry out their typical daily occupational tasks were excluded from this study. Pregnant subjects were recruited at a community maternity centre, while non-pregnant subjects were recruited through local contacts to match the pregnant women sample in age and height. Mean height and mass for the non-pregnant women were 159 cm (± 6) and 57 kg (± 11), respectively, while the mean height and mass for the pregnant subjects were 159 cm (± 6) and 63 kg (± 15), respectively. Due to problems in locating all the pregnant subjects at their residences (refer to section 6.2.1 for further details on these problems), only 17 (age 26 ± 5 years, height 158 ± 6cm, mass 62 ± 12 kg) of the initial 26 pregnant women participated in the second part of the study where trunk postures were measured throughout the day. The study protocol was approved by the Queen’s University Research Ethics Board and by the Institut National de la Jeunesse, de l’Éducation Physique et Sportive (INJEPS) Ethics Board in Porto-Novo, Benin (Appendix B). Informed consent was obtained from all subjects (Appendix C).
3.2.2 Instrumentation

3.2.2.1 Questionnaires

Three questionnaires were used in this study. The first questionnaire was designed to obtain information about the demographics and daily occupational tasks of our subject population. A section on head load carriage was also included in this questionnaire to gain descriptive knowledge of this specific task. The second questionnaire was a modified version of the Oswestry 2.0 questionnaire where the original questions were adapted to the lifestyles of women in West Africa. The purpose of the Oswestry Low Back Pain Disability Questionnaire is to assess pain-related disability in individuals with low back pain. In this study, it was used to rate the severity of back pain experienced in the six months prior to the start of the study for non-pregnant women or since the start of pregnancy for pregnant subjects. The Oswestry disability index was computed as suggested by Fairbank and Pynsent (2000) from the answers to the 10 questions in the questionnaire. The scores range between 0.0-1.0 and indicate the degree of functional limitations due low back pain. The last questionnaire was a pain drawing (Sturesson et al., 1997) where all subjects identified the body parts where they experienced pain during the specific task of head load carriage. More than one area could be pointed out. These locations were coded as neck & shoulders, upper back, lower back, pelvis, buttocks, thigh, calf, foot, front pelvis, and pubic region. A visual scale was used to indicate the level of bodily pain where a value of 0 corresponded to slight discomfort and 10 to severe pain. The original version of those questionnaires can be found in Appendix D.
3.2.2.2 Trunk posture

Trunk postural data during a typical day for women in Benin were collected using a Virtual Corset™ (VC) (MicroStrain, Williston, VT, USA). This device is an inclinometer system combined to a miniature datalogger enclosed in a light pager-sized plastic case. It is battery-powered, wireless and composed of two bi-axial accelerometers positioned orthogonally. Using an algorithm developed by the manufacturer, the accelerations measured by the accelerometers are transformed into angle data to monitor trunk inclination with respect to the line of gravity or with respect to a subject’s upright position in two directions (flexion and lateral bending). The VC continuously records data once it is powered; however, the press-button (PB) function allows the identification of events by introducing “PB” in the stream of angle data collected at the instant where the button is pressed. Data were sampled at a rate of 7.5 Hz and stored on the built-in non-volatile memory of the device until the end of data collection at which point the data were downloaded to a computer via the Windows-based Virtual Corset control software (VC-323, Microstrain Inc, Williston, VT, USA) for further analysis. Based on the sampling rate and the on board memory capacity, trunk angles could be monitored for approximately 10 hours.

3.2.3 Procedure

3.2.3.1 Questionnaires

As part of another study on head load carriage by the same group (Chapter 4), 25 non-pregnant and 26 pregnant subjects were invited to come to the INJEPS. At the beginning
of that visit, all participants were asked to answer two of the three questionnaires; the
demographic questionnaire and the Oswestry 2.0. The subjects then lifted and carried
loads on their heads as part of the other study included in Chapter 4. Immediately after
completing this task, the subjects were asked to identify the areas where they experienced
bodily pain during head load carriage on the pain drawing and to indicate the severity of
the pain using the visual scale. Due to the illiteracy of most our subjects, the
questionnaires were translated from French to the local dialect, read aloud and the
answers were transcribed by a student from the INJEPS.

3.2.3.2 Trunk posture

A maximum of two subjects per day could be monitored due to the availability of only
two VCs. Consequently, for nine days, the investigators (E.B-G and M.L.) of this study
went to the home of a maximum of two of the pregnant subjects at the beginning of the
day to instrument them with the VC. Participants were equipped with one device at the
level of C7 to obtain the inclination angles of the upper trunk with respect to the subject’s
upright neutral posture in two directions: flexion-extension and lateral bending. The VC
was placed as close as possible to the bony landmark of C7 on the back of the subject in a
custom pocket secured to the trunk using elastic Velcro straps around the torso and
shoulders (Figure 3.1). The VC was also placed in a waterproof bag in order to protect
the instrument against any bad weather. Prior to launching the VC, participants were
asked to stand in their most upright posture to set the reference position of the VC.
Subjects were instructed to carry out their normal activities and ignore the presence of the
VC on their back for the whole day. The investigators then returned to the subjects’
residences several hours after the start of data collection to remove the instrument. The PB on the VC was pressed at the start and end of the day to allow the identification of the limits of data collection.

![Image of side views of pregnant women instrumented with a VC](image)

Figure 3.1. A) Pregnant women instrumented with one VC at the level of C7. The VC is enclosed in the navy blue pocket to minimize its displacement. Tape was also used over the adjustable feature of the harness to secure it to the women’s torso. B) Zoomed view of the attachment of the VC on the torso. C) Front view of the harness secured around the torso and shoulders.

### 3.2.4 Data Processing

All data were processed using custom software developed in Matlab R2007B (The Math Works Inc., Nathick, MA, USA).

#### 3.2.4.1 Trunk postures

First, all lateral bending angles, as well as their corresponding flexion-extension angles, above 70° on either side were manually removed from the stream of angle data as this maximum limit was stated by the manufacturer. Angles larger than this limit were also
believed to occur for postures where the subjects were lying on their sides to rest, and thus irrelevant for our study on postures throughout the day when performing occupational tasks. Furthermore, once the lateral bending angles exceeded 70°, cross-talk occurred with the flexion-extension angles rendering them invalid for analysis.

The trunk flexion and lateral bending angles were analyzed separately. An amplitude probability distribution function (APDF) analysis was performed to determine the 10th, 50th, and 90th percentiles of trunk flexion and lateral bending for the entire day for each subject. An average of each of these percentiles was also calculated to obtain the general 10th, 50th, and 90th percentiles for the group of pregnant women included in this study.

Another analysis was performed for the trunk flexion angles based on the guidelines of the rapid upper limb assessment (RULA) (McAtamney & Corlett, 1993); the percentage of time spent at 0° (neutral position), between 0° and 20°, between 20° and 60°, and above 60° was calculated. The underlying idea in these angle classifications is that joint position is most favorable when it is near its neutral position. Trunk extension was also analyzed and separated into two categories: percentage of time spent in trunk extension smaller than 10° and trunk extension larger than 10°. For side bending, the percentage of time spent at 0° (neutral position), angles between 0° and 20°, and above 20° on both sides was determined based on an article by Freitag et al. (2007).

The number of trunk flexion occurrences in excess of 60° throughout the day was also determined counting each bending motions. The numbers of these sagittal bends lasting
longer than four seconds were also counted as they are thought to represent static postures (Freitag et al., 2007).

3.3 Results

3.3.1 Questionnaires

3.3.1.1 Demographic information

The demographic information for the subject population of this study is summarized in Table 3.1. The mean age of the pregnant and non-pregnant participants was identical, while the mean gravidity was also very similar between the two groups. All subjects but one were right-hand dominant while one subject did not complete that question in the questionnaire. Most subjects were self-employed, which in this case corresponded to commercial activities. Approximately half of the two subject groups had a low monthly income under 15,000 CFA which converts to approximately $32 CAD. The mean stage of pregnancy for the pregnant women was 25 ± 9 weeks; however, there was a large variation between the different stages of pregnancy of the subjects with weeks into the pregnancy ranging from 10 to 36 weeks. The complete details about the pregnancy stage of each subject are shown in Table 3.2. None of the participants reported smoking or chewing tobacco.
Table 3.1. Demographic information on the subject population of this study obtained by the demographic questionnaire.

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Non-Pregnant</th>
<th>Pregnant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age</td>
<td>26 years</td>
<td>26 years</td>
</tr>
<tr>
<td>Mean Gravidity</td>
<td>2.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Education level*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No education</td>
<td>56% (14)</td>
<td>54% (14)</td>
</tr>
<tr>
<td>Elementary school</td>
<td>32% (8)</td>
<td>31% (8)</td>
</tr>
<tr>
<td>Middle school</td>
<td>12% (3)</td>
<td>8% (2)</td>
</tr>
<tr>
<td>Dominant hand*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>96% (24)</td>
<td>96% (25)</td>
</tr>
<tr>
<td>Left</td>
<td>4% (1)</td>
<td>-</td>
</tr>
<tr>
<td>Ethnic group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fon</td>
<td>8% (2)</td>
<td>4% (1)</td>
</tr>
<tr>
<td>Yoruba</td>
<td>56% (14)</td>
<td>15% (4)</td>
</tr>
<tr>
<td>Goun</td>
<td>32% (8)</td>
<td>81% (21)</td>
</tr>
<tr>
<td>Employment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stay at home</td>
<td>-</td>
<td>31% (8)</td>
</tr>
<tr>
<td>Self-employed</td>
<td>100% (25)</td>
<td>69% (18)</td>
</tr>
<tr>
<td>Employee</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Income* (x1000 CFA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 15</td>
<td>52% (13)</td>
<td>50% (13)</td>
</tr>
<tr>
<td>15 -30</td>
<td>32% (8)</td>
<td>35% (9)</td>
</tr>
<tr>
<td>30 - 50</td>
<td>4% (1)</td>
<td>4% (1)</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>12% (3)</td>
<td>8% (2)</td>
</tr>
</tbody>
</table>

*Indicates these questions were not answered by all subjects.
Table 3.2. Stage of pregnancy (in weeks) of the pregnant subjects.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Number of weeks into pregnancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>unknown</td>
</tr>
<tr>
<td>3</td>
<td>unknown</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>6</td>
<td>28</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
</tr>
<tr>
<td>9</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>18</td>
<td>36</td>
</tr>
<tr>
<td>19</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>21</td>
<td>unknown</td>
</tr>
<tr>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>23</td>
<td>36</td>
</tr>
<tr>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>25</td>
<td>32</td>
</tr>
<tr>
<td>26</td>
<td>24</td>
</tr>
</tbody>
</table>

Average 25 (±9)

3.3.1.2 Daily Activities

The ten activities most frequently reported in the questionnaires by the two groups are listed in Table 3.3. The postures adopted for doing dishes, getting water from the wells, doing laundry, cleaning/sweeping, and grinding condiments are shown in Figure 3.2.
Highly flexed trunk postures and sustained trunk postures are viewed in most of these tasks. All pregnant women noted that they had more difficulty completing these tasks during pregnancy.

Figure 3.2. A) Woman doing the dishes; B) Woman drawing water from the well; C) Woman doing laundry; D) Woman sweeping the floor with a short-handled broom; E) Woman cooking using coal; F) Women grinding condiments
<table>
<thead>
<tr>
<th>Daily activities</th>
<th>Number of subjects</th>
<th>Mean Occurrence (weekly)</th>
<th>Estimated mean time to complete task (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
<td>25 (100%)</td>
<td>25 (96%)</td>
<td>11</td>
</tr>
<tr>
<td>Doing dishes</td>
<td>22 (88%)</td>
<td>24 (92%)</td>
<td>13</td>
</tr>
<tr>
<td>Going to market</td>
<td>24 (96%)</td>
<td>24 (92%)</td>
<td>3</td>
</tr>
<tr>
<td>Cleaning in the house</td>
<td>22 (88%)</td>
<td>23 (88%)</td>
<td>9</td>
</tr>
<tr>
<td>Grinding condiments</td>
<td>19 (76%)</td>
<td>23 (88%)</td>
<td>3</td>
</tr>
<tr>
<td>Going to get water</td>
<td>23 (92%)</td>
<td>20 (77%)</td>
<td>14</td>
</tr>
<tr>
<td>Making bed/spreading out mattress</td>
<td>25 (100%)</td>
<td>24 (92%)</td>
<td>8</td>
</tr>
<tr>
<td>Doing laundry</td>
<td>25 (100%)</td>
<td>25 (96%)</td>
<td>5</td>
</tr>
<tr>
<td>Cleaning around the house</td>
<td>12 (48%)</td>
<td>10 (38%)</td>
<td>9</td>
</tr>
<tr>
<td>Going to get wood</td>
<td>-</td>
<td>2 (8%)</td>
<td>-</td>
</tr>
</tbody>
</table>
Answers to the questions about the head load carriage task included in the demographic questionnaire are summarized in Table 3.4. It can be noticed that there is a large day-to-day variation in the duration of head load carriage, with a mean of nearly 2.5 hours for the non-pregnant women and 2 hours for the pregnant women. A large percentage of the pregnant population reported that lifting, carrying, and lowering of the load were more difficult during pregnancy, with the enlargement of the abdomen being the cause in half of the subjects. Lifting of the load alone was the method of choice for over half of the non-pregnant and pregnant women before pregnancy. However, 62% of pregnant women reported using a partner to lift the load during pregnancy as opposed to only 42% before pregnancy. The team lifting method, which is typically employed for heavier loads, consists of two people lifting the load simultaneously on opposite sides of the tray that holds the load and placing it on one of the lifters’ head. Vendor’s type can be classified in two categories: walking and fixed merchant, with the former being the more common of the two. Walking merchants refer to women who carry their merchandise on their head all day only stopping to make a sale while fixed merchants only carry their goods on their heads to and from their sale stand at the start and end of the day. The latter type of merchant occupies the same location throughout the day. Very few women reported taking voluntary breaks during the day to rest. However, that percentage slightly increased during pregnancy with 15% of pregnant women admitting to take 6-10 breaks per day to rest up.
Table 3.4. Descriptive information on head load carriage obtained from the subjects of this study.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Non-Pregnant</th>
<th></th>
<th>Pregnant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation of duration of head load carriage throughout the week*</td>
<td>Yes</td>
<td>56% (14)</td>
<td>No</td>
<td>44% (11)</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>38% (10)</td>
<td>No</td>
<td>58% (15)</td>
</tr>
<tr>
<td>Mean day-to-day variation (min)</td>
<td>195 (± 144)</td>
<td></td>
<td></td>
<td>151 (± 122)</td>
</tr>
<tr>
<td>Head load carriage more difficult during pregnancy*</td>
<td>N/A</td>
<td></td>
<td>Yes</td>
<td>65% (17)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
<td>No</td>
<td>27% (7)</td>
</tr>
<tr>
<td>Lifting of the load more difficult during pregnancy*</td>
<td>N/A</td>
<td></td>
<td>Yes</td>
<td>73% (19)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
<td>No</td>
<td>19% (5)</td>
</tr>
<tr>
<td>Lowering of the load more difficult during pregnancy*</td>
<td>N/A</td>
<td></td>
<td>Yes</td>
<td>85% (22)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td></td>
<td>No</td>
<td>8% (2)</td>
</tr>
<tr>
<td>Cause of increased difficulty for pregnant women</td>
<td>N/A</td>
<td></td>
<td>Enlargement of abdomen</td>
<td>50% (13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Back pain</td>
<td>8% (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Others</td>
<td>23% (6)</td>
</tr>
<tr>
<td>Method to lift load when non-pregnant*</td>
<td>Alone</td>
<td>52% (13)</td>
<td>Team of 2</td>
<td>48% (12)</td>
</tr>
<tr>
<td></td>
<td>Alone</td>
<td>54% (14)</td>
<td>Team of 2</td>
<td>42% (11)</td>
</tr>
<tr>
<td>Method to lift load during pregnancy*</td>
<td>N/A</td>
<td></td>
<td>Alone</td>
<td>31% (8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Team of 2</td>
<td>62% (16)</td>
</tr>
<tr>
<td>Type of merchant*</td>
<td>Walking</td>
<td>56% (14)</td>
<td>Fixed</td>
<td>44% (11)</td>
</tr>
<tr>
<td></td>
<td>Walking</td>
<td>73% (19)</td>
<td>Fixed</td>
<td>23% (6)</td>
</tr>
<tr>
<td>Variation of mass of load throughout week</td>
<td>Yes</td>
<td>88% (22)</td>
<td>No</td>
<td>12% (3)</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>77% (20)</td>
<td>No</td>
<td>19% (5)</td>
</tr>
<tr>
<td>Number of voluntary stops to rest*</td>
<td>&lt; 5</td>
<td>100% (25)</td>
<td>6-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&lt;5</td>
<td>88% (23)</td>
<td>6-10</td>
<td>4% (1)</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Number of voluntary stops to rest during pregnancy*</td>
<td>N/A</td>
<td></td>
<td>&lt;5</td>
<td>65% (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6-10</td>
<td>15% (4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;10</td>
<td>-</td>
</tr>
</tbody>
</table>

*Indicates these questions were not answered by all subjects.

Characteristics of the merchandise carried by the women are shown in Table 3.5 and Table 3.6 and illustrated in Figure 3.3. A large percentage of women in both groups
reported carrying heavy loads with masses above 10 kg while about a quarter and a fifth of the non-pregnant and pregnant subjects, respectively, described their typical load carried on the head to be heavier than 20 kg. A large variety of goods are carried on the head as shown in Table 3.6. The “other” category includes products such as shoes, bread, cooked food, chickens, brooms, mats, soaps, and cosmetic goods.

<table>
<thead>
<tr>
<th>Subject group</th>
<th>Mass of load</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-5 kg</td>
<td>5.1-10 kg</td>
<td>10.1-15 kg</td>
<td>15.1-20 kg</td>
<td>&gt;20 kg</td>
</tr>
<tr>
<td>Non-Pregnant</td>
<td>4% (1)</td>
<td>24% (6)</td>
<td>36% (9)</td>
<td>12% (3)</td>
<td>24% (6)</td>
</tr>
<tr>
<td>Pregnant*</td>
<td>8% (2)</td>
<td>12% (3)</td>
<td>27% (7)</td>
<td>31% (8)</td>
<td>19% (5)</td>
</tr>
</tbody>
</table>

*Indicates question was not completed by all subjects

Figure 3.3 A) Woman carrying vegetables and fruits; B) Woman carrying mattresses; C) Woman carrying toothpaste; D) Women carrying varying products such as coal, nuts, and vegetables.

3.3.1.3 Oswestry Disability Index

Fifty-eight percent (58%) of pregnant women reported experiencing back pain since the start of their pregnancy while only 36% of the non-pregnant subject group suffered from back pain in the last six months. However, the mean Oswestry score of the affected
participants was very similar between the two groups: 0.19 ± 0.11 for the non-pregnant women and 0.20 ± 0.12 for the pregnant women on a scale from 0 to 1.
Table 3.6. Descriptive information on the types of load carried on the head by women in Benin.

<table>
<thead>
<tr>
<th>Subject group</th>
<th>Type of load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fruits &amp; Vegetables</td>
</tr>
<tr>
<td>Non-pregnant</td>
<td>12% (3)</td>
</tr>
<tr>
<td>Pregnant*</td>
<td>19% (5)</td>
</tr>
</tbody>
</table>

*Indicates these questions were not completed by all subjects

**Fuel for vehicles is commonly sold illegally on the side of the streets.
3.3.1.4 Pain drawing

The pain drawing used in this study is included in Appendix D. The body parts identified as painful during head load carriage by the two subject groups are shown in Table 3.7. Front pelvis, pubic region, and buttocks were the regions identified only by the pregnant group. A higher percentage of pregnant women experienced pain in the other body parts with the exception of the lower back. The main difference between the two subject groups is observed for the pelvis region with reported pain in 42% of pregnant women compared to only 24% in non-pregnant participants.

<table>
<thead>
<tr>
<th>Body parts</th>
<th>Non-Pregnant</th>
<th>Pregnant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage of subjects with pain</td>
<td>Mean VAS score</td>
</tr>
<tr>
<td>Neck and shoulders</td>
<td>12% (3)</td>
<td>2</td>
</tr>
<tr>
<td>Upper back</td>
<td>4% (1)</td>
<td>1</td>
</tr>
<tr>
<td>Lower back</td>
<td>8% (2)</td>
<td>5</td>
</tr>
<tr>
<td>Pelvis</td>
<td>24% (6)</td>
<td>6</td>
</tr>
<tr>
<td>Front pelvis</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pubic region</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Buttocks</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

3.3.2 Trunk postures

3.3.2.1 APDF

Trunk postures were recorded on 17 pregnant subjects for an average of 7.9 hours (±2.0 hrs). The 10\textsuperscript{th}, 50\textsuperscript{th}, and 90\textsuperscript{th} percentiles of the APDF for the trunk flexion-extension and
lateral bending are shown in Table 3.8 and Table 3.9, respectively. Negative angles indicate trunk flexion while positive angles correspond to trunk extension. Left lateral bending is associated with positive angles and right lateral bending with negative angles.

Mean 10th, 50th and 90th percentile trunk flexion-extension for the full day were $2.6^\circ \pm 6.1^\circ$, $-12.7^\circ \pm 5.5^\circ$, $-43.9^\circ \pm 20.8^\circ$, respectively. Mean 10th, 50th and 90th percentile trunk lateral bending for the full day were $2.6^\circ \pm 6.1^\circ$, $-12.7^\circ \pm 5.5^\circ$, $-43.9^\circ \pm 20.8^\circ$, respectively.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>10th percentile</th>
<th>50th percentile</th>
<th>90th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2.6</td>
<td>-20.9</td>
<td>-29.7</td>
</tr>
<tr>
<td>2</td>
<td>-0.1</td>
<td>-16.8</td>
<td>-40.7</td>
</tr>
<tr>
<td>3</td>
<td>5.6</td>
<td>-9.7</td>
<td>-46.5</td>
</tr>
<tr>
<td>4</td>
<td>8.4</td>
<td>-8.7</td>
<td>-68.7</td>
</tr>
<tr>
<td>5</td>
<td>18.2</td>
<td>-5.7</td>
<td>-21.3</td>
</tr>
<tr>
<td>6</td>
<td>5.9</td>
<td>-7.0</td>
<td>-26.6</td>
</tr>
<tr>
<td>7</td>
<td>0.2</td>
<td>-16.8</td>
<td>-88.5</td>
</tr>
<tr>
<td>8</td>
<td>2.6</td>
<td>-9.5</td>
<td>-29.4</td>
</tr>
<tr>
<td>9</td>
<td>5.7</td>
<td>-5.7</td>
<td>-29.6</td>
</tr>
<tr>
<td>10</td>
<td>1.3</td>
<td>-14.0</td>
<td>-49.4</td>
</tr>
<tr>
<td>11</td>
<td>-5.6</td>
<td>-19.8</td>
<td>-40.6</td>
</tr>
<tr>
<td>12</td>
<td>-0.1</td>
<td>-15.6</td>
<td>-36.7</td>
</tr>
<tr>
<td>13</td>
<td>9.6</td>
<td>-5.8</td>
<td>-91.6</td>
</tr>
<tr>
<td>14</td>
<td>-3.0</td>
<td>-17.1</td>
<td>-39.3</td>
</tr>
<tr>
<td>15</td>
<td>-7.0</td>
<td>-21.3</td>
<td>-33.7</td>
</tr>
<tr>
<td>16</td>
<td>1.3</td>
<td>-9.9</td>
<td>-25.4</td>
</tr>
<tr>
<td>17</td>
<td>4.5</td>
<td>-11.0</td>
<td>-49.0</td>
</tr>
</tbody>
</table>

Table 3.8. 10th, 50th, and 90th percentiles for the trunk flexion-extension postures for a full day where extension is positive and flexion is negative.

Angles (°) for trunk flexion-extension

Average $2.6 (\pm 6.1)$ $-12.7 (\pm 5.5)$ $-43.9 (\pm 20.8)$
Table 3.9. 10th, 50th, and 90th percentiles for the trunk lateral bending postures for a full day where left bending is positive and right bending is negative.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>10th percentile</th>
<th>50th percentile</th>
<th>90th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-9.0</td>
<td>-1.4</td>
<td>5.1</td>
</tr>
<tr>
<td>2</td>
<td>-8.5</td>
<td>4.1</td>
<td>14.8</td>
</tr>
<tr>
<td>3</td>
<td>-17.7</td>
<td>-4.8</td>
<td>7.2</td>
</tr>
<tr>
<td>4</td>
<td>-13.3</td>
<td>2.7</td>
<td>14.0</td>
</tr>
<tr>
<td>5</td>
<td>-3.7</td>
<td>5.5</td>
<td>21.2</td>
</tr>
<tr>
<td>6</td>
<td>-8.5</td>
<td>-0.1</td>
<td>9.1</td>
</tr>
<tr>
<td>7</td>
<td>-11.0</td>
<td>0.6</td>
<td>10.4</td>
</tr>
<tr>
<td>8</td>
<td>-6.5</td>
<td>3.6</td>
<td>14.9</td>
</tr>
<tr>
<td>9</td>
<td>-12.7</td>
<td>-0.7</td>
<td>7.6</td>
</tr>
<tr>
<td>10</td>
<td>-4.0</td>
<td>5.6</td>
<td>14.2</td>
</tr>
<tr>
<td>11</td>
<td>4.4</td>
<td>12.8</td>
<td>24.7</td>
</tr>
<tr>
<td>12</td>
<td>1.5</td>
<td>9.8</td>
<td>18.3</td>
</tr>
<tr>
<td>13</td>
<td>-0.6</td>
<td>9.6</td>
<td>24.7</td>
</tr>
<tr>
<td>14</td>
<td>-4.8</td>
<td>2.6</td>
<td>11.9</td>
</tr>
<tr>
<td>15</td>
<td>-8.5</td>
<td>1.5</td>
<td>10.3</td>
</tr>
<tr>
<td>16</td>
<td>-4.7</td>
<td>2.3</td>
<td>11.3</td>
</tr>
<tr>
<td>17</td>
<td>-5.0</td>
<td>7.9</td>
<td>22.3</td>
</tr>
<tr>
<td>Average</td>
<td>-6.6 (±5.5)</td>
<td>3.6 (±4.5)</td>
<td>14.2 (±6.1)</td>
</tr>
</tbody>
</table>

3.3.2.2 RULA

The percentage of time of the full day spent in certain postures outlined by RULA is shown in Table 3.10. Lateral bending positions are included in Table 3.11. An average of 36% of the recording time was spent in trunk flexion larger than 20°. Subjects tended to lean more towards their left side than their right, with an average of 56% of the recorded time compared to 28%, respectively. A small percentage of time was spent in lateral bend angles larger than 20°.
Table 3.10. Percentage of time spent in different trunk flexion postures outlined by RULA and in trunk extension.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Flexion &gt;60°</th>
<th>Flexion 20°-60°</th>
<th>Flexion 0°-20°</th>
<th>0°-neutral position</th>
<th>Extension 0°-10°</th>
<th>Extension &gt;10°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3%</td>
<td>54%</td>
<td>35%</td>
<td>4%</td>
<td>4%</td>
<td>0%</td>
</tr>
<tr>
<td>2</td>
<td>7%</td>
<td>35%</td>
<td>43%</td>
<td>6%</td>
<td>7%</td>
<td>1%</td>
</tr>
<tr>
<td>3</td>
<td>6%</td>
<td>33%</td>
<td>28%</td>
<td>7%</td>
<td>23%</td>
<td>2%</td>
</tr>
<tr>
<td>4</td>
<td>13%</td>
<td>18%</td>
<td>40%</td>
<td>6%</td>
<td>15%</td>
<td>8%</td>
</tr>
<tr>
<td>5</td>
<td>0%</td>
<td>12%</td>
<td>50%</td>
<td>5%</td>
<td>12%</td>
<td>22%</td>
</tr>
<tr>
<td>6</td>
<td>3%</td>
<td>17%</td>
<td>45%</td>
<td>10%</td>
<td>22%</td>
<td>2%</td>
</tr>
<tr>
<td>7</td>
<td>13%</td>
<td>29%</td>
<td>48%</td>
<td>5%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>8</td>
<td>3%</td>
<td>29%</td>
<td>48%</td>
<td>7%</td>
<td>11%</td>
<td>2%</td>
</tr>
<tr>
<td>9</td>
<td>3%</td>
<td>17%</td>
<td>43%</td>
<td>10%</td>
<td>25%</td>
<td>2%</td>
</tr>
<tr>
<td>10</td>
<td>9%</td>
<td>29%</td>
<td>42%</td>
<td>7%</td>
<td>12%</td>
<td>1%</td>
</tr>
<tr>
<td>11</td>
<td>5%</td>
<td>52%</td>
<td>41%</td>
<td>2%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>12</td>
<td>3%</td>
<td>32%</td>
<td>52%</td>
<td>5%</td>
<td>9%</td>
<td>1%</td>
</tr>
<tr>
<td>13</td>
<td>15%</td>
<td>19%</td>
<td>24%</td>
<td>8%</td>
<td>26%</td>
<td>8%</td>
</tr>
<tr>
<td>14</td>
<td>9%</td>
<td>30%</td>
<td>53%</td>
<td>3%</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>15</td>
<td>3%</td>
<td>54%</td>
<td>41%</td>
<td>2%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>16</td>
<td>2%</td>
<td>19%</td>
<td>57%</td>
<td>10%</td>
<td>12%</td>
<td>0%</td>
</tr>
<tr>
<td>17</td>
<td>7%</td>
<td>34%</td>
<td>30%</td>
<td>8%</td>
<td>19%</td>
<td>2%</td>
</tr>
<tr>
<td>Average</td>
<td>6% (±4)</td>
<td>30%(±13)</td>
<td>42%(±9)</td>
<td>6%(±3)</td>
<td>12%(±8)</td>
<td>3%(±5)</td>
</tr>
</tbody>
</table>
Table 3.11. Percentage of time spent in trunk lateral bend postures larger and smaller than 20°, as well as neutral position.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Right Lateral Bending &gt;20°</th>
<th>Right Lateral Bending 0°-20°</th>
<th>0°-neutral position</th>
<th>Left Lateral Bending 0°-20°</th>
<th>Left Lateral Bending &gt;20°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1%</td>
<td>56%</td>
<td>13%</td>
<td>28%</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>1%</td>
<td>25%</td>
<td>8%</td>
<td>62%</td>
<td>4%</td>
</tr>
<tr>
<td>3</td>
<td>8%</td>
<td>60%</td>
<td>7%</td>
<td>24%</td>
<td>1%</td>
</tr>
<tr>
<td>4</td>
<td>6%</td>
<td>29%</td>
<td>8%</td>
<td>54%</td>
<td>4%</td>
</tr>
<tr>
<td>5</td>
<td>1%</td>
<td>17%</td>
<td>8%</td>
<td>61%</td>
<td>14%</td>
</tr>
<tr>
<td>6</td>
<td>1%</td>
<td>46%</td>
<td>11%</td>
<td>41%</td>
<td>1%</td>
</tr>
<tr>
<td>7</td>
<td>3%</td>
<td>38%</td>
<td>11%</td>
<td>47%</td>
<td>1%</td>
</tr>
<tr>
<td>8</td>
<td>2%</td>
<td>23%</td>
<td>9%</td>
<td>62%</td>
<td>4%</td>
</tr>
<tr>
<td>9</td>
<td>3%</td>
<td>50%</td>
<td>13%</td>
<td>32%</td>
<td>1%</td>
</tr>
<tr>
<td>10</td>
<td>2%</td>
<td>16%</td>
<td>7%</td>
<td>73%</td>
<td>2%</td>
</tr>
<tr>
<td>11</td>
<td>0%</td>
<td>4%</td>
<td>2%</td>
<td>75%</td>
<td>19%</td>
</tr>
<tr>
<td>12</td>
<td>0%</td>
<td>6%</td>
<td>3%</td>
<td>84%</td>
<td>7%</td>
</tr>
<tr>
<td>13</td>
<td>1%</td>
<td>10%</td>
<td>4%</td>
<td>67%</td>
<td>17%</td>
</tr>
<tr>
<td>14</td>
<td>1%</td>
<td>21%</td>
<td>14%</td>
<td>61%</td>
<td>3%</td>
</tr>
<tr>
<td>15</td>
<td>2%</td>
<td>33%</td>
<td>12%</td>
<td>51%</td>
<td>2%</td>
</tr>
<tr>
<td>16</td>
<td>1%</td>
<td>25%</td>
<td>13%</td>
<td>59%</td>
<td>2%</td>
</tr>
<tr>
<td>17</td>
<td>1%</td>
<td>15%</td>
<td>4%</td>
<td>65%</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>2%(±2)</strong></td>
<td><strong>28%(±17)</strong></td>
<td><strong>9%(±4)</strong></td>
<td><strong>56%(±17)</strong></td>
<td><strong>6%(±6)</strong></td>
</tr>
</tbody>
</table>

An average of 328 (±247) trunk flexion events (flexion angles of 60° or more) were recorded during the day with 66 (±54) of them lasting longer than four seconds.

### 3.4 Discussion

The objective of this study was to gain knowledge of the head load carriage task and different daily occupational tasks of merchant pregnant West African women, as well as perform an analysis on the postural demands of their occupational activities during a typical day to assess the risk of back pain problems during gestational months. The results
showed that these pregnant women were at a high risk of developing back pain during pregnancy because of the heavy mass of the loads lifted for head load carriage, as well as the large number of trunk flexions above 60° and the sustained flexed postures throughout the day.

### 3.4.1 Back pain in African women

The incidence rate of back pain among pregnant women in this study, 58%, agrees with previous studies that reported prevalence rates in the range of 48-56% (Mantle et al., 1977; Fast et al., 1987; Ostgaard et al., 1991). Furthermore, the low mean Oswestry scores show that most of the subjects experienced only mild back pain at worst, similarly to what was found by To and Wong (2003) and Wu et al. (2004). On the other hand, 36% of the non-pregnant subjects reported experiencing low back pain in the last six months. This prevalence rate is higher than the 20-25% estimated from a study in the non-pregnant population of the same age (Biering-Sörensen, 1982). However, the mean Oswestry score was also low for this group, reflecting once again a mild back pain at worst. Approximately 85% of the sample were poorly educated with no schooling or only the completion of elementary school. This lack of education typically leaves these women with few options to gain a salary. Consequently, most of them go on to become self-employed merchants who carry various heavy loads (Table 3.5 for load mass and Table 3.6 for load types) on their heads. In line with this presumption, all of the non-pregnant subjects and a large majority of pregnant women (69%) were self-employed street vendors. This profession, although physically demanding, is not rewarded by high wages as shown by the low monthly earnings of less than 30,000 CFA monthly (approximately...
$64 CAD) in 85% of the participants. People in lower socioeconomic classes and with low education have been shown to experience more lower back pain than those in upper socioeconomic class (Nagi et al., 1973; Carey et al., 1995; Toroptsova et al., 1995). The low social economic status of the majority of the subjects included in this study could explain why the prevalence of back pain in the pregnant women group was in the upper range of earlier findings and why the incidence rate in the non-pregnant women was higher than the 20-25% previously reported (Biering-Sörensen, 1982).

3.4.2 Head load carriage and related bodily pain

Descriptive information about the street merchant trade in Benin was collected in this study. However, due to the large day-to-day variability in this commercial occupation, it is difficult to determine the average head load carriage time and the average weight of the merchandise. Furthermore, it is not easy to quantify the number of pick-ups and put-downs of the loads in a day as they fluctuate based on the number of sales made. Loads are typically only put down for selling purposes and not with the intention to rest; therefore, a busy day with numerous transactions would result in more trunk bends and lifts than slower days. Nevertheless, a small percentage of pregnant women reported having to put down their loads 6 -10 times a day in order to take a break. These frequent rest periods are recommended, especially during pregnancy, to avoid postural fixation and allow a better blood circulation enabling the flow of nutrients to working muscles. The American Congress of Obstetricians and Gynecologists (ACOG) (2002) recommended that prolonged standing/walking (>4 hours) be stopped at 32 weeks of gestation, with only intermittent standing/walking for a maximum duration close to 30
min per hour suggested for the remainder of the pregnancy. The mean duration of 2.5 hours of walking with loads on the head is well in excess of the proposed limits.

Lifting or carrying heavy loads have also been shown to increase intra-abdominal pressure and possibly stimulate early contractions (Hayne, 1981). Although there is some controversy in the literature, some studies suggest that there is a link between heavy lifting, prolonged standing and/or walking and adverse pregnancy outcomes, such as spontaneous abortion, pre-term delivery, and low birthweight in addition to being one of the causes of back pain (Ahlborg et al., 1990; Launer et al., 1990; Teitelman et al., 1990). The ACOG (2002) recommended that intermittent lifting of loads greater than 23 kg be ceased at 30 weeks while repetitive lifting of the same load be eliminated at 20 weeks. The American Medical Women’s Association (AMWA) (1993) suggested stricter weight restriction with a maximum load of 10 to 12 kg for pregnant women. Nearly 80% of the expectant mothers in this study exceeded the maximum recommended loads, thus exposing themselves to the possible adverse consequences of heavy lifting.

Pregnant women must also support the additional body weight related to pregnancy when lifting an object. The localized weight gain in the abdomen region also impedes pregnant women from holding objects close to their body during lifts, thus increasing the lever arm of the loads. Therefore, it comes to no surprise that 73% and 85% of the expectant women reported experiencing more difficulty in lifting and lowering the load carried on the head, respectively. Lifting loads farther from the spine is especially dangerous during pregnancy due to the additional stress of the foetus on the pelvic muscles and ligaments (Tapp, 2001). Due to ligament laxity in the pelvis region, spine joints become less stable,
which in turn increases the risk of back injury (Tapp, 2001). It is therefore suggested that pregnant women seek help when lifting loads to reduce the demand on the back muscles. Sixty-two percent (62%) of the pregnant subjects reported lifting and lowering their merchandise in a team of two to facilitate the task. As observed during field data collection, this assistance can easily be obtained from individuals on the street. Consequently, more pregnant women in Benin should be encouraged to look for a partner when performing those tasks.

The pain drawing combined with the VAS scores also indicated that more pregnant women experienced pain than their non-pregnant counterparts during the lift, carriage, and put down of the load in all body parts identified but one: lower back pain was more common and more severe among non-pregnant women. The higher score observed in the non-pregnant group may be explained by the subjectivity of the test and the individuals recruited for this study. On the other hand, the low occurrence, 4%, of lower back pain in pregnant women is an unexpected result because the enlarged abdomen was thought to complicate the lifting, carriage, and lowering task as well as increase the demand on lower back muscles. However, it has been suggested in the literature that there is a certain level of misclassification when localizing pain in the lower back and posterior pelvic region (Albert et al., 2000; Wu et al., 2004). Therefore, confusion between these two regions could be a possible explanation for the small percentage of women experiencing pain in the lower back area. In fact, there is a much larger percentage of women showing signs of pain in the posterior pelvic region in both subject groups with nearly half of the pregnant women (42%) reporting experiencing pain at this location during the lifting, carrying and/ or lowering of the load on their heads compared to 24%
in the non-pregnant group. It is not surprising to see such a large percentage of expectant women with pain in the pelvic region due to increased joint laxity and strain on ligaments and muscles in this region as a result of the weight of the foetus. However, the pregnant group was expected to show a higher score since this region has been reported to affect the functionality of women during their pregnancy (Ostgaard et al., 1991). Furthermore, only the pregnant group identified the front pelvis and pubic region as a source of pain. This region was the most painful during activities related to head load carriage as it was rated the highest on the VAS. Once again, this discomfort is probably caused by the increased biomechanical strain on ligaments, muscles, and skeleton during pregnancy. Although these posterior and front pelvic regions were considered as separate on the body map, they can also be combined under one entity, the pelvic region, as seen in previous studies (Kristiansson et al., 1996). When combining the results for the two subdivisions of the pelvic region, the occurrence rate of 50% agrees with figures published in the literature (Mantle et al., 1977; Fast et al., 1987; Ostgaard et al., 1991).

### 3.4.3 Daily occupational activities

Sagittal trunk inclinations exceeding 20° are regarded as critical in the risk of developing musculoskeletal injuries by several postural assessment tools (McAtamney & Corlett, 1993; Hignett & McAtamney, 2000). These postures are considered worse if trunk twist and/or lateral bending are performed simultaneously. Although trunk twist could not be monitored due to the limitations of the instrument, the trunk postural analysis and field observations showed that trunk lateral bending occurred concurrently with trunk flexion during the measurement time. In fact, subjects only spent an average of 9% in the neutral
position in the frontal plane. Recordings of trunk postures of 17 pregnant women revealed that the pregnant women spent an average of 36% of the time period when data was collected bending forward at angles larger than 20°, corresponding to an average of 2.8 hours daily. Sagittal trunk flexion angles have been identified as a risk factor for the development of low back disorders in industries (Marras et al., 1993). Doing the laundry, doing the dishes, cooking, making the bed/rolling the sleeping mat and cleaning inside and outside the house (sweeping) are six of the top ten activities (Table 3.3) that all are performed in highly flexed standing posture. Trunk postures well in excess of 20° of flexion are adopted to complete these tasks, thus increasing the demand on the back muscles. The lower back extensor muscles must work harder during trunk flexion to counteract the increased mechanical moment created by the weight of the upper body (Keyserling, 2000). These exertions result in high compressive forces on the spinal motion segments (Keyserling, 2000). On the other hand, the risk posed by awkward postures from lateral bending was relatively low with only 8% of the total measurement time spent outside the safe range of 20° of lateral bend (Freitag et al., 2007).

A large inter-subject variability evidenced by a large standard deviation was observed for the number of sagittal trunk inclinations. This large variability may be due to pregnancy-related health problems as some women were severely affected by side effects such as nausea or back pain thus limiting the amount of physical work performed. Nevertheless, an average of 328 inclination events greater than 60° were recorded for the monitoring duration corresponding to 41.5 inclinations per hour. This high number of trunk flexions shows that the movements of women in Benin are highly repetitive throughout the day.
Repetitive bending motion below the knee level more than ten times per hour are recommended by the ACOG (2002) to be stopped at 20 weeks. Repetitive motion is another independent risk factor for low back pain as it results in cumulative loading of the spine (Norman et al., 1998). Studies on cadavers have shown that cyclical loading reduces the mechanical tolerance limits of the lumbar spine, indicating a greater risk of failure due to fatigue (Brinckmann et al., 1987; Hansson et al., 1987; Callaghan & McGill, 2001). Three of the ten listed daily occupational tasks, going to get water, going to get wood, and going to the market, require frequent bending and lifting of a load. Lifting frequency is one of the five variables identified as a risk factor for predicting lower back injuries (Marras et al., 1993). In addition to the weight of the load in hand and/or the forward bent postures, the lifting speed was also found to increase the compressive force in the lumbar spinal discs (Keyserling, 2000). Consequently, these three activities involving frequent bending and lifting of loads put these African women at risk of developing back pain disorders.

The duration of trunk flexion outside the neutral range is an additional factor that must be included in the evaluation of postures. Postures held for longer than four seconds are designated as static postures (Freitag et al., 2007). Risk of injury from static postures with unsupported trunk inclination is believed to be caused by the muscular exhaustion (Freitag et al., 2007). This muscle fatigue leads to changes in metabolism, pain perception, and kinematic patterns, ultimately leading to excessive stress on passive structures in the musculoskeletal system (Freitag et al., 2007). An average of 66 events of trunk flexion were held for longer than four seconds throughout the day. These results suggest that pregnant women are exposed to stress from static postures, which is an
important factor in the evaluation of the overall stress exposure. It has also been shown by Hui et al. (2001) that the risk of injury increases during the shift in an industry setting. Therefore, the danger of back injury would increase as the day goes on in the context of this study.

3.5 Limitations

The use of a VAS and questionnaires in this study represent a limitation because these tools are subjective and open to interpretation. Furthermore, a number of questions were left unanswered by the participants of this study, thus reducing the amount of information collected. Nevertheless, these methods represented a relatively low cost mean to gather a large amount of information for this study.

The VC allows the measurement of the orientation of one segment. In this study, only the orientation of the upper trunk was known, while the orientations of other body segments, such as lower trunk or legs, were unknown. Consequently, it is impossible to know if the subject was in a squat or stoop position or even sitting down. These different postures would have an effect on the internal loading of the muscles, joints, and ligaments. Ultimately, this lack of information on the orientations of other body segments represents a limitation of the instrument used in this study.

The cross-talk associated with lateral bending angles exceeding the measuring range of ±70° is another limitation because it affects the validity of the angles measured in the sagittal plane. This limitation caused the loss of data in the recordings of trunk postures for all subjects recruited for this study. A mean of 16% (±15) of the data for each
participant was lost due to the cross-talk associated with the limited range of measurement in lateral bending. Validation of the VC and a discussion of its limitation are included in Chapter 5 and Chapter 6, respectively.

There are also some limitations associated with the protocol developed for this study. The fixation of the instrumentation onto the subject’s body represents the main drawback. Tape and a custom harness secured with adjustable elastic straps were used to attach the VC onto the subject’s trunk. However, the device probably moved during data collection. This limitation particularly affects the results of this study because all angles are reported relative to the subject’s upright standing posture. Therefore, when the instrument is displaced from its original position, incorrect angles are reported. Angles measured during a full day data collection are probably most affected by this limitation as the device was worn for a long period of time and strenuous movements were performed. Nevertheless, no major shift in the instrument attached to the back was observed at the end of the day when the investigators returned to the subjects’ homes to remove the VC.

In order to protect the VC against possible damage, it was placed into a waterproof plastic bag. However, the reference position of the instrument had to be set before it was inserted in the shield. The device was positioned in the custom pocket for the calibration step and for the data collection during the day; however, it is most probable that the VC was not replaced in the pocket in its exact reference position, thus resulting in some errors.

Other limitations include the small sample of only 17 pregnant participants who were recruited for the daily occupational portion of this study. Due to the full-day length of
data collection and the limited duration of the field trip to Benin, it was difficult to test more women. However, a larger sample would have provided a better representation of postures adopted during the day as there is a large variety of tasks. On the other hand, given the short period of time allowed for data collection, 17 subjects still gave a good insight into the risk associated with the postures held throughout a typical day.

3.6 Conclusion

Strenuous physical work puts expectant mothers at risk of experiencing back pain during the gestational months. Pregnant women in Benin perform physically demanding occupational tasks that include the carriage of heavy loads on their heads for commercial activities. These loads were found to exceed the maximum limit recommended by the AMWA and ACOG. A large percentage of pregnant subjects (58%) suffered from back pain since the start of their pregnancy. An evaluation of the postural demands of the occupational activities of these women revealed that they performed on average 328 trunk flexions at angles exceeding 60° per day, with 66 of these flexions sustained for more than four seconds. These results show that pregnant women in Benin are at great risk for developing back disorders during pregnancy.

Five suggestions to reduce back pain are: 1) decrease the mass of the loads carried on the head; 2) encourage the team lifting technique; 3) increase the number of breaks during the day; 4) reduce the walking duration and encourage the fixed merchant technique during pregnancy; and 5) avoid highly flexed postures during occupational tasks for long periods of time.
3.7 References


Chapter 4

4  Head load carriage and pregnancy in West Africa

4.1  Introduction

Back pain is a common problem among pregnant women from all ethnicities with a high prevalence ranging from 48-56% depending on the study (MacEvilly & Buggy, 1996; Mantle et al., 1977; Fast et al., 1987; Ostgaard et al., 1991). This universal back pain predicament can significantly decrease the quality of life of pregnant women and interfere with their normal daily activities and work (Ostgaard et al., 1991). Intensive farm work and heavy weight lifting were found to be factors that increase the severity of back pain during pregnancy (Worku, 2003). In some parts of the world, women commonly participate in daily agricultural and commercial activities that require strenuous physical work involving heavy loads carried on the head and back. More precisely, African women are known to frequently balance on their heads heavy loads corresponding to as high as 70% of their body weight (Heglund et al., 1995). The repetitive trunk flexion to lift and lower the load carried on the head also represents a physically taxing motion. This demanding task combined with pregnancy can result in back pain that may persist after delivery in some cases (Poole, 1998; Worku, 2003). Due to the physical nature of head load carriage and the stress borne by the vertebral column, this specific activity was identified as a risk factor for back pain, especially during pregnancy, for women in West Africa.
Up to now, the literature has mainly documented the physiological aspects of head load carriage (Maloiy et al., 1986; Heglund et al., 1995; Lloyd et al., 2010) as well as the degenerative changes of the neck vertebrae as a result of this practice (Jager et al., 1997; Echarri & Forriol, 2005), but little is known about the postures adopted during this task. However, it has been shown that the postures assumed during a work task are an important determinant of musculoskeletal injuries (Vieira & Kumar, 2004). Consequently, there is a gap in the literature on the postural analysis and biomechanics of this particular form of load carriage that needs to be filled. Therefore, the objectives of this study were to 1) determine how the walking trunk postures of pregnant women are affected by a load carried on the head, 2) compare these walking postures with a control group of non-pregnant women, 3) describe and compare the maximum trunk flexion angles for the pregnant and non-pregnant subjects during lifting and lowering of the load, 4) determine how the movement of the head with respect to the trunk for the pregnant and non-pregnant women is affected by head load carriage, and 5) compare these movements of the head with respect to the trunk between the pregnant and control subject groups.

4.2 Methods

4.2.1 Participants

Twenty-five non-pregnant women (age 26 ± 7 years) and 26 pregnant women (age 26 ± 5 years) with past or present experience of head load carriage were recruited in Porto-Novo, Benin for this study. Women unable to lift and carry a mass corresponding to approximately 20% of their body mass were excluded from this study. Pregnant subjects were recruited at a community maternity centre while non-pregnant subjects were
recruited through local contacts to match the pregnant women sample in age and height. Mean height and mass for the non-pregnant women were 159 cm (± 6) and 57 kg (± 11), respectively, while the mean height and mass for the pregnant subjects were 159 cm (± 6) and 63 kg (± 15), respectively. The pregnant subjects were 25 weeks (±9) into their pregnancy on average (Chapter 3). The study protocol was approved by the Queen’s University Research Ethics Board and by the Institut National de la Jeunesse, de l’Éducation Physique et Sportive (INJEPS) Ethics Board in Benin (Appendix B). Informed consent was obtained from all subjects (Appendix C).

4.2.2 Data acquisition

4.2.2.1 Trunk

Trunk postural data during the specific task of carrying loads on the head were collected using two Virtual Corset™ (VC) (MicroStrain, Williston, VT, USA). This device is an inclinometer system combined with a miniature datalogger enclosed in a light pager-sized plastic case. It is battery-powered, wireless, and composed of two bi-axial accelerometers positioned orthogonally. Using an algorithm developed by the manufacturer, the accelerations measured by the accelerometers are transformed into angle data to monitor trunk inclination with respect to an individual’s upright position or the line of gravity in two directions (flexion and lateral bending). The VC continuously records data once it is powered; however, the press-button (PB) function allows the identification of events by introducing “PB” in the stream of angle data collected at the instant where the button is pressed.
Participants were instrumented with two devices at the C7 and sacrum (S1) levels to obtain the trunk inclination angles of the upper trunk and pelvis, respectively, relative to the subject’s upright neutral posture. The VC monitoring the upper trunk postures was placed as close as possible to the bony landmark of C7 on the back of the subject in a custom pocket secured to the trunk using elastic Velcro straps around the torso and shoulders, while the VC at the sacrum was attached to a Velcro belt fastened around the waist (Figure 4.2). Data were sampled at a rate of 7.5 Hz and were stored on the built-in non-volatile memory of the device until the completion of all trials for each subject at which point the data were downloaded to a computer via the Windows-based Virtual Corset control software (VC-323, Microstrain Inc, Williston, VT, USA) for further analysis.

4.2.2.2 Head with respect to the trunk

The movement of the head with respect to the trunk in the sagittal plane was measured using an electrogoniometer (model M180, Penny and Giles Inc., Blackwood, UK) (Figure 4.1). The top end-block of the electrogoniometer was attached to the head using one or two elastic head bands, while the other end-block was fixed to the trunk with medical tape (Figure 4.2). The bottom end-block of the electrogoniometer was taped to the back of the subjects in a manner such that the spring connecting the two blocks was fully extended when the heads of the subjects were held in their neutral upright postures. Data were sampled at 100 Hz and acquired onto a laptop using a customized computer program developed within Labview 8.0 (National Instruments, Austin, TX, USA) and stored on a computer for further processing.
4.2.3 Procedure

In order to evaluate the effect of head load carriage on the walking trunk postures and positions of the head with respect to the trunk, the subjects were asked to walk under two loading conditions. The first task consisted of walking without any load on the head, while the second task included the lifting, carrying and lowering of a load. The mass of
the load was chosen to correspond to approximately 20% of each subject’s body mass based on preliminary field data collected in Benin. These preliminary data showed that the average load carried on the head by pregnant and non-pregnant corresponded to 28% of their body mass. Typical loads carried on the head were mocked by a bag of sand to facilitate the adjustment of its mass for different subjects. Field observations revealed that loads were typically not placed directly on the head but rather on a circular metal or wooden tray (Figure 3.3). It was also noticed that loads were lifted from a raised surface such as a small stool as opposed to being lifted from the ground level. These lifting and head load carriage conditions observed in the field were replicated in the laboratory by placing the bag of sand on a circular metal tray which was in turn placed on a plastic stool approximately 45cm tall (Figure 4.3). Data for this study were collected in a small laboratory set up at the INJEPS.

Prior to data collection, each participant was instructed to stand in their most upright trunk and head postures to set the zero (reference) position for the two VCs and the electrogoniometer. The walking trajectory for both loading conditions consisted of a straight walkway of about 3 meters followed by a turn and the same 3 meters walkway to return to the start location, for a total walking distance of approximately 6 meters. Each walking condition, loaded and unloaded, was repeated three times for a total of six trials. The unloaded walking trials were always performed prior to those in the loading condition to facilitate data identification in the continuous stream of data recorded by the VC. Body mass was measured upon arrival of the subject at the data collection site on a bathroom scale and recorded by one of the investigators in kilograms with one decimal to determine the mass of the load to be lifted.
The PB button on the VC was pressed at the start and end of each trial to allow the identification of all six trials, while each electrogoniometer trial was saved separately.

![Subject lifting the bag of sand placed on a tray from the stool height.](image)

Figure 4.3. Subject lifting the bag of sand placed on a tray from the stool height.

### 4.2.4 Data Processing

All data were processed using custom programs developed in Matlab R2007B (The Math Works Inc., Nathick, MA, USA).

#### 4.2.4.1 Trunk

First, the trunk postural data recorded on the VCs were separated into the six trials using the PB trial markers. Afterwards, the walking portions of the loaded trials were manually selected and removed from the trial to separate the walking trunk angles from the trunk postures during the pick up and put down of the load phases (Figure 4.4). The start and end points of the walking portion of each trial were determined by visual inspection of the flexion-extension angles in the sagittal plane for each VC as the bending motion is more detectable in that plane than in the frontal plane. These points were then applied to
the corresponding lateral bending data to obtain the walking portion of each trial. All walking data were normalized to 100 data points to match the length of all six trials.

The data from the three trials for each condition were grouped together and assumed to be only one stream of data in order to obtain the mean trunk angle and standard deviation of those angles for the two loading conditions for each subject. Finally, the mean trunk walking angle and mean standard deviation of the walking angles for the non-pregnant and pregnant groups were calculated by averaging the data from all subjects in the same subject group. The maximum trunk flexion angles were also identified during the lifting and lowering of the load at the beginning and end of the trials in the loaded condition. Raw trunk data are included in Appendix E.

![Figure 4.4. Example of angle data measured by the VC for non-pregnant subject #1 for one unloaded and one loaded trial. The walking portion section was defined manually by inspection and separated from the other data to compare to the unloaded walking angles. The large flexion angles at the start and end of the loaded trial represents the lifting and lowering of the load motions, respectively.](image)
4.2.4.2 Head with respect to trunk

The angles were corrected based on a validation equation developed for the electrogoniometer (Appendix F). Corrected data of the head relative to the trunk are included in Appendix E. The data from the electrogoniometer were then processed similarly to those of the VC with the exception of trial separation as all trials were already individually saved. Furthermore, maximum flexion angles of the head relative to the trunk were not compared between subject groups because large angles were not measured accurately by the electrogoniometer even after correction.

4.2.5 Statistical Analysis

Mixed-design analyses of variance (ANOVA) were applied to make comparisons between the mean walking trunk angles, mean walking angle of the head with respect to the trunk, and the standard deviation of the walking angles in the loaded and unloaded conditions for the two subject groups. The between-subject variable was pregnancy and the within-subject variable was the loading condition. Significance level was set to 0.05. In the case of interaction between the two variables, t-tests with Holm adjustment were conducted.

Maximum put down and pick up upper trunk flexion angles were also compared using the mixed-design ANOVA with a significance level of 0.05. In that case, the between-subject variable was pregnancy and the within-subject variable was the motion executed, that is lifting and lowering of the load.
All repeated measures ANOVA’s were performed with SPSS 15 for Windows (SPSS Corporation, Chicago, IL, USA) statistical software. Descriptive statistics of the two subject groups were also obtained using this software.

4.3 Results

The mean masses of the load carried on the head by the non-pregnant and pregnant women were 11.3 ± 2.1 kg and 11.8 ± 2.2 kg, respectively. Complete sets of trunk posture data were successfully measured and processed on 22 non-pregnant subjects and 22 pregnant subjects. One pregnant subject completed only two loaded trials due to fatigue and bodily pain, while the data from the VC at the sacrum were lost on six participants (3 from each group) due to malfunction of the instrument during data collection. Complete sets of data for the movements of the head with respect to the trunk were successfully collected and processed on 19 non-pregnant and 16 pregnant subjects. Data from the other 16 subjects were discarded due to malfunction of the instrument during data collection or data loss during processing.

The mean flexion-extension (FE) and lateral bending (LB) walking angles of both subject groups under the loaded and unloaded conditions are summarized in Table 4.1 along with the mean standard deviations (SD) of those walking angles. The mean angle of the head with respect to the trunk and the standard deviation of those angles during the walking trials are also included in Table 4.1.
Table 4.1. Mean walking angles with respect to the subjects’ upright position in FE and LB and mean SD of these angles in the loaded and unloaded conditions for non-pregnant and pregnant subjects. Negative angles correspond to trunk flexion while positive angles represent trunk extension. Left lateral bending is associated with positive angles and right lateral bending with negative angles. Positive angles for the head movement represent extension of the head relative to the trunk and negative angles correspond to flexion.

<table>
<thead>
<tr>
<th></th>
<th>Flexion-Extension</th>
<th>Lateral Bending</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No load</td>
<td>Load</td>
</tr>
<tr>
<td>Mean angle C7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Nnp=25, Np=26)</td>
<td>-1.3° (±3.4)</td>
<td>10.4° (±6.2)</td>
</tr>
<tr>
<td>Mean SD at C7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Nnp=25, Np=26)</td>
<td>3.9° (±1.1)</td>
<td>3.5° (±0.8)</td>
</tr>
<tr>
<td>Mean angle at sacrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Nnp=22, Np=23)</td>
<td>-0.5° (±3.6)</td>
<td>-0.3° (±4.3)</td>
</tr>
<tr>
<td>Mean SD at sacrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Nnp=22, Np=23)</td>
<td>5.5° (±1.1)</td>
<td>6.7° (±1.3)</td>
</tr>
<tr>
<td>Mean angle of head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Nnp=19, Np=16)</td>
<td>-5.4° (±10.6)</td>
<td>0.2° (±13.4)</td>
</tr>
<tr>
<td>Mean SD of head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Nnp=19, Np=16)</td>
<td>9.9° (±3.4)</td>
<td>4.6° (±1.1)</td>
</tr>
</tbody>
</table>
The statistical results of the walking angles are shown in Table 4.2. Loading had a significant effect on all mean walking angles and mean SDs of the walking angles with the exception of the mean FE walking angles measured at the sacrum (Table 4.2). Trunk extension at C7 increased in both subject groups when they were walking with a load on the head. Head flexion angles also decreased to an almost neutral position in the loaded condition. Both subject groups also increased their upper trunk tilt towards the left when walking in the loaded condition but decreased that tilt towards the left at the sacrum level. The SD of the upper trunk FE and LB walking angles at C7 significantly decreased with load, while the opposite effect was demonstrated at the sacrum. Pregnancy only had a significant effect on the SD of the FE and LB walking angles measured at C7, showing larger SD values for pregnant women.
Table 4.2. Mixed-design ANOVA results between the pregnant and non-pregnant women for the mean flexion-extension (FE) and lateral bending (LB) walking angles and Standard Deviation (SD) of those walking angles at C7, sacrum and neck during loaded and unloaded conditions.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Main effect of pregnancy</th>
<th></th>
<th>Main effect of loading</th>
<th></th>
<th>Interaction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F Statistic</td>
<td>p-Value</td>
<td>F Statistic</td>
<td>p-Value</td>
<td>F Statistic</td>
<td>p-Value</td>
</tr>
<tr>
<td>FE at C7</td>
<td>2.195</td>
<td>0.145</td>
<td>438.261</td>
<td>0.000(^a)</td>
<td>0.622</td>
<td>0.434</td>
</tr>
<tr>
<td>SD FE at C7</td>
<td>8.080</td>
<td>0.007(^b)</td>
<td>34.586</td>
<td>0.000(^a)</td>
<td>10.447</td>
<td>0.002(^a)</td>
</tr>
<tr>
<td>LB at C7</td>
<td>0.670</td>
<td>0.417</td>
<td>16.311</td>
<td>0.000(^a)</td>
<td>0.456</td>
<td>0.503</td>
</tr>
<tr>
<td>SD LB at C7</td>
<td>5.988</td>
<td>0.018(^b)</td>
<td>147.194</td>
<td>0.000(^a)</td>
<td>1.713</td>
<td>0.197</td>
</tr>
<tr>
<td>FE at sacrum</td>
<td>0.276</td>
<td>0.602</td>
<td>0.675</td>
<td>0.416</td>
<td>0.028</td>
<td>0.868</td>
</tr>
<tr>
<td>SD FE at sacrum</td>
<td>2.366</td>
<td>0.131</td>
<td>127.545</td>
<td>0.000(^a)</td>
<td>0.473</td>
<td>0.495</td>
</tr>
<tr>
<td>LB at sacrum</td>
<td>0.377</td>
<td>0.542</td>
<td>7.580</td>
<td>0.009(^b)</td>
<td>0.001</td>
<td>0.981</td>
</tr>
<tr>
<td>SD LB at sacrum</td>
<td>0.082</td>
<td>0.776</td>
<td>10.421</td>
<td>0.002(^b)</td>
<td>0.428</td>
<td>0.517</td>
</tr>
<tr>
<td>Neck angle</td>
<td>0.001</td>
<td>0.971</td>
<td>7.042</td>
<td>0.012(^b)</td>
<td>0.931</td>
<td>0.342</td>
</tr>
<tr>
<td>SD neck angles</td>
<td>0.310</td>
<td>0.582</td>
<td>81.599</td>
<td>0.000(^a)</td>
<td>0.106</td>
<td>0.747</td>
</tr>
</tbody>
</table>

\(^a\)Indicates significance at the p < 0.001 level.
\(^b\)Indicates significance at the p < 0.05 level.
Due to the interaction between pregnancy and loading for the SD of FE angles at C7, four t-tests were performed to determine the effect of these independent variables (Table 4.3). These four t-tests were: 1) pregnant unloaded vs pregnant loaded; 2) non-pregnant unloaded vs pregnant unloaded; 3) non-pregnant unloaded vs non-pregnant loaded; 4) non-pregnant loaded vs pregnant loaded. The level of significance of these t-tests was adjusted using the Holm criteria. Load significantly decreased the SD values of the upper trunk angles during walking for the pregnant subjects (t-test 1). Non-pregnant subjects only showed a marginally significant difference for the SD values between unloaded and loaded conditions when the α-level was adjusted according to Holm criteria (t-test 3). Pregnant subjects showed significantly larger SD values than the control group in the unloaded condition (t-test 2), but the two groups were not significantly different in the loaded condition (t-test 4).

The maximum flexion angles during lifting and lowering of the load during the loaded trials for both subject groups are summarized in Table 4.4 along with their statistical results in Table 4.5. There was no significance difference between the maximum flexion angles during lifting and lowering of the load between the two subject groups.
### Table 4.3. Results of post-hoc t-tests for SD of the walking flexion-extension angles measured at C7.

<table>
<thead>
<tr>
<th></th>
<th>Post-hoc t-tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pregnant unloaded vs. Pregnant loaded</td>
</tr>
<tr>
<td>p-Value</td>
<td>Adjusted α level&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SD of FE angles at C7</td>
<td>0.000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.0125</td>
</tr>
<tr>
<td></td>
<td>Non-pregnant unloaded vs. Pregnant unloaded</td>
</tr>
<tr>
<td>p-Value</td>
<td>Adjusted α level&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.0005&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.01667</td>
</tr>
<tr>
<td></td>
<td>Non-pregnant unloaded vs. Non-pregnant loaded</td>
</tr>
<tr>
<td>p-Value</td>
<td>Adjusted α level&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.0451&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.0250</td>
</tr>
<tr>
<td></td>
<td>Non-pregnant loaded vs. Pregnant loaded</td>
</tr>
<tr>
<td>p-Value</td>
<td>Adjusted α level&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.5140</td>
</tr>
<tr>
<td></td>
<td>0.0500</td>
</tr>
</tbody>
</table>

<sup>a</sup> Indicates that the significance level was adjusted using the Holm criteria.

<sup>b</sup> Indicates significance at the p < 0.001 level.

<sup>c</sup> Indicates significance at the p < 0.05 level.

### Table 4.4. Mean maximum flexion angles for the non-pregnant and pregnant women during the pick up and put down of the load motions.

<table>
<thead>
<tr>
<th></th>
<th>Pick up of the load</th>
<th>Put down of the load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Pregnant</td>
<td>Pregnant</td>
</tr>
<tr>
<td>Mean maximum flexion</td>
<td>82.7° (±11.7)</td>
<td>87.4° (±11.1)</td>
</tr>
</tbody>
</table>

### Table 4.5. Repeated measures mixed design ANOVA for the maximum flexion angle between the pregnant and non-pregnant women during the pick up and put down of the load motions.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Main effect of pregnancy</th>
<th>Main effect of motion</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F Statistic</td>
<td>p-Value</td>
<td>F Statistic</td>
</tr>
<tr>
<td>Mean maximum flexion</td>
<td>0.979</td>
<td>0.327</td>
<td>1.212</td>
</tr>
</tbody>
</table>
4.4 Discussion

The specific purpose of this study was to compare the postures of the trunk and postures of the head relative to the trunk adopted during walking in an unloaded and loaded condition for two female subject groups: pregnant and non-pregnant. The maximum trunk flexion angles during lifting and lowering of the load were also compared between the two subject groups. The main results were a significant increase in upper trunk extension in the loaded condition accompanied by a significant decrease of the SD of the FE and LB walking angles at C7. This decrease in the SD of walking angles at the upper trunk was compensated by a significant increase of the SD of walking angles at the sacrum. Furthermore, pregnancy did not have any significant effect on the maximum trunk flexion angles.

4.4.1 Main effect of load

4.4.1.1 Trunk and head inclination during walking

In accordance with previous observations for a normal population (Syczewska et al., 1999), the results of this study show that the trunk was bent forward during unloaded walking in relation to the standing position. This forward bend of the trunk was observed to be a characteristic phase of gait initiation (Breniere & Do, 1987). It is also believed to minimize the energy consumption during the propulsion phase and help the hip extensors (Syczewska et al., 1999). Similarly, the head was also tilted downward in the unloaded condition for both subject groups. Although it has been shown that the head rotates downward as it translates up and rotates upward as it translates down to maintain contact
with the head fixation point (Pozzo et al., 1990), the average angle of the head below the horizontal observed in this study is believed to have been adopted by the subjects to observe the half-way point marked on the ground. Conversely, upper trunk extensions as well as smaller flexed angles of the head relative to the trunk were observed during the walking portion of the head load carriage task. When the load is placed on the top of the head, it is located slightly anteriorly of the neck and vertebral column. The load then creates flexion moments of the head and trunk about the centre of rotation of the neck, C1, and about the centre of rotation in the lower back, L5/S1, respectively. Consequently, it is hypothesized that the increase in trunk extension and decrease in flexion angles of the head with respect to the trunk were performed to shift the center of gravity of the upper body-and-load and head-and-load over their centers of rotation, L5/S1 and C1, respectively, to counteract the flexion moments caused by the load. This compensation mechanism for trunk inclination has been shown for load carriage in backpacks, where forward tilt postures are adopted to counteract the moment created by the load placed on the back (Bobet & Norman, 1984; Kinoshita, 1985; Hong & Cheung, 2003). Furthermore, our results agree with those of Filaire et al. (2001) who showed a horizontal backward displacement of the thoracic region during static standing with loads placed on the head. It is also hypothesized that the head and trunk are not moved independently. Thus, extension or backward tilt of the head would have induced some trunk extension as well. These changes in trunk and head angles from the normal position can stress the back muscles and ultimately lead to back problems due to the prolonged postural strain on these muscles (Chaffin & Andersson, 1991). Furthermore, heavier loads do not move
in synchrony with the trunk (Pierrynowski et al., 1981), thus causing cyclic stress to the back ligaments and muscles (Harman et al., 1992).

In the frontal plane, the mean upper trunk angle was oriented towards the left in the loaded and unloaded conditions. It has been shown that the upper trunk bends towards the supporting leg when walking (Syczewska et al., 1999). Consequently, a mean upper trunk angle nearing a neutral position ($0^\circ$) would have been expected as the lateral shift for each stride would have cancelled each other. An uneven number of steps with each foot during data collection or an asymmetrical gait are possible explanations for this average trunk tilt towards the left. On the other hand, the increase in the average lateral tilt towards the left during loaded walking may be explained by the load carriage method employed by the women. Women typically use their dominant arm and hand to help balance the load while walking. All our subjects, with one exception, were right-handed and therefore used their right arm and hand to hold the load. As a result of this practice, the upper trunk is more inclined towards the left during loaded walking. It is also possible that the VC was moved towards the left by the scapula when the arm was raised to hold the load, thus increasing the inclination of the VC at C7 towards the left in the loaded condition. The mean lateral walking angle at the sacrum shifted in the opposite direction as the upper trunk during load walking. The decrease in tilt angle of the sacrum towards the left is assumed to be a compensation mechanism to counterbalance the lateral bend of the upper trunk. However, it must be noticed that the changes in mean angles between the loaded and unloaded conditions are very small; therefore, these results must be interpreted with caution.
From an ergonomic point of view, the posture of the upper arm adopted during load carriage is considered critical because the shoulder is abducted and flexed by approximately 90° (McAtamney & Corlett, 1993). Prolonged shoulder flexion during a work task has been shown to cause fatigue in the surrounding musculature (Herberts et al., 1980). This fatigue can ultimately lead to injuries in the muscles and tendons in the shoulder area.

### 4.4.1.2 Motion of the trunk and head during walking

The load placed on the head is unstable due to its high placement with respect to the body centre of gravity and the lack of attachment to the head. In fact, significantly larger swaying motion of the body in the horizontal plane was observed when static standing of head load carriage method was compared to that of other methods of carriage (Filaire et al., 2001). The instability of the load is further increased during walking because of the raised position of centre of gravity and the moments due to angular accelerations. The high position of the load results in a larger moment of inertia of the body-and-load that in turn increases the moments due to angular acceleration during walking. In order to avoid dropping of the weight, reduced motion of the head and upper trunk is required to minimize the movements of the load. The decline in the SD of the walking upper trunk angles and movements of the head with respect to the trunk illustrates this phenomenon of reduced upper body motion to balance the load on the head as the movements are contained within a smaller range of angles. Motion restriction for the trunk at C7 was observed in both the frontal and sagittal planes. The movements of the head with respect to the trunk displayed the largest decrease in motion. This result is plausible since the
head is in direct contact with the load and large movements would probably cause the load to be dropped. The contraction of the core muscles to compensate for the sway of the load and to counterbalance the load requires some amount of static work. This static muscular effort demands considerable energy expenditure and is fatiguing (Soule & Goldman, 1969), and it may possibly lead to musculoskeletal injuries. On the other hand, the SD of the FE and LB angles at the sacrum increased significantly in the loaded condition. This increase in movements at the sacrum during head load carriage is hypothesized to be a compensation mechanism to counteract the lack of motion in the upper trunk and allow for normal motion of the legs.

4.4.2 Main effect of pregnancy

4.4.2.1 Trunk and head inclination during walking

The parameters measured in this experiment were similar between the two subject groups. These results are in accordance with those of Foti et al. (2000) who found that the gait and trunk tilt during pregnancy remained remarkably unchanged. However, it can be noticed that the mean trunk walking angle for pregnant women at C7 in the unloaded condition was slightly larger (more flexion) than that of non-pregnant women. Furthermore, the mean extension angle of the pregnant women in the loaded condition was smaller (less extension) than that of the non-pregnant women. Although pregnancy did not have a significant effect on trunk inclination angles, this difference can possibly be explained by the fact that the angles are measured relative to the individual’s upright position. Pregnant women may have adopted a static standing posture with the upper trunk slightly tilted backward to counteract the additional weight of the foetus.
Consequently, since all angles are measured with respect to this neutral position, the mean forward trunk tilt in unloaded walking is larger and the mean backward tilt angle is smaller when compared to the non-pregnant group.

4.4.2.2 Trunk and head motion during walking

Pregnancy had a significant effect only on the SD of the upper trunk angles in the unloaded condition. Increased instability in the antero-posterior direction was also observed during standing for pregnant women (Jang et al., 2008). The significantly higher SD of the upper trunk may be explained by the enlarged abdomen of pregnant women. This localized weight creates larger moments about the centre of rotation of the lower back, L5/S1, thus creating an imbalance of the upper trunk. It is hypothesized that the pregnant women attempted to replace the center of gravity of the upper trunk, now displaced in the forward direction, over the centre of rotation of the lower back, L5/S1, by rotating the trunk backward to maintain balance during walking. However, the trunk has also been shown to be slightly tilted forward during locomotion (Syczewska et al., 1999). The combination of the slight trunk flexion and the attempt to replace the centre of gravity backwards could have contributed to creating this larger SD observed in the unloaded condition for pregnant women. The instability in the antero-posterior direction may also have induced instability in the medio-lateral direction.

4.4.2.3 Maximum flexion angles

The maximum flexion angles were not significantly different during lifting and lowering of the load between the two subject groups. However, pregnant women reported
experiencing more difficulty in handling the load during the pick up and put down of the weight in Chapter 3. This increased difficulty was explained by the enlargement of the abdomen in 50% of the pregnant women. Consequently, pregnant women were expected to have smaller flexion angles as a result of the enlarged abdomen. However, this localized additional weight did not appear to affect the capacity of pregnant women to fully bend forward. The maximum values obtained agree with the trunk angle ranges of 84.6° reported by Lindbeck & Kjellberg (2001) for fast back lifts in women.

4.5 Limitations

The VC is an inclinometer that reports inclination angles relative to the line of gravity in static situations (Hansson, 2001). However, the presence of dynamic accelerations directly affects the angles outputted by the VC because the acceleration vector can deviate from the line of gravity (Hansson, 2001). As a result, angular errors were probably introduced during the lifting, walking, and lowering of the load as these movements are dynamic. Angle values must be analyzed with caution as the inclinometric interpretation may not be valid with large accelerations. However, the angles measured by the VC in this study were compared between subject groups and conditions. Dynamic accelerations were assumed to be similar between subjects and conditions and to affect all measurements similarly, thus counteracting their effects on the angles when comparing results. Consequently, the comparisons performed in this study were thought to be valid despite the effects of dynamic accelerations on the angles. Validation of the VC and a discussion of its limitations are included in Chapter 5 and Chapter 6, respectively.
The walking trunk postures from the different trials under each of the two conditions were combined together as they were assumed to be similar between trials. However, the order of execution of the trials was not random. Subjects always walked in the unloaded condition first, followed by the loaded walking. This order was not changed or randomized during data collection to avoid possible mixups in the identification of trials because of the continuous recording of the VC. However, it was assumed that the order in which the trials were performed had no effect on the measurements and that all trials were similar since subjects were accustomed to the tasks. Randomization could be preferred in future studies where each individual trial can be identified.

There are also some limitations associated with the fixation of the instrumentation onto the subject’s body. Medical tape, head bands, and a custom harness secured with adjustable elastic straps were used to attach the electrogoniometer and VC onto the subject’s head and trunk, respectively. However, it is possible that the device became slightly displaced during data collection. This displacement of the VC from its reference position particularly increases the errors of the angles reported by the VC because all angles are reported relative to the subject’s upright standing posture.

### 4.6 Conclusion

The postures of the trunk and of the head relative to the trunk adopted during the specific task of head load carriage were measured for a group of pregnant women and a control group of non-pregnant women because this activity was identified as a risk factor for back pain during pregnancy. During walking, the load on the head caused significantly larger upper trunk extension and smaller flexion of the head relative to the trunk. The
amplitude of motion of the upper trunk and of the head relative to the trunk, as measured by the SD of walking angles, was found to decrease as a result of carrying a load on the head and compensated by increased motion at the sacrum. These posture modifications were believed to be adopted by the subjects to provide better stability for the load during walking. These prolonged postural strains caused by the trunk being displaced from its normal position can lead to muscle fatigue and ultimately to musculoskeletal injuries.

Women used their dominant arm, the right arm for most subjects, to help balance the load on their head creating an increase in the lateral upper trunk tilt towards the left. Pregnant women showed larger upper trunk movements than their counterpart in the frontal and sagittal planes during the unloaded walking trials. These larger movements were hypothesized to be due to the enlarged abdomen of pregnant women as it creates a larger moment about L5/S1 and increases instability. However, this enlarged abdomen did not seem to affect the pregnant women in their ability to bend down and pick up or put down the load.
4.7 References


Chapter 5

5 Virtual Corset Validation

5.1 Introduction

Working postures have been found to be a risk factor for the development of work-related musculoskeletal disorders (Vieira & Kumar, 2004). Consequently, objective and quantitative methods of measuring posture and movement are essential to estimate the risk rates for the development of work-related musculoskeletal disorders and to establish exposure-response relationships (Hansson, 2001). A variety of methods can been used, but many of the high-end systems are limited to a laboratory setting due to the cost of equipment, the need for trained technicians, the risk of damage to costly equipment, the need for proper calibration, the limited recording time, or the constrained recording area.

In recent years, technological progress has made it possible to produce miniature sensors with integrated calibrating modules for use in a real work environment (Aminian & Najafi, 2004). These miniature sensors are typically less expensive than high-end systems, easy to set up and do not require highly skilled operators (Aminian & Najafi, 2004). Of these sensors, accelerometers have been used as inclinometers in field research due to their small size and their capacity to detect the orientation of body segments relative to the line of gravity. The Virtual Corset™ (VC) (MicroStrain, Williston, VT, USA) is pager sized and battery powered, and it consists of two bi-axial linear...
accelerometers with an integrated datalogger and without any associated cables. It is commercially available for postural analysis in the workplace.

The VC has been used in several field studies to determine the orientation of the trunk (Trask et al., 2007; Slot et al., 2010) and the shoulder (Amasay, 2008; Rempel et al., 2010; Hess et al., 2010) during different tasks. However, accelerometers are sensitive to dynamic acceleration, and the latter may bias the calculated angles. The VC has been validated under static and dynamic conditions (Amasay et al., 2009; Amasay, 2008; Van Driel, 2009). The root mean square (RMS) angle error under static conditions was reported to be less than 1° with a maximal angle error less than 2° (Amasay et al., 2009), comparable to the accuracy specification of ±0.5° reported by the manufacturer.

Under dynamic conditions, the VC was validated against potentiometers on a pendulum by Amasay et al. (2009) and in an in-vivo setting by Amasay (2008) and Van Driel (2009) against a magnetic tracking device and optoelectric system, respectively. Large radii of rotation and high angular accelerations were found to increase the angular errors of the VC when placed on the pendulum because they increased the tangential and radial accelerations (Amasay et al., 2009). Therefore, it was recommended to place the VC close to the joint of rotation and to avoid its use in highly dynamic motions. However, these angular measurements were not obtained by the algorithm developed by Microstrain Inc., thus the results of the comparison might not be applicable to this study as the two algorithms may process dynamic accelerations differently.

The in-vivo studies found poor correlation between the measurements of the VC and the system it was tested against (Amasay, 2008; Van Driel, 2009). However, Amasay (2008)
placed the device on the most mobile joint, the shoulder, which might have influenced the conclusions due to its rapid movements and large range of motion. Van Driel (2009) tested the VC during a lifting motion, which is also a rapid activity that is performed over a large range of trunk angles. Winter (1979) showed that angular and linear accelerations are small during locomotion. Therefore, the large angular errors found in the previous dynamic validations might be an overestimation for the studies in Chapters 3 and 4 because during these validations the VC was submitted to much larger accelerations than those of the trunk during walking. The purpose of this study was to evaluate the VC against a system of potentiometers in flexion-extension and lateral bending with angular accelerations more similar to those of the trunk during walking to establish the error margin in the studies on occupational activities and head load carriage (Chapters 3 and 4).

5.2 Methods

5.2.1 Data acquisition

In order to validate the VC under dynamic activities, the VC was tested against a system of potentiometers. These potentiometers were fixed to a device with three degrees of freedom built to simulate a knee joint. This device is a modified version of the gimbal developed by Deluzio et al. (1993) and is capable of measuring three-dimensional angles. For the purpose of this study, only the flexion-extension and lateral bending movements were logged since the VC is only capable of measuring these two angles. The VC was placed into a custom attachment piece fixed to the upper section of the gimbal (Figure 5.1). This top component can be rotated about three axes to replicate the flexion-extension, lateral bending, and torsion movements of the trunk. Data were sampled at a
rate of 7.5 Hz and 750 Hz for the VC and gimbal, respectively. VC data were stored on the built-in non-volatile memory of the device until the completion of all trials, at which point the data were downloaded to a computer via the Windows-based Virtual Corset control software (VC-323, Microstrain Inc, Williston, VT, USA). The gimbal voltages were directly saved on a computer for further analysis.

![Figure 5.1](image)

**Figure 5.1.** A) Rotation joint of the gimbal. The bottom is fixed to a base and the upper part with the VC is free to move about the three axes; B) Zoomed view of the VC in the custom attachment fixed to the upper component of the gimbal; C) Zoomed view of the VC attached to the upper component of the gimbal. The spring-loaded clip of the VC secures it to the gimbal.

### 5.2.2 Procedure

Before recording data, the gimbal was fixed in its upright position to set the reference position of the VC. Then, the upper section of the gimbal was manually rotated in a single plane about one of the three axes at three different velocities classified as slow,
medium, and fast by the investigator. The mobile part of the gimbal was then moved into a range of angles in all three directions simultaneously as opposed to restricting the motion to a single plane. This three-dimensional motion was repeated twice and was meant to replicate the three-dimensional trunk motions during walking. The same procedure was performed on both VCs. The press-button (PB) on the VC was pressed at the start and end of each trial to allow for the identification of all trials during later processing while each gimbal trial was saved separately.

5.2.3 Data Processing and Analysis

The voltage data obtained from the potentiometers were transformed into angle measurements using the calibration matrix of the device. Then, the data recorded on the VCs were separated into the different trials using the PB trial markers. The gimbal data was then down sampled to the sampling rate of the VC data to obtain a temporal synchronization between the two systems using the cross-correlation function in Matlab R2007B (The Math Works Inc., Nathic, MA, USA) to find the phase differences between signals and shift them accordingly. The root mean square deviation (RMSD) and the maximum angular error between the two signals were then calculated.

5.3 Results

The flexion-extension and lateral bending angles measured by the two devices for the single plane motions are shown in Figure 5.2 and Figure 5.3. The RMSD and maximum angular error values for both VCs and for all types of motion are shown in Table 5.1 and Table 5.2, respectively. Flexion-extension and lateral bending induced some cross-talk in
the opposite channel in the range of -2° to 2° when moved in a single plane, while torsion induced cross-talk of up to 5° in flexion-extension and lateral bending.

Single Plane Motion

Figure 5.2. Comparison of the angles measured by VC1 and the gimbal at slow, medium, and fast velocities. The mobile part of the gimbal was moved in a single plane, with the flexion-extension results shown in the left column and the lateral bending results in the right column.
Single Plane Motion

Figure 5.3. Comparison of the angles measured by VC2 and the gimbal at slow, medium, and fast velocities. The mobile part of the gimbal was moved in a single plane, with the flexion-extension results shown in the left column and the lateral bending results in the right column.

The angles measured for the three-dimensional movements with VC1 and VC2 are shown in Figure 5.4 and Figure 5.5, respectively. The range of acceleration and the mean absolute acceleration for the different trials are shown in Table 5.3.
Three-dimensional motion

Figure 5.4 Comparison of the angles measured by VC1 and the gimbal during three-dimensional motion.
Three-dimensional motion

Figure 5.5. Comparison of the angles measured by VC2 and the gimbal during three-dimensional motion.

Table 5.1. RMSD for the angles between each VC and the gimbal for all types of motion.

<table>
<thead>
<tr>
<th>Type of motion</th>
<th>Flexion-Extension RMSD (°)</th>
<th>Lateral Bending RMSD (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VC1</td>
<td>VC2</td>
</tr>
<tr>
<td>Slow</td>
<td>1.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Medium</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Fast</td>
<td>5.1</td>
<td>7.8</td>
</tr>
<tr>
<td>3D motion 1</td>
<td>3.9</td>
<td>4.2</td>
</tr>
<tr>
<td>3D motion 2</td>
<td>4.3</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Table 5.2. Maximum angular error between each VC and the gimbal for all types of motion.

<table>
<thead>
<tr>
<th>Type of motion</th>
<th>Flexion-Extension maximum error (°)</th>
<th>Lateral Bending maximum error (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VC1</td>
<td>VC2</td>
</tr>
<tr>
<td>Slow</td>
<td>6.9</td>
<td>3.4</td>
</tr>
<tr>
<td>Medium</td>
<td>7.2</td>
<td>5.1</td>
</tr>
<tr>
<td>Fast</td>
<td>13.0</td>
<td>21.3</td>
</tr>
<tr>
<td>3D motion 1</td>
<td>13.8</td>
<td>17.1</td>
</tr>
<tr>
<td>3D motion 2</td>
<td>12.6</td>
<td>10.8</td>
</tr>
</tbody>
</table>

Table 5.3. Mean minimum, mean maximum, and mean absolute angular accelerations for the different types of motion for the two VCs.

<table>
<thead>
<tr>
<th>Type of motion</th>
<th>Flexion-Extension Angular accelerations (°/s²)</th>
<th>Lateral Bending Angular accelerations (°/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Slow</td>
<td>-94</td>
<td>84</td>
</tr>
<tr>
<td>Medium</td>
<td>-148</td>
<td>143</td>
</tr>
<tr>
<td>Fast</td>
<td>-568</td>
<td>594</td>
</tr>
<tr>
<td>3D motion</td>
<td>-521</td>
<td>531</td>
</tr>
</tbody>
</table>

5.4 Discussion

The flexion-extension and lateral bending angles measured by the VC overestimated the reference angles obtained with the potentiometers on the gimbal. This finding is in agreement with the consistent overestimation of flexion-extension angles reported by Van Driel (2009). RMSD values were under 5° for angles in the sagittal plane for all speeds of motion but the fast motion. Similarly, the lateral bending angle errors were mostly under 6°. On the other hand, the maximum angular errors between the two systems were larger with values as high as 29.7°. The largest maximum angular errors were observed for the fast trials, with all other values under 15° for flexion-extension and 20° for lateral bending. Nevertheless, these results are much better than the maximum angle error range
of 10° to 80° reported by Amasay et al. (2009). The pendulum represents a unique form of motion with very high angular velocities and accelerations (up to 2109°/s²) that might not be a good depiction of human motion, particularly when considering the trunk. The angular accelerations of the upper component of the gimbal to which the VC was attached were more similar to those of the head-arms-trunk found by Winter (1979), which ranged between -465°/sec² and 541°/sec² with an average of 233°/sec². These accelerations are much smaller than the peak pendulum acceleration and might explain the smaller differences observed in our results.

The RMSD, maximum angular errors, and phase lag increased as the VC was moved faster. Although the algorithm developed by the manufacturer is reported to filter out dynamic accelerations, it can be observed that these accelerations increased the errors between the two systems. The phase lag between the signals might also have contributed to increasing the RMSD and maximum angular error values in rapid motions. This phase lag between the two systems could have been caused by a slow response of the accelerometers in the VC or the lack of rigid attachment between the VC and gimbal that could have created a delay in the movement of the VC with respect to the gimbal. However, although there was a phase lag, the actual values calculated by the VC were close to those measured by the potentiometers. The primary use of the VC is to measure and identify exposure parameters during a work day in an occupational setting, not to measure specific angles at specific times. Consequently, this phase lag is inconsequential for our purpose as the values of trunk inclination were of interest, not the time of their occurrence.
The RMSD remained small even when the VC was moved over a wide range of motion, with approximately \(-100^\circ\) to \(70^\circ\) of flexion-extension and \(-30^\circ\) to \(50^\circ\) of lateral bending. Conversely, when comparing angles of the VC to the spinal kinematics determined by a motion capture system, Van Driel (2009) found that the angle errors increased as posture moved towards greater degrees of flexion. The frontal placement of the VC in the study by Van Driel (2009) might explain the large overestimation with greater flexion angles. The instrument might have tilted forward due to gravity as the individual bent down, thus not following the motion of the trunk closely. In our study on occupational activities and head load carriage, the VC was placed on the posterior side of the subjects, resting against their backs. This placement might have ensured a better monitoring of the trunk motion, especially in large trunk flexions. However, the overestimation of trunk flexion angles by the VC might hold true during \textit{in-vivo} testing because the single inclinometer placed on the upper trunk also records the movements of the hips and pelvis (Williams \textit{et al.}, 1993). Hip and pelvis motion are more prominent with increased flexion; therefore resulting in higher errors. For this reason, Van Driel (2009) recommended that a single inclinometer may be best suited for monitoring postures in predominately upright tasks. The trunk is essentially in a vertical position during walking with only small trunk movements in the range of \(0.5^\circ\) and \(4.0^\circ\) in the sagittal plane (Hirasaki \textit{et al.}, 1999). Therefore, the overestimation of angles by the VC was probably minimized during head load carriage. The small RMSD values observed in the three-dimensional trials confirm the small errors expected during walking as these trials were meant to simulate the smaller movements of the trunk during locomotion. On the other hand, since the trunk moves within such a small range of angles, the RMSD values have a more important
effect on these measurements. This limitation must be taken into consideration when analyzing the results during walking. It must also be noted that the VC was moved in a range of angles larger than those of the trunk during walking (Hirasaki et al., 1999). Consequently, it is recommended to test the VC in-vivo to simulate the actual motion of the trunk during walking as it can be difficult to replicate its exact movements.

Trunk inclinations have been reported to reach 84.6° for stoop lifts and 51.9° for squat lifts in a female population (Lindbeck & Kjellberg, 2001). These angles were associated with peak trunk angular velocities of 206°/s and 160°/s and peak trunk angular accelerations of 945°/s² and 854°/s², respectively (Lindbeck & Kjellberg, 2001). Consequently, trunk angles measured during the lifting and lowering of the load in the head load carriage tasks were probably affected by larger errors due to the quick motion and large deviation from upright postures. As a result, the values of the trunk inclination angles might be inaccurate although quite similar to those obtained by Lindbeck and Kjellberg (2001). However, in the current study, the maximum trunk inclination angles were compared between subject groups. It can be assumed that the trunk accelerations between subject groups were similar and that they affected the results similarly, rendering the comparison between subject groups valid. The same rationale can be used to argue the validity of the comparison between the subject groups for the trunk angles during the unloaded and loaded walking trials. Therefore, despite the effect of dynamic accelerations on the small trunk angles during walking, the small significant differences between conditions can be assumed to be valid.
Van Driel (2009) also studied spinal motion during lifting tasks using two VCs, with one placed at T5 and the other at the pelvis (S1), and compared the results to the spinal kinematics determined by a motion capture system. This method proved to be more successful than the single inclinometer as the VC inclinometers and rigid-link model motion capture system measurements were highly correlated, with average differences between -4.4° and 2.0°, and regression slopes near 1. These discrepancies between systems are quite small relative to the range of posture during lifting tasks, thus confirming that the method using two VCs provides accurate posture measurements, even in rapid motions over a wide range of angles. Two VCs were also used in our study of head load carriage; however, their measurements were not combined because their angles were not measured with respect to the same reference position but rather from the subject’s most upright posture at the C7 and S1 levels.

The cross-talk induced by motion in a different plane was an unexpected result as the previous studies did not discuss this issue. Torsion created the largest amount of cross-talk with angles of up to 5° in flexion-extension and lateral bending in the faster motions. These errors represent another limitation of the VC in addition to the errors created by the dynamic accelerations. However, the walking and lifting tasks involved movements primarily restricted to the sagittal plane and would probably not have been affected by this cross-talk as it occurs during large and rapid motions in other planes. Daily occupational postures were probably more influenced by this limitation as the motions were typically not restricted to a single plane and were more dynamic.
5.5 Limitations

There are several limitations associated with the present study. Firstly, the small sample size for each motion represents a major limitation as only one and two trials were performed for the single plane motion and three-dimensional tests, respectively. More trials should have been completed for each motion to observe the repeatability of the VCs. However, equipment failure did not allow for additional testing.

Furthermore, the upper part of the gimbal was moved manually at three different speeds. These speeds were not constant and somewhat arbitrary as the upper part of the gimbal was moved based on the operator’s perception of the three different speeds. It would have been preferred to use a servo-motor to move the gimbal and VC at a constant velocity. This automation would also have ensured that both VCs be moved at the same velocities for the same type of motion.

The VC was only subjected to angular accelerations when fixed to the gimbal but should also have been tested for linear motion to observe the effects of linear accelerations on measurements by the device. In-vivo testing, suggested previously, would show the effects of linear accelerations on the VC when individuals are moving forward.

The VC was simply clipped to the gimbal and was unrestrained on one of its side (Figure 5.1 C); therefore the VC could have moved slightly with respect to the gimbal, especially when direction changes occurred. Consequently, this lack of rigid attachment between the two devices might have contributed to increase the overestimation of the angles measured.
by the VC, and more particularly in lateral bending because of the lack of restriction for the VC in that direction.

The two systems, the VC and potentiometers, were also not measuring angles at the exact same location as the VC was placed higher on the gimbal than the potentiometers (Figure 5.1 B). This larger radius of rotation for the VC probably increased the errors between the two signals because it has been shown that a large radius of rotation increases angular errors for the VC (Amasay et al., 2009).

The measurements of the VC were compared to those of the gimbal, which were considered to be standard reference values. However, there are always inherent errors associated with any measurement system. Consequently, the angles measured by the potentiometers inevitably had some errors that could have increased the differences observed between the two systems. Furthermore, there is some uncertainty about the angles measured by the gimbal as it has not been validated against any other system. The system of potentiometers should be tested against another system that has already been validated to determine its accuracy.

5.6 Conclusions

The VC was validated against a system of potentiometers in a series of single-plane and three-dimensional movements. The RMSD between signals were better than those reported in previous studies with values below 5° and 6° for all flexion-extension and lateral bending trials, respectively, with the exception of the fast motion trials. However, cross-talk of up to 5° was observed in planes other than the one where the motion was
performed. Despite these limitations, the VC is still considered a good instrument for field research because of its other advantages such as small size, no wires, memory capacity, and low weight.
5.7 References


Chapter 6

6 General Discussion

Three different studies are included in this thesis. The first study evaluated the trunk postures adopted by a population of pregnant women in Benin during their daily activities. A biomechanical analysis of the trunk postures during the specific task of head load carriage was performed in the second study as this activity was considered a risk factor for back pain during pregnancy. Finally, the instrument used for data collection, the Virtual Corset™ (VC), was validated against a system of potentiometers in the third study.

6.1 Relevance of this study

Guidelines on maximum loads to be lifted and posture recommendations for pregnant women are present in our contemporary society. However, we are aware that pregnant women, especially those living in rural or underdeveloped areas, cannot always follow these guidelines as they can be impractical for the tasks performed in everyday life. For example, pregnant women in Africa might not be able to reduce the load carried on their heads as it would decrease the amount of goods to be sold as well as reduce their income. Furthermore, the number of lifts and the distance walked in a typical day are unpredictable and difficult to control. The basic tools available for the execution of daily occupational tasks also do not always allow for the adoption of good postures. The intent of this study is not to change the customs and lifestyle of the specific population of
merchant pregnant women in West Africa but rather to make a first contribution to the literature by identifying the stressful postures adopted during a typical day and during head load carriage. Prenatal courses are slowly emerging in Benin, and their benefits have been shown by Lawani et al. (2003). They would represent a good commencement strategy to teach pregnant women on ways to work with their changing bodies. It must also be noted that although more than half of the pregnant subject sample suffered from back pain during pregnancy, their Oswestry disability index scores were relatively low, thus corresponding to only mild back pain. In fact, no women participating in our study had to stop carrying loads on the head due to back pain. Nevertheless, proper techniques in executing different physical activities could prevent or reduce the possible risk of experiencing back pain during pregnancy. The observations and findings of this study can help in the development of preventative concepts to decrease the occurrence of back pain. The ultimate goal of this study is to implement a postural modification unit in the prenatal courses in Benin to reduce postural loading of pregnant women.

6.2 Limitations

As with any study, and particularly field studies, there are some limitations associated with the results obtained. Although many variables are out of the researchers’ control in this type of applied research, field studies allow the measurement of realistic exposures and represents the real work environment with subjects that typically perform the same tasks. The limitations of this study have been divided in two main categories: the language and cultural barriers and the instrumentation.
6.2.1 Language and cultural barriers

We ventured to Benin believing that French was a language spoken by most of the population since it is its official language. Much to our surprise, we discovered that only individuals who attended school spoke French. Several local languages are used for communication in everyday life, but all education is in French. However, most of the street vendors, our target population, had not attended school, and consequently do not know French or poorly understand and speak it. Therefore, communication was difficult as an interpreter was needed at all times. Furthermore, since our sample was uneducated for the most part, they were also illiterate and could not read the questionnaires. Students from the INJEPS kindly volunteered to act as translators for the completion of the questionnaires. This help was necessary, but it also complicated the process of verifying the validity of the answers given as we could not confirm them ourselves. Students were given a brief tutorial on the goals of the different questionnaires and the importance of completing all questions. However, several questions remained unanswered in a number of questionnaires, thus decreasing the amount of information collected. Furthermore, instructions on the testing procedures were translated by a third party. Some details might have been omitted during the translation; it is impossible to know if all information was passed on correctly. It would also have been useful to obtain direct feedback from the subjects on the bodily pain experienced during head load carriage. Direct interaction with the women could also have provided more information on the activities performed during the day when trunk postures were monitored.
Foreign visitors are always welcomed in the community with great enthusiasm and treated as royalty. They also definitely stand out when walking down the streets. Direct monitoring of head load carriage tasks and other occupational daily tasks was attempted by following the women throughout the day. However, this method proved to be unsuccessful as most subjects did not feel comfortable having a noticeable person tracking their actions all day. Furthermore, the customs of this culture do not allow the presence of a visitor to go unnoticed. Consequently, the women embraced our visit by cooking extra food for us, bringing us to visit their relatives, or touring us around town. All these gestures were very thoughtful and appreciated though they defeated the purpose of the study to observe the daily occupational biomechanics of a typical day in the life of women from Benin. After several attempts, the investigators decided that it would be best to stop the field observations to obtain a more representative set of data on daily trunk postures recorded by the VC. Although our presence in the community was well received, the situation was quite different in the laboratory for the experiment on head load carriage. Many subjects were frightened by us and did not understand the goal of the study. The instrumentation made them nervous because of their lack of familiarity with these types of devices. Furthermore, as direct communication was not possible, it was difficult to reassure the subjects on the safety of the procedures. This shyness and sense of fear might have affected the way they performed the test and answered the questionnaires.

Lifestyle and customs are also worlds apart from ours. The community and friends are an essential part of everyday life and most activities are performed in groups. The pace of life is relatively slow when compared to North America. We began to realize this way of
life when five subjects or more arrived all at once on testing days. At first, faithful to the standards of subject experimentation of North America, we attempted to minimize the waiting time for all subjects by rushing through the protocol. This method proved to be unsuccessful as several steps were skipped or simply forgotten. Malfunctions of instruments could probably have been avoided if more time had been available for their verification, and we could have checked every questionnaire to ensure their completion. However, we became familiar with their lifestyle a few days after the start of testing, and we adjusted our pace to check more steps in the protocol while still trying to decrease the waiting time. Although this delay in testing would have been unacceptable here, it seemed to be unavoidable in Benin as all subjects preferred to come to the laboratory accompanied by other fellow pregnant women.

The investigators also had to deal with several power outages that occurred during their stay in Benin. Power outages are common and even more frequent during the rainy season, which happened to be during part of the time period when this study took place. The lack of electricity inevitably caused delay in the data collection. Several subjects had to come back to complete testing while others were not available to come back, causing the loss of some data.

The locating of the subjects previously tested in the laboratory at their home for the postural analysis of daily tasks was also an adventure in itself. Street names and addresses were not always present in the residential areas of Porto-Novo where this study took place. Additionally, very few subjects could be contacted by phone to be advised of our visit or to obtain directions to their domicile. Individuals’ home were then found by first
reaching their neighborhood and then interrogating neighbors or pedestrians about a particular subject’s residence by stating her name. Directions from one place to another were obtained, and without a failure, the final destination was always located, although sometimes taking up to an hour. This method, although successful, was clearly not very efficient. Some subjects had already left their house by the time we reached it, and we had to come back. Furthermore, more data postures could also have been collected would we have arrived earlier in the morning. Postural data for the early morning activities could not be collected as we often did not arrive at the home before 9 am or later.

Despite the anxiety and pressure caused by these few cultural and language differences, I cannot stress enough the warm welcome we received during our stay. The willingness and enthusiasm of the participants to complete our questionnaires and experiments was overwhelming. The fact that 26 pregnant and 25 non-pregnant women were recruited over a period of 10 days is nothing short of impressive! The support of the local maternity centre definitely played an important role in the recruitment. The collaboration demonstrated by the INJEPS was also outstanding, as one of the few classrooms available at the University was blocked for our exclusive use for almost two full weeks. Students at the INJEPS contributed very valuable support, and this study could undoubtedly not have been completed without their assistance in transforming a classroom into a data collection laboratory in a matter of minutes.

6.2.2 Instrumentation

No instrumentation or computer was available at the site of experimentation. Consequently, all measuring devices used in the study had to be transported to the
destination by the investigators. The VC and electrogoniometers were the instruments of choice because of their light weights and small sizes. The angles measured by the two electrogoniometers were validated on a simple hinge mechanism with a goniometer upon our return to Queen’s University. All data from one electrogoniometer were invalid and had to be discarded, while the angles measured by the other electrogoniometer needed to be corrected by a calibration equation. Although these angles were corrected, there were still some inaccuracies for large angles of the head relative to the trunk. As a result, maximum flexion angles of the head relative to the trunk during lifting and lowering of the load were not analyzed. Only the head angles with respect to the trunk during walking were analyzed as they are in a small range close to the neutral position.

The VC represented a cost-effective apparatus for measurement in the field as it could be replaced more easily due its low cost if damaged when exposed to the harsh conditions of the outdoors. Furthermore, its capacity to collect data over long periods of time was an important feature for the purposes of this study. However, this capability of recording trunk angles for up to 10 hours also came with a downfall: a low sampling rate. The sampling rate of 7.5 Hz is relatively low when compared to kinematics studies that typically sample markers’ positions at a rate of 30 Hz or higher for similar activities. This low sampling rate especially affects analysis of rapid motion, such as lifting or trunk flexion, because the trunk angles change quickly.

The cross-talk associated with lateral bending angles exceeding the measuring range of \( \pm 70^\circ \) is another limitation because it affects the validity of the angles measured in the sagittal plane as well.
Inclinometers, such as the VC, are considered to measure angles relative to the line of gravity. However, this interpretation can be limited because the angles are actually measured relative to the orientation of the acceleration vector (Hansson, 2001). In the presence of dynamic accelerations, the acceleration vector can deviate from the line of gravity (Hansson, 2001). Consequently, angular errors are generally introduced during movements that are not constant in speed or direction. Hence, results must be analyzed with caution as the inclinometric interpretation may not always be valid. However, as mentioned in Chapters 4 and 5, dynamic accelerations were assumed to affect all measurements equally, and as a result, their effect on the angles was neutralized when comparing trunk inclination angles between subjects and conditions.

Another fundamental limitation of inclinometry is its inability to measure the rotation around the line of gravity (Hansson, 2001). The true three-dimensional orientation of the trunk cannot be assessed. This limitation must be considered when interpreting the trunk orientation. Although trunk twisting appeared to be minimal during the load carriage task, it would have been valuable to know the fully three-dimensional trunk orientation, especially during the daily occupational tasks as trunk twist is considered a critical factor in the ergonomic evaluation of postures (McAtamney & Corlett, 1993). Knowledge of the three-dimensional trunk orientations would also allow for the combination of the measures from the two VCs to obtain the relative trunk bending between upper trunk and sacrum.

The VC starts logging data as soon as it is powered by the battery. As it continuously records data, it is arduous to separate the useful data from the meaningless recordings.
The PB function helped in identifying the specific trials but the data analysis still remained lengthy because each trial had to be extracted individually and checked manually. It took a considerable amount of time to separate all six trials from the 51 different subjects and to identify their walking portions. Furthermore, the start and end of the walking segment during walking was selected manually, thus inducing the potential of human errors in the interpretation of results. Anomalies or instrument malfunction also complicated the separation of the trials.

6.3 Future Work

To the author’s best knowledge, this is the first study on daily occupational activities, and the biomechanics of head load carriage for the specific population of women in West Africa, and more precisely in Benin. One research goal was to gain basic knowledge on these topics as their documentation in the literature is almost non-existent. The information obtained through the experiments of this study only represents a basic, but essential, investigation on these subjects. Consequently, there are many avenues still open for future work.

The sample of the first study was relatively small for a questionnaire study. A longitudinal study with a larger number of participants on back pain in pregnant and non-pregnant women would provide a better representation of the presence and severity of this phenomenon in this population.

As mentioned previously, the cultural and language barriers between the main investigator and the subjects recruited for this study prohibited a proper ergonomic
evaluation of the daily occupational tasks. Therefore, it would be recommended that a trained local observer speaking the same language follow the women to assess the different postures adopted throughout the day. Although observational methods have several downfalls, they do represent a cheap and effective way to evaluate postures of the entire body. Only limited funds are available for research in the region where this study took place, therefore this method would be a good option to obtain more details about trunk and other body segments’ postures. This observational assessment of the occupational activities would also facilitate the development of postural modifications and therapy as the context and settings where the tasks are performed would be identified. The trained observer could also follow these women during their commercial activities to monitor more closely the average number of lifts during a typical day.

The measuring device used in this study only allowed an evaluation of the trunk angles in the frontal and sagittal planes. A true three-dimensional assessment of the trunk angles during the walking portion of the head load carriage should be performed to obtain a complete understanding of its movements in all planes. Furthermore, an instrument with higher precision and accuracy as well as a higher sampling rate, such as motion capture systems, should be employed in the future to acquire more reliable results. A complete biomechanical analysis of the head load carriage method and its impact on walking gait parameters would also represent a good contribution to the literature as this form of load carriage is widespread in several parts of the world. This examination could potentially provide some insight on the mechanism used to balance such heavy weights on the head. An examination of the principal muscles thought to be recruited during this activity should also be performed to assess their levels of exertion.
Several studies have demonstrated through X-Rays the increased degenerative changes occurring in the cervical spine caused by heavy loads carried on the head for several years (Echarri & Forriol, 1996; Jager et al., 1997). However, it was also shown that despite this radiographic evidence of severe degenerative changes, many individuals were completely asymptotic (Jager et al., 1997). Consequently, it would be interesting to understand the effects of the loads on the spine tissues as they leave some porters pain-free. Furthermore, to the author’s best knowledge, no study has looked at the influence of the loads on the other components of the spine or their curvature. Consequently, a study on the long-term effects and risks of the loads on the different components of the spine as well as its tissues and curvatures would represent an important contribution to the literature.
6.4 References


Chapter 7

7 Summary and Conclusions

The purpose of this study was to assess the postural demands of the occupational activities for the specific population of pregnant merchant women in Benin. This study also examined trunk postures as well as postures of the head relative to the trunk in the specific task of carrying loads on the head, a common activity in African countries. Finally, the accuracy of the Virtual Corset™, the instrument used in this study to measure trunk postures, was evaluated.

7.1 Summary of results

Fifty-eight percent (58%) of the pregnant subjects recruited in the first study suffered from back pain since the start of their pregnancy. The questionnaire on the specific activity of head load carriage demonstrated the physical demands of this task as most women exceeded the maximum walking duration and maximum load for lifting recommended by the ACOG and AMWA. The first study also showed that the pregnant subjects spent 36% of the recording time in trunk flexion above 20°. It was also found that the subjects bent down 328 times per day at an angle exceeding 60°, with 66 of these bends lasting more than four seconds. These postures are considered critical as sustained postures and repetitive movements increase the risk of musculoskeletal disorders.
The second study took a closer look at the head load carriage task as it was identified as a high risk activity for back pain. The results showed that trunk postures significantly changed during head load carriage with higher upper trunk extension. Reduced motion of the upper trunk and head were also observed in the sagittal and frontal plane to provide better stability for the load balanced on the head. Conversely, motion at the sacrum increased during head load carriage to compensate for the reduced motion of the upper trunk and allow for normal gait. These trunk posture deviations from its normal position can lead to muscle fatigue and ultimately lead to musculoskeletal injuries.

The third study validated the VC against a system of potentiometers in a range of accelerations. RMSD values obtained were smaller than those previously reported in the literature and were almost all under 5° for flexion-extension and 6° for lateral bending. The results showed that this instrument was valid for the context in which it was used. Furthermore, although the accuracy and precision are not excellent, this device represented a mean to obtain exploratory data on trunk postures of pregnant women in a field setting.

Future work suggested for this study includes a complete biomechanical evaluation of the specific task of head load carriage with an assessment of the level of exertion of the muscles recruited for this activity. An evaluation of the effects of loads on the spine tissues is also recommended.
Appendix A: Datasheet for the accelerometers in the Virtual Corset™
Low Cost ±2 g/±10 g Dual Axis
iMEMS® Accelerometers
with Digital Output

ADXL202/ADXL210

FEATURES
- 2-Axis Acceleration Sensor on a Single IC Chip
- Measures Static Acceleration as Well as Dynamic Acceleration
- Duty Cycle Output with User Adjustable Period
- Low Power <0.5 mA
- Faster Response than Electrolytic, Mercury or Thermal Tilt Sensors
- Bandwidth Adjustment with a Single Capacitor Per Axis
- 5-mg Resolution at 60 Hz Bandwidth
- ±3 V to ±2.5 V Single Supply Operation
1000 g Shock Survival

APPLICATIONS
- Tilt Sensing
- Computer Peripherals
- Inertial Navigation
- Seismic Monitoring
- Vehicle Security Systems
- Battery Powered Motion Sensing

GENERAL DESCRIPTION
The ADXL202/ADXL210 are low cost, low power, complete 2-axis accelerometers with a measurement range of either ±2 g/±10 g. The ADXL202/ADXL210 can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity).

The outputs are digital signals whose duty cycles (ratio of pulse width to period) are proportional to the acceleration in each of the 2 sensitive axes. These outputs may be measured directly with a microprocessor counter, requiring no A/D converter or glue logic. The output period is adjustable from 0.5 ms to 10 ms via a single resistor (RSET). If a voltage output is desired, a voltage output proportional to the acceleration is available from the XOUT and YOUT pins, or may be reconstructed by filtering the duty cycle outputs.

The bandwidth of the ADXL202/ADXL210 may be set from 0 Hz to 5 kHz with capacitors Cx and Cy. The typical noise floor is 500 µg/√Hz allowing signals below 5 mg to be resolved for bandwidths below 60 Hz.

The ADXL202 is available in a hermetic, 14-lead Plastic MSOP in a CERDIP or 14-lead ceramic, ±40°C to ±125°C industrial temperature range.

![Diagram of ADXL202/ADXL210]

REV. B

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<td><strong>SELF TEST</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duty Cycle Change</td>
<td>Self/Test “0” to &quot;1&quot;</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>DUTY CYCLE OUTPUT STAGE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FREF</td>
<td>125 MΩ/REF</td>
<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>FREF Tolerance</td>
<td>25 kΩ</td>
<td>1.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Output High Voltage</td>
<td>V_HE = 200 mV</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Output Low Voltage</td>
<td>I = 25 mA</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>T2 Drift vs. Temperature</td>
<td>V_L = 200 mV</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Rise/Fail Time</td>
<td>R_{REF} = 125 kΩ</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>POWER SUPPLY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Voltage Range</td>
<td>Specified Performance</td>
<td>3.0</td>
<td>5.25</td>
</tr>
<tr>
<td>Quiescent Supply Current</td>
<td>160 C_{REF} + 0.3</td>
<td>4.75</td>
<td>5.25</td>
</tr>
<tr>
<td>Turn-On Time(^5)</td>
<td>160 C_{REF} + 0.3</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>TEMPERATURE RANGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Range</td>
<td>Specified Performance</td>
<td>0</td>
<td>+0.7</td>
</tr>
<tr>
<td>Specified Performance</td>
<td>QJC</td>
<td>–40</td>
<td>+85</td>
</tr>
</tbody>
</table>

**NOTES:**

\(^1\)For all combinations of offset and sensitivity variation.

\(^2\)Alignment error is specified as the angle between the true and indicated axes of sensitivity.

\(^3\)Transverse sensitivity is the algebraic sum of the alignment and the inherent sensitivity errors.

\(^4\)Specification refers to the maximum change in parameter from its initial at +25°C to its worst case value at T_{MAX} or T_{MIN}.

\(^5\)Noise density (μV/√Hz) is the average noise at any frequency in the bandwidth of the pass.

\(^6\)V_{G2} in pF. Addition of filter capacitor will increase tRR on time. Please see the Application section on power cycling.

All min and max specifications are guaranteed. Typical specifications are not tested or guaranteed. Specifications subject to change without notice.
ABSOLUTE MAXIMUM RATINGS*
Acceleration (Any Axis, Unpowered) ........ 1000 g
Acceleration (Any Axis, Powered) ........ 500 g
$V_{DD}$ .................................................. 0.3 V to +7.0 V
Output Short Circuit Duration .............. Indefinite
Operating Temperature ......................... -55°C to +125°C
Storage Temperature ............................... -65°C to +150°C

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Drops onto hard surfaces can cause shocks of greater than 1000 g and exceed the absolute maximum rating of the device. Care should be exercised in handling to avoid damage.

**PIN FUNCTION DESCRIPTIONS**

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>2</td>
<td>VDD</td>
<td>Power Input, Do Not Connect</td>
</tr>
<tr>
<td>3</td>
<td>ST</td>
<td>Sleep Test</td>
</tr>
<tr>
<td>4</td>
<td>COM</td>
<td>Common</td>
</tr>
<tr>
<td>5</td>
<td>T2</td>
<td>Connect Reg to Set T2 Period</td>
</tr>
<tr>
<td>6</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>7</td>
<td>COM</td>
<td>Common</td>
</tr>
<tr>
<td>8</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>9</td>
<td>YOUT</td>
<td>Y Axis Duty Cycle Output</td>
</tr>
<tr>
<td>10</td>
<td>XOUT</td>
<td>X Axis Duty Cycle Output</td>
</tr>
<tr>
<td>11</td>
<td>YFLT</td>
<td>Connect Capacitor for Y Filter</td>
</tr>
<tr>
<td>12</td>
<td>XFLT</td>
<td>Connect Capacitor for X Filter</td>
</tr>
<tr>
<td>13</td>
<td>VDD</td>
<td>+3 V to +5.25 V, Connect to 14</td>
</tr>
<tr>
<td>14</td>
<td>VDD</td>
<td>+3 V to +5.25 V, Connect to 13</td>
</tr>
</tbody>
</table>

**PACKAGE CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Package</th>
<th>$\theta_{JA}$</th>
<th>$\theta_{JC}$</th>
<th>Device Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-Lead CERPAK</td>
<td>110°C/W</td>
<td>30°C/W</td>
<td>5 Grams</td>
</tr>
</tbody>
</table>

**ORDERING GUIDE**

<table>
<thead>
<tr>
<th>Model</th>
<th>$g$ Range</th>
<th>Temperature Range</th>
<th>Package Description</th>
<th>Package Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADXL202QC</td>
<td>$\pm 2$</td>
<td>$0^\circ$C to $+70^\circ$C</td>
<td>14-Lead CERPAK</td>
<td>QC-14</td>
</tr>
<tr>
<td>ADXL202AC</td>
<td>$\pm 2$</td>
<td>$-40^\circ$C to $+85^\circ$C</td>
<td>14-Lead CERPAK</td>
<td>QC-14</td>
</tr>
<tr>
<td>ADXL202QC</td>
<td>$\pm 10$</td>
<td>$0^\circ$C to $+70^\circ$C</td>
<td>14-Lead CERPAK</td>
<td>QC-14</td>
</tr>
<tr>
<td>ADXL202AC</td>
<td>$\pm 10$</td>
<td>$-40^\circ$C to $+85^\circ$C</td>
<td>14-Lead CERPAK</td>
<td>QC-14</td>
</tr>
</tbody>
</table>

**CAUTION**

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADXL202/ADXL210 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

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ADXL202/ADXL210

TYPICAL CHARACTERISTICS

(@ +25°C Rfet = 125 kΩ, Vcc = +5 V, unless otherwise noted)

Figure 2. Normalized DCX Period (T2) vs. Temperature

Figure 3. Typical Zero g Offset vs. Temperature

Figure 4. Typical Supply Current vs. Temperature

Figure 5. Typical X Axis Sensitivity Drift Due to Temperature

Figure 6. Typical Turn-On Time

Figure 7. Typical Zero g Distribution at +25°C

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Figure 9. Typical Sensitivity per g at +25°C

Figure 10. Typical Noise at Digital Outputs

Figure 9. Typical Noise at XAC Output

Figure 11. Rotational Die Alignment
ADXL202/ADXL210

DEFINITIONS

T1: Length of the "on" portion of the cycle.
T2: Length of the total cycle.
Duty Cycle: Ratio of the "on" time (T1) of the cycle to the total cycle (T2). Defined as T1/T2 for the ADXL202/ADXL210.
Pulsewidth: Time period of the "on" pulse. Defined as T1 for the ADXL202/ADXL210.

THEORY OF OPERATION

The ADXL202/ADXL210 are complete dual axis acceleration measurement systems on a single monolithic IC. They contain a polysilicon surface-micromachined sensor and signal conditioning circuits to implement an open loop acceleration measurement architecture. For each axis, an output circuit converts the analog signal to a dithered DC (nondirectional) output signal that can be decoded with a combiner circuit on a microprocessor. The ADXL202/ADXL210 are capable of measuring both positive and negative accelerations from a maximum of ±5000 g. The accelerometer's internal signal amplification factors can be varied, allowing it to be used as a tilt sensor.

The sensor is a surface-micromachined polysilicon structure built on top of the silicon wafer. Polysilicon is a material that has a high stiffness against acceleration forces. Deflection of the structure is measured using a differential capacitor that consists of independent fixed plates and central plates attached to the moving mass. The fixed plates are driven by 180° out of phase square waves. An accelerometer will deflect the beam and unbalance the differential capacitor, resulting in an output square wave whose amplitude is proportional to the acceleration. Phase sensitive demodulation techniques are then used to rectify the signal and determine the direction of the acceleration.

The output of the demodulator drives a duty cycle modulator (DCM) stage through a 12-kΩ resistor. At this point a pin is available on each channel to allow the user to set the signal bandwidth of the device by adding a capacitor. This filtering improves measurement resolution and helps prevent aliasing. After being low-pass filtered, the analog signal is converted to a duty cycle modulated signal by the DCM stage. A single resistor sets the period for a complete cycle (T2), which can be set between 0.5 ms and 10 ms (see Figure 12). A 9 g acceleration produces a nominally 50% duty cycle. The acceleration signal can be determined by measuring the length of the T1 and T2 pulses with a counter/timer or with an RC filter using a low-cost microcontroller.

An analog output voltage can be obtained either by buffering the signal from the XOUT and YOUT pins, or by passing the duty cycle signal through an RC filter to reconstruct the dc value. The ADXL202/ADXL210 will operate with supply voltages as low as 3.0 V or as high as 5.25 V.

![Figure 12. Typical Output Duty Cycle](image)

APPLICATIONS

POWER SUPPLY DECOUPLING

For most applications a single 0.1 μF capacitor, CDEC, will adequately decouple the accelerometer from signal and noise on the power supply. However, in some cases, especially where digital devices such as microcontrollers share the same power supply, digital noise on the supply may cause interference on the ADXL202/ADXL210 output. This is often observed as a slowly undulating fluctuation of voltage at VCC and VEE. If additional decoupling is needed, a 100 μF (or smaller) capacitor, or ferrite bead, may be inserted in the ADXL202/ADXL210's supply line.

DESIGN PROCEDURE FOR THE ADXL202/ADXL210

The design procedure for using the ADXL202/ADXL210 with a duty cycle output involves selecting a duty cycle period and a filter capacitor. A proper design will take into account the application requirements for bandwidth, signal resolution and acquisition time, as discussed in the following sections.

VCC

The ADXL202/ADXL210 have two power supply (VCC) pins: V+ and V-. These two pins should be connected directly together.

COM

The ADXL202/ADXL210 have two commons, Pins 4 and 7. These two pins should be connected together and Pin 7 grounded.

VOUT

This pin is to be used if one makes any connections of any kind to this pin.

Decoupling Capacitor CDEC

A 0.1 μF capacitor is recommended from VOUT to COM for power supply decoupling.

ST

The ST pin controls the self-test feature. When this pin is set to Vcc, an electrostatic force is exerted on the beam of the accelerometer. The resulting movement of the beam allows the user to test if the accelerometer is functional. The typical change in output will be 10% at the duty cycle output (corresponding to ±800 mV). This pin may be left open circuit or connected to common in normal use.

Duty Cycle Decoding

The ADXL202/ADXL210's digital output is a duty cycle modulator. Acceleration is proportional to the ratio T1/T2. The nominal output of the ADXL202 is:

0 g = 50% Duty Cycle

Scale factor is 12.5% Duty Cycle Change per g

The nominal output of the ADXL210 is:

0 g = 50% Duty Cycle

Scale factor is 4% Duty Cycle Change per g

These nominal values are affected by the initial tolerance of the device including zero g offset error and sensitivity error.

T2 does not have to be measured for every measurement cycle. It need only be updated to account for changes due to temperature, (a relatively slow process). Since the T2 time period is shared by both X and Y channels, it is necessary only to measure it on one channel of the ADXL202/ADXL210. Decoding algorithms for various microcontrollers have been developed. Consult the appropriate Application Note.

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Setting the Bandwidth Using \( C_x \) and \( C_y \)

The ADXL202/ADXL210 have provisions for bandlimiting the \( X_{lin} \) and \( Y_{lin} \) lanes. Capacitors must be added at these pins to implement low-pass filtering for bandwidth and noise reduction. The equation for the 3 dB bandwidth is:

\[
F_{3dB} = \frac{1}{2 \pi (32 \Omega) \times C_x(x,y)}
\]

or, more simply,

\[
F_{3dB} = \frac{5 \mu F}{C_{x(x,y)}}
\]

The tolerance of the internal resistor (\( R_{int} \)), can vary as much as ±25% of its nominal value of 32 \( \Omega \), so the bandwidth will vary accordingly. A minimum capacitance of 1000 \( \mu F \) for \( C_{x(x,y)} \) is required in all cases.

### Table I. Filter Capacitor Selection, \( C_x \) and \( C_y \)

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>( C_x ) Value</th>
<th>( C_y ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Hz</td>
<td>0.47 ( \mu F )</td>
<td>0.10 ( \mu F )</td>
</tr>
<tr>
<td>50 Hz</td>
<td>0.10 ( \mu F )</td>
<td>0.05 ( \mu F )</td>
</tr>
<tr>
<td>100 Hz</td>
<td>0.05 ( \mu F )</td>
<td>0.027 ( \mu F )</td>
</tr>
<tr>
<td>200 Hz</td>
<td>0.027 ( \mu F )</td>
<td>0.01 ( \mu F )</td>
</tr>
<tr>
<td>500 Hz</td>
<td>0.01 ( \mu F )</td>
<td>0.003 ( \mu F )</td>
</tr>
</tbody>
</table>

Setting the DCM Period with \( R_{out} \)

The period of the DCM output is set for both channels by a single resistor from \( R_{out} \) to ground. The equation for the period is:

\[
T2 = \frac{R_{out} \times (\Omega)}{125 \, \text{M} \Omega}
\]

A 125 \( \Omega \) resistor will set the duty cycle repetition rate to approximately 1 kHz, or 1 ms. The device is designed to operate at duty cycle periods between 0.5 ms and 10 ms.

### Table II. Resistor Values to Set \( T2 \)

<table>
<thead>
<tr>
<th>( T2 )</th>
<th>( R_{out} ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 ms</td>
<td>135 ( \Omega )</td>
</tr>
<tr>
<td>1.25 ms</td>
<td>279 ( \Omega )</td>
</tr>
<tr>
<td>0.5 ms</td>
<td>636 ( \Omega )</td>
</tr>
<tr>
<td>0.25 ms</td>
<td>125 ( \Omega )</td>
</tr>
<tr>
<td>0.125 ms</td>
<td>250 ( \Omega )</td>
</tr>
</tbody>
</table>

Note that \( R_{out} \) should always be included, even if only an analog output is desired. Use an \( R_{out} \) value between 300 \( \Omega \) and 2 \( \Omega \) when taking the output from \( X_{lin} \) or \( Y_{lin} \). The \( R_{out} \) resistor should be placed close to the DC bias to minimize parasitic capacitance at this node.

Selecting the Right Accelerometer

For most tilt sensing applications, the ADXL202 is the most appropriate accelerometer. Its higher sensitivity (12.5\%g) allows the user to use a lower speed counter for PWM decoding while maintaining high resolution. The ADXL210 should be used in applications where accelerations greater than ±3 g are expected.

### MICROCOMPUTER INTERFACES

The ADXL202/ADXL210 were specifically designed to work with low cost microcontrollers. Specific code sets, reference designs, and application notes are available from the factory. This section will outline a general design procedure and discuss the various tradeoffs that need to be considered.

The designer should have some idea of the required performance of the system in terms of:

- **Resolution**: the smallest signal change that needs to be detected.
- **Bandwidth**: the highest frequency that needs to be detected.
- **Acquisition Time**: the time that will be available to acquire the signal on each axis.

These requirements will help to determine the accelerometer bandwidth, the speed of the microcontroller clock and the length of the T2 period.

When selecting a microcontroller it is helpful to have a counter timer port available. The microcontroller should have provisions for software calibration. While the ADXL202/ADXL210 are highly accurate accelerometers, they have a wide tolerance for
ADXL202/ADXL210

Initial offset. The easiest way to null this offset is with a calibration factor saved on the microcontroller or by using a zero calibration for zero g. In the case where the offset is calibrated during manufacture, there are several options, including external EEPROM and microcontrollers with “one-time programmable” features.

**DESIGN TRADE-OFFS FOR SELECTING FILTER CHARACTERISTICS: THE NOISE/BW TRADE-OFF**

The accelerometer bandwidth selected will determine the measurement resolution (smallest detectable acceleration). Filtering can be used to lower the noise floor and improve the resolution of the accelerometer. Resolution is dependent on both the analog filter bandwidth at \( f_{	ext{cutoff}} \) and \( f_{	ext{BW}} \) and on the speed of the microcontroller counter.

The analog output of the ADXL202/ADXL210 has a typical bandwidth of \( f_{	ext{cutoff}} \), much higher than the duty cycle stage is capable of converting. The user must filter the signal at this point to limit aliasing errors. To minimize DCM errors, the analog bandwidth should be less than \( f_{	ext{BW}} \) to \( f_{	ext{osc}} \) frequency. Noise bandwidths that are measured up to \( f_{	ext{BW}} \) frequency in many applications. This will result in greater dynamic error generated at the DCM.

The analog bandwidth can be further decreased in practice to improve noise and improve resolution. The ADXL202/ADXL210 noise has the characteristics of white Gaussian noise that contributes equally at all frequencies and is described in terms of g per root Hz, i.e., the noise is proportional to the square root of the bandwith of the accelerometer. It is recommended that the user limit bandwidth to the lowest frequency needed by the application, to maximize the resolution and dynamic range of the accelerometer.

With the single pole roll-off characteristic, the typical noise of the ADXL202/ADXL210 is determined by the following equation:

\[
\text{Noise} = \left( \frac{500 \, \mu g}{\sqrt{Hz}} \right) \times \left( B F \times L \right)
\]

At 100 Hz the noise will be:

\[
\text{Noise} = \left( \frac{500 \, \mu g}{\sqrt{Hz}} \right) \times \left( 100 \times 3.5 \right) = 6.12 \, \mu g
\]

Often the peak value of the noise is desired. Peak-to-peak noise can only be estimated by statistical methods. Table III is useful for estimating the probabilities of encoding various peak values, given the rms value.

**Table III. Estimation of Peak-to-Peak Noise**

<table>
<thead>
<tr>
<th>Nominal Peak-to-Peak Value</th>
<th>% of Time that Noise Will Exceed Nominal Peak-to-Peak Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 x rms</td>
<td>32%</td>
</tr>
<tr>
<td>4.0 x rms</td>
<td>4.6%</td>
</tr>
<tr>
<td>6.0 x rms</td>
<td>2.2%</td>
</tr>
<tr>
<td>8.0 x rms</td>
<td>0.0006%</td>
</tr>
</tbody>
</table>

The peak-to-peak noise value will give the best estimate of the uncertainty in a single measurement.

Table IV gives typical noise output of the ADXL202/ADXL210 for various \( C_1 \) and \( C_2 \) values.

**Table IV. Filter Capacitor Selection, \( C_1 \) and \( C_2 \)**

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>rms Noise</th>
<th>Peak-to-Peak Noise Estimate 93% Probability (rms x 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Hz</td>
<td>0.47 ( \mu F )</td>
<td>1.9 ( \mu g )</td>
<td>7.6 ( \mu g )</td>
<td></td>
</tr>
<tr>
<td>50 Hz</td>
<td>0.10 ( \mu F )</td>
<td>4.3 ( \mu g )</td>
<td>17.2 ( \mu g )</td>
<td></td>
</tr>
<tr>
<td>100 Hz</td>
<td>0.05 ( \mu F )</td>
<td>6.1 ( \mu g )</td>
<td>24.8 ( \mu g )</td>
<td></td>
</tr>
<tr>
<td>200 Hz</td>
<td>0.027 ( \mu F )</td>
<td>8.7 ( \mu g )</td>
<td>35.8 ( \mu g )</td>
<td></td>
</tr>
<tr>
<td>500 Hz</td>
<td>0.01 ( \mu F )</td>
<td>13.7 ( \mu g )</td>
<td>54.8 ( \mu g )</td>
<td></td>
</tr>
</tbody>
</table>

**CHOOSING T2 AND COUNTER FREQUENCY. DESIGN TRADE-OFFS**

The noise level is one determinant of accelerometer resolution. The second relates to the measurement resolution of the counter when decoding the duty cycle output.

The ADXL202/ADXL210's duty cycle converter has a resolution of approximately 14 bits; better resolution than the accelerometer itself. The actual resolution of the acceleration signal is, however, limited by the time resolution of the counting device used to decode the duty cycle. For a fixed duty cycle, the higher the resolution of the duty cycle and the shorter the T2 period can be for a given resolution. The following table shows some of the trade-offs. It is important to note that the resolution due to the microcontroller's counter. It is possible that the accelerometer's noise floor may set the lower limit on the resolution, as discussed in the previous section.

**Table V. Trade-Offs Between Microcontroller Counter Rate, T2 Period and Resolution of Duty Cycle Modulator**

<table>
<thead>
<tr>
<th>T2 (ms)</th>
<th>( R_{\text{counter}} ) (MHz)</th>
<th>ADXL202/ADXL210</th>
<th>Counter-ADXL210 Clock Rate (MHz)</th>
<th>Counts per T2 Cycle</th>
<th>Counts per g</th>
<th>Resolution (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>124</td>
<td>1000</td>
<td>2.0</td>
<td>2500</td>
<td>9.0</td>
<td>4.0</td>
</tr>
<tr>
<td>1.0</td>
<td>124</td>
<td>1000</td>
<td>1.0</td>
<td>1000</td>
<td>125</td>
<td>8.0</td>
</tr>
<tr>
<td>1.0</td>
<td>124</td>
<td>1000</td>
<td>0.5</td>
<td>500</td>
<td>62.5</td>
<td>16.0</td>
</tr>
<tr>
<td>5.0</td>
<td>625</td>
<td>200</td>
<td>2.0</td>
<td>10000</td>
<td>1250</td>
<td>0.8</td>
</tr>
<tr>
<td>5.0</td>
<td>625</td>
<td>200</td>
<td>1.0</td>
<td>5000</td>
<td>625</td>
<td>1.6</td>
</tr>
<tr>
<td>5.0</td>
<td>625</td>
<td>200</td>
<td>0.5</td>
<td>2500</td>
<td>312.5</td>
<td>3.2</td>
</tr>
<tr>
<td>10.0</td>
<td>1250</td>
<td>100</td>
<td>2.0</td>
<td>20000</td>
<td>2500</td>
<td>0.4</td>
</tr>
<tr>
<td>10.0</td>
<td>1250</td>
<td>100</td>
<td>1.0</td>
<td>10000</td>
<td>1250</td>
<td>0.8</td>
</tr>
<tr>
<td>10.0</td>
<td>1250</td>
<td>100</td>
<td>0.5</td>
<td>5000</td>
<td>625</td>
<td>1.6</td>
</tr>
</tbody>
</table>
STRATEGIES FOR USING THE DUTY CYCLE OUTPUT WITH MICROCONTROLLERS

Application notes outline various strategies for using the duty cycle output with low-cost microcontrollers available from the factory.

USING THE ADXL202/ADXL210 AS A DUAL AXIS TILT SENSOR

One of the most popular applications of the ADXL202/ADXL210 is tilt measurement. An accelerometer uses the force of gravity as an input vector to determine orientation of an object in space. An accelerometer is most sensitive to tilt when its sensitive axis is perpendicular to the force of gravity, i.e., parallel to the earth’s surface. At this orientation, its sensitivity to changes in tilt is highest. When the accelerometer is oriented on axis to gravity (i.e., 0°) with a -1 g or +1 g reading, the change in output is linear for changes of tilt magnitude below 10°. When the accelerometer is perpendicular to gravity, its output will change nearly 17.5 mg per degree tilt, due to the changing component of gravity as the device is tilted ±90° through gravity.

A DUAL AXIS TILT SENSOR: CONVERTING ACCELERATION TO TILT

When the accelerometer is oriented so both its X and Y axes are parallel to the earth’s surface it can be used as a two-axis tilt sensor with a roll and a pitch axis. Once the output signal from the accelerometer has been converted to an acceleration that varies between -1 g and +1 g, the output tilt in degrees is calculated as follows:

\[
\text{Pitch} = \text{ASIN}(X \div 1 g) \\
\text{Roll} = \text{ASIN}(Y \div 1 g)
\]

Be sure to account for overranges. It is possible for the accelerometers to output a signal greater than ±1 g due to vibration, shock, or other accelerations.

MEASURING 360° OF TILT

It is possible to measure a full 360° of orientation through gravity by using two accelerometers oriented perpendicular to one another (see Figure 15). When one sensor is reading a maximum change in output per degree, the other is at its minimum.

![Figure 15. Using a Two-Axis Accelerometer to Measure 360° of Tilt](image)

<table>
<thead>
<tr>
<th>X AXIS ORIENTATION TO HORIZONTAL</th>
<th>X OUTPUT A PER DEGREE OF TILT (mg)</th>
<th>Y OUTPUT A PER DEGREE OF TILT (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-90</td>
<td>-1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>-75</td>
<td>-0.966</td>
<td>0.100</td>
</tr>
<tr>
<td>-60</td>
<td>-0.938</td>
<td>0.200</td>
</tr>
<tr>
<td>-45</td>
<td>-0.902</td>
<td>0.300</td>
</tr>
<tr>
<td>-30</td>
<td>-0.868</td>
<td>0.400</td>
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<tr>
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<td>-0.839</td>
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</tr>
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<td>0.178</td>
<td>0.900</td>
</tr>
<tr>
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<td>1.000</td>
</tr>
<tr>
<td>75</td>
<td>0.299</td>
<td>1.100</td>
</tr>
<tr>
<td>90</td>
<td>0.359</td>
<td>1.200</td>
</tr>
</tbody>
</table>

Figure 14. How the X and Y Axes Respond to Changes in Tilt
ADXL202/ADXL210

USING THE ANALOG OUTPUT
The ADXL202/ADXL210 was specifically designed for use with its digital outputs, but has provisions to provide analog outputs as well.

Duty Cycle Filtering
An analog output can be reconstructed by filtering the duty cycle output. This technique requires only passive components. The duty cycle period (T2) should be set to 1 ms. An RC filter with a 3 dB point at least a factor of 10 less than the duty cycle frequency is connected to the duty cycle output. The filter resistor should be no less than 100 kΩ to prevent loading of the output stage. The analog output signal will be ratiometric to the supply voltage. The advantage of this method is an output scale factor of approximately double the analog output. Its disadvantage is that the frequency response will be lower than when using the XOUT and YOUT pins.

XOUT, YOUT Output
The second method is to use the analog output present at the XOUT and YOUT pins. Unfortunately these pins have 33 kΩ output impedance and are open-drain to 5 V. They should be pulled up to 5 V using an external 33 kΩ resistor. The voltage on the output pins can be read using an open-drain driver. The duty cycle information should be kept running using a buffer. Note the accelerometer offset and sensitivity are ratiometric to the supply voltage. The offset and sensitivity are nominally:

- $V_{OFF} = \frac{V_{OS}}{2}$
- $V_{OS} = 2.5 \text{ V at } +5 \text{ V}$
- ADXL202 Sensitivity = $(60 \text{ mV} \times V_{OS})$
- ADXL210 Sensitivity = $(50 \text{ mV} \times V_{OS})$

USING THE ADXL202/ADXL210 IN VERY LOW POWER APPLICATIONS
An application note outlining low power strategies for the ADXL202/ADXL210 is available. Some key points are presented here. It is possible to reduce the ADXL202/ADXL210’s average current from 0.6 mA to less than 20 μA by using the following techniques:

1. Power Cycle the accelerometer.
2. Run the accelerometer at a Lower Voltage, (Down to 3 V).

Power Cycling with an External A/D
Depending on the value of the $R_{XOUT}$ capacitor, the ADXL202/ADXL210 is capable of turning on and giving a good reading in 1.6 ms. Most microcontroller based A/Ds can acquire a reading in another 25 μs. Thus it is possible to turn on the ADXL202/ADXL210 and take a reading in <2 ms. If we assume that a 20 Hz sample rate is sufficient, the total current required to take 20 samples is 2 ms × 20 samples × 0.6 mA = 24 μA average current. Running the part at 3 V will reduce the supply current from 0.6 mA to 0.4 mA, bringing the average current down to 16 μA.

The A/D should read the analog output of the ADXL202/ADXL210 at the XOUT and YOUT pins. A buffer amplifier is recommended, and may be required in any case to amplify the analog output to give enough resolution with an 8-bit to 10-bit converter.

Power Cycling When Using the Digital Output
An alternative is to run the microcontroller at a higher clock rate and put it into shutdown between readings, allowing the use of the digital output. In this approach the ADXL202/ADXL210 should be set at its fastest sample rate (T2 = 0.5 ms), with a 500 Hz filter at XOUT and YOUT. The concept is to acquire a reading as quickly as possible and then shut down the ADXL202/ADXL210 and the microcontroller until the next sample is needed.

In either of the above approaches, the ADXL202/ADXL210 can be turned on and off directly using a digital port pin on the microcontroller to power the accelerometer without additional components. The port should be used to switch the common pin of the accelerometer so the port pin is “pulling down.”

CALIBRATING THE ADXL202/ADXL210
The initial value of the offset and scale factor for the ADXL202/ADXL210 will require calibration for applications such as tilt measurement. The ADXL202/ADXL210 architecture has been designed so that these calibrations take place in the software of the microcontroller used to decode the duty cycle signal. Calibration factors can be stored in EEPROM or determined at run-time and saved in RAM memory.

For many applications, the least stable part of the system is the most stable, accurate and convenient acceleration reference available. A reading of the 0 g plane can be determined by orienting the device upside-down on its own surface and then reading the output. A more accurate calibration method is to make a measurement at +1 g and –1 g. The sensitivity can be determined by taking two measurements.

To calibrate, the accelerometer’s measurement axis is pointed directly at the earth. The 1 g reading is saved and the sensor axis is turned 180° to measure –1 g. Using the two readings, the sensitivity is:

\[ A = \text{Accelerometer output with axis oriented at } +1 \text{ g} \]
\[ B = \text{Accelerometer output with axis oriented at } -1 \text{ g} \]

\[ \text{Sensitivity} = \frac{A - B}{2g} \]

For example, if the +1 g reading (A) is 55% duty cycle and the –1 g reading (B) is 32% duty cycle, then:

\[ \text{Sensitivity} = \frac{55\% - 32\%}{2} \times g = 11.5\%/g \]

These equations apply whether the output is analog, or duty cycle.

Application notes outlining algorithms for calculating acceleration from duty cycle and automated calibration routines are available from the factory.
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

14-Lead CERDIP (QC-14)

REV. B

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Appendix B: Ethics approval
Study Title: Biomechanical and ergonomic assessment of the daily physical tasks performed by pregnant women in Benin
Co-Investigators: Dr. G. Dumas, Dr. M. Lawani

I am writing to acknowledge receipt of your recent ethics submission. We have examined the protocol, questionnaires and consent form for your project (as stated above) and consider it to be ethically acceptable. This approval is valid for one year from the date of the Chair's signature below. This approval will be reported to the Research Ethics Board. Please attend carefully to the following list of ethics requirements you must fulfill over the course of your study:

- **Reporting of Amendments:** If there are any changes to your study (e.g. consent, protocol, study procedures, etc.), you must submit an amendment to the Research Ethics Board for approval. (see https://www.queensu.ca/ethics).

- **Reporting of Serious Adverse Events:** Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.

- **Reporting of Complaints:** Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. Note: All documents supplied to participants must have the contact information for the Research Ethics Board.

- **Annual Renewal:** Prior to the expiration of your approval (which is one year from the date of the Chair's signature below), you will be reminded to submit your renewal form along with any new changes or amendments you wish to make to your study. If there have been no major changes to your protocol, your approval may be renewed for another year.

Yours sincerely,

[Signature]

Chair, Research Ethics Board

June 25, 2009

Study Code: MECH-040-09

Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete.
QUEEN’S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING
HOSPITALS RESEARCH ETHICS BOARD

The membership of this Research Ethics Board complies with the membership requirements for Research Ethics Boards as defined by the Tri-Council Policy Statement, Part C Division 5 of the Food and Drug Regulations, OHRP, and U.S DHHS Code of Federal Regulations Title 45, Part 46 and carries out its functions in a manner consistent with Good Clinical Practices.

Federalwide Assurance Number : #FWA0004184
#IRB0001173

Current 2009 membership of the Queen’s University Health Sciences
& Affiliated Teaching Hospitals Research Ethics Board

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Sciences, Queen’s University (Chair)

Dr. H. Abdollah Professor, Department of Medicine, Queen’s University

Dr. C. Cline Assistant Professor, Department of Medicine
Director, Office of Bioethics, Queen’s University
Clinical Ethicist, Kingston General Hospital

Rev. T. Deline Community Member

Dr. M. Evans Community Member

Dr. S. Irving Psychologist, Providence Care, St. Mary’s of the Lake Hospital Site

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Dr. A.N. Singh WHO Professor in Psychoactive Medicine and Psychopharmacology
Professor of Psychiatry and Pharmacology
Chair and Head, Division of Psychopharmacology, Queen’s University
Director & Chief of Psychiatry, Academic Unit, Quinte Health Care, Belleville General Hospital

Dr. E. Tsai Associate Professor, Department of Paediatrics and Office of Bioethics, Queen’s University

Rev. J. Warren Community Member

Ms. K. Weisbaum LL.B. and Adjunct Instructor, Department of Family Medicine (Bioethics)

Dr. S. Wood Director, Office of Research Services (Ex-Officio)
Appendix C: Form of Consent

1) Original version for pregnant subjects
2) Original version for non-pregnant subjects
3) English version for pregnant subjects
4) English version for non-pregnant subjects
Titre du Projet: Évaluation biomécanique et ergonomique des tâches physiques et quotidiennes des femmes enceintes du Bénin.

Information générale sur le projet :

Vous êtes invitée à participer à une étude qui évalue les mouvements du tronc des femmes enceintes et non-enceintes pendant les activités impliquant le port de charges sur la tête. Cette étude est co-dirigée par Dr. Mohamed Lawani de l’INJEPS et Dr. Geneviève Dumas de l’Université Queen’s au Canada. Erica Beaucage-Gauvreau, une étudiante à la maîtrise à l’Université de Queen’s, est aussi une autre chercheure sur le projet. Cette étude a été rendue possible grâce à la contribution financière de la Société Internationale de Biomécanique. Un des trois chercheurs de cette étude lira ce formulaire de consentement avec vous et décrira les détails des procédures tout en répondant à vos questions. Cette étude a été évaluée pour conformité aux règles d’éthiques par le comité d’éthique de recherche des sciences santé et des hôpitaux enseignants affiliés à l’Université de Queen’s et le comité d’éthique au Bénin.

Détails sur le projet :

1.0 But de l'étude

Le but de ce projet est de comparer les techniques de charges et décharges des poids portés sur la tête pour les femmes enceintes et non-enceintes du Bénin. Vous pouvez être concernée par ce projet si vous êtes active physiquement dans des tâches quotidiennes incluant le port de charges sur la tête.

2.0 Description des tests

Lors de la rencontre pour cette étude, des questionnaires comportant des questions sur vos activités quotidiennes et des douleurs physiques ressenties dans le passé devront être complétés. Après la complétion de ces questionnaires, deux inclinomètres seront fixés à votre tronc, à la hauteur du sacrum et du sternum, à l’aide de bandes ajustables. Subséquemment, vous serez filmée en train de charger et décharger sur votre tête une charge qui représente un poids typique de ceux que vous transporteriez durant vos activités quotidiennes. La durée de cette rencontre sera d’environ une heure.

3.0 Risques

Si vous ressentez des douleurs physiques anormales pendant ou après la durée des tests, veuillez informer Dr. Lawani afin de prendre des dispositions nécessaires.

4.0 Bénéfices

Bien que vous ne bénéficiez pas nécessairement directement de cette étude, les résultats des cette étude augmenteront les connaissances sur les douleurs corporelles.
potentiellement causées par les tâches physiques durant la grossesse et les femmes enceintes du Bénin pourront bénéficier des conclusions de l’étude dans le futur.

5.0 Exclusions

Vous ne serez pas considérée pour cette étude si vous souffrez de douleurs corporelles vous empêchant d’effectuer des tâches physiques ou si un membre du personnel médical vous a interdit d’exécuter des activités impliquant des charges lourdes.

6.0 Confidentialité

Toutes les informations obtenues pendant le cours de cette étude seront strictement confidentielles et votre anonymat sera protégé en tout temps. Vous serez identifiée à l’aide d’un code d’identification. Les données collectées pendant cette étude seront secrètes et accessibles seulement au Dr. Lawani, Dr. Dumas ou Erica Beaucage-Gauvreau, les trois chercheurs responsables de ce projet. Vous ne serez pas identifiée ou nommée dans aucune publication ou aucun rapport et vos photos ou films ne seront éventuellement publiés que si vous en donnez la permission et après avoir brouillé votre visage afin d’éviter votre identification.

7.0 Nature volontaire de l’étude/Liberté de se retirer ou de refuser d’y participer

Votre participation dans cette étude est strictement volontaire. Vous pouvez décider de vous en retirer en tout temps.

8.0 Retrait du sujet par les chercheurs

Les chercheurs de cette étude peuvent décider de vous retirer de cette étude pour des raisons de santé et de sécurité.

9.0 Responsabilités

Des soins médicaux appropriés seront fournis dans le cas de blessures ayant lieu pendant la séance de tests. Une trousse de premiers soins sera disponible en tout temps pour soigner les blessures mineures et les blessures plus sérieuses seront traitées à l’infirmérie située à proximité des lieux de tests.

10.0 Compensation

Vous recevrez une compensation monétaire couvrant les frais de vos déplacements pour vous rendre aux lieux des tests à l’INJEP ou clinique Déo Gratias et retourner à votre demeure.

Signature et déclaration du sujet

J’ai lu et compris le formulaire de consentement pour cette étude. Les buts, procédures, et termes techniques m’ont été expliqués clairement. Une période de temps suffisante
m’a été allouée afin de considérer les informations incluses ci-dessus et me permettre de demander conseil si besoin. J’ai eu l’opportunité de poser des questions auxquelles des réponses satisfaisantes m’ont été fournies. Je signe ce formulaire volontairement et je recevrai une copie de ce formulaire de consentement pour mon information personnelle.

Si j’ai d’autres questions ou dans le cas de problèmes ou réactions défavorables survenus à la suite des tests, je peux contacter en tout temps :

Dr. Lawani au 97440356 ou 90942144

Si j’ai des questions sur mes droits en tant que participante dans un projet de recherche, je peux contacter Dr. Falola Jean-Marie, Laboratoire APS et Motricité INJEPS (UAC) au 97.88.00.76.

En signant ce formulaire de consentement, j’indique que j’accepte de participer dans cette étude.

____________________________    ______________________
Signature du Sujet             Date

____________________________    ______________________
Signature d’un témoin             Date

Déclaration du Chercheur :

J’ai expliqué clairement à la participante la nature du projet de recherche décrit ci-dessus. Je certifie, au meilleur de mes capacités, que la participante comprend clairement la nature de ce projet de recherche ainsi que les bénéfices, exigences, et risques impliqués dans la participation de cette étude.

____________________________    ______________________
Signature du Chercheur             Date
**Titre du Projet:** Évaluation biomécanique et ergonomique des tâches physiques et quotidiennes des femmes enceintes du Bénin.

**Information générale sur le projet :**

Vous êtes invitée à participer à une étude qui évalue les mouvements du tronc des femmes enceintes pendant leurs tâches quotidiennes ainsi que pendant les activités impliquant le port de charges sur la tête. De plus, cette étude a pour but de construire une bande de données anthropométriques sur les femmes enceintes du Bénin. Cette étude est co-dirigée par Dr. Mohamed Lawani de l’INJEPS et Dr. Geneviève Dumas de l’Université Queen’s au Canada. Erica Beaucage-Gauvreau, une étudiante à la maîtrise à l’Université de Queen’s, est aussi une autre chercheure sur le projet. Cette étude a été rendue possible grâce à la contribution financière de la Société Internationale de Biomécanique. Un des trois chercheurs de cette étude lira ce formulaire de consentement avec vous et décrira les détails des procédures tout en répondant à vos questions. Cette étude a été évaluée pour conformité aux règles d’éthique par le comité d’éthique de recherche des sciences santé et des hôpitaux enseignants affiliés à l’Université de Queen’s et le comité d’éthique au Bénin.

**Détails sur le projet :**

1.0 **But de l’étude**

Le but de ce projet est de déterminer quelles activités physiques exposent les femmes enceintes à un plus grand risque de blessure. Les techniques de charges et décharges des poids portés sur la tête seront aussi évaluées pour identifier les mouvements pouvant causer des blessures. Vous pouvez être concernée par ce projet si vous êtes enceinte et que vous êtes active physiquement dans des tâches quotidiennes incluant le port de charges sur la tête.

2.0 **Description des tests**

Deux rencontres seront nécessaires pour votre participation à cette étude. Lors de la première rencontre, des questionnaires comportant des questions sur vos activités quotidiennes et les changements physiques ressentis durant la grossesse devront être complétés. Après la complétion de ces questionnaires, deux inclinomètres seront fixés à votre tronc, à la hauteur du sacrum et du sternum, à l’aide de bandes ajustables. Subséquemment, vous serez filmée en train de charger et décharger sur votre tête une charge qui représente un poids typique de ceux que vous transporterez durant vos activités quotidiennes. La durée de cette première rencontre sera d’environ une heure.

Lors de la deuxième rencontre, un seul inclinomètre sera fixé à votre sternum pour la durée d’une journée complète, soit approximativement huit heures. Cet inclinomètre sera retenu à l’aide de bandes ajustables autour de votre tronc. À la fin de la journée, après que l’inclinomètre ait été enlevé, une série de marqueurs autocollants seront appliqués sur votre peau afin de déterminer les délimitations des principaux membres du corps.
Ensuite, deux photos, une de face et une de côté, seront prises simultanément et seront ultérieurement numérisées. Des vêtements moulant les formes de votre corps seront nécessaires pour cette partie de l’étude afin de mieux définir les segments de votre corps. Cette seconde portion de la deuxième rencontre prendra environ une heure.

3.0 Risques

Si vous ressentez des douleurs physiques anormales pendant ou après la durée des tests, veuillez informer Dr. Lawani afin de prendre des dispositions nécessaires.

4.0 Bénéfices

Bien que vous ne bénéficiez pas nécessairement directement de cette étude, les résultats des cette étude augmenteront les connaissances sur les douleurs corporelles potentiellement causées par les tâches physiques durant la grossesse et d’autres femmes enceintes pourront bénéficier des conclusions de l’étude dans le futur.

5.0 Exclusions

Vous ne serez pas considérée pour cette étude si vous souffrez de douleurs corporelles vous empêchant d’effectuer des tâches physiques ou si un membre du personnel médical vous a interdit d’exécuter des activités impliquant des charges lourdes, ou si vous avez des risques de complications pendant la grossesse.

6.0 Confidentialité

Toutes les informations obtenues pendant le cours de cette étude seront strictement confidentielles et votre anonymat sera protégé en tout temps. Vous serez identifiée à l’aide d’un code d’identification. Les données collectées pendant cette étude seront secrètes et accessibles seulement au Dr. Lawani, Dr. Dumas ou Erica Beaucage-Gauvreau, les trois chercheurs responsables de ce projet. Vous ne serez pas identifiée ou nommée dans aucune publication ou aucun rapport et vos photos ou films ne seront éventuellement publiés que si vous en donnez la permission et après avoir brouillé votre visage afin d’éviter votre identification.

7.0 Nature volontaire de l’étude/Liberté de se retirer ou de refuser d’y participer

Votre participation dans cette étude est strictement volontaire. Vous pouvez décider de vous en retirer en tout temps et ce retrait n’affectera aucunement les soins reçus par votre sage femme ou les cours prénataux donnés par Dr. Lawani.

8.0 Retrait du sujet par les chercheurs

Les chercheurs de cette étude peuvent décider de vous retirer de cette étude pour des raisons de santé ayant des effets nuisibles pour vous ou pour le fœtus.
9.0 **Responsabilités**

Des soins médicaux appropriés seront fournis dans le cas de blessures ayant lieu pendant la séance de tests. Une trousse de premiers soins sera disponible en tout temps pour soigner les blessures mineures et les blessures plus sérieuses seront traitées à l’infirmérie située à proximité des lieux de tests.

10.0 **Compensation**

Vous recevrez une compensation monétaire couvrant les frais de vos déplacements pour vous rendre aux lieux des tests à l’INJEPS ou la clinique Déo Gratias et retourner à votre demeure.

**Signature et déclaration du sujet**

J’ai lu et compris le formulaire de consentement pour cette étude. Les buts, procédures, et termes techniques m’ont été expliqués clairement. Une période de temps suffisante m’a été allouée afin de considérer les informations incluses ci-dessus et me permettre de demander conseil si besoin. J’ai eu l’opportunité de poser des questions auxquelles des réponses satisfaisantes m’ont été fournies. Je signe ce formulaire volontairement et je recevrai une copie de ce formulaire de consentement pour mon information personnelle.

Si j’ai d’autres questions ou dans le cas de problèmes ou réactions défavorables survenus à la suite des tests, je peux contacter en tout temps :

Dr. Lawani au 97440356 ou 90942144

Si j’ai des questions sur mes droits en tant que participante dans un projet de recherche, je peux contacter Dr. Falola Jean-Marie, Laboratoire APS et Motricité INJEPS (UAC) au 97.88.00.76.

En signant ce formulaire de consentement, j’indique que j’accepte de participer dans cette étude.

____________________________  _____________________
Signature du Sujet  Date

____________________________  _____________________
Signature d’un témoin  Date
Déclaration du Chercheur :

J’ai expliqué clairement à la participante la nature du projet de recherche décrit ci-dessus. Je certifie, au meilleur de mes capacités, que la participante comprend clairement la nature de ce projet de recherche ainsi que les bénéfices, exigences, et risques impliqués dans la participation de cette étude.

______________________________  _______________________  
Signature du Chercheur  Date
Title of project: Biomechanical and ergonomic assessment of the daily physical tasks performed by pregnant women in Benin.

Background information:

You are being invited to participate in a research study to evaluate the trunk movements of pregnant and non-pregnant women during load carriage on their head. This study is co-directed by Dr. Mohamed Lawani from l’INJEPS in Benin and Dr. Dumas from Queen’s University in Canada. Erica Beaucage-Gauvreau, a Master’s candidate at Queen’s University, is also another investigator of this study. This study was made possible by the financial contribution of the International Society of Biomechanics. One of the three investigators will read through this consent form with you and describe the procedures in details and answer any questions you may have. This study has been reviewed for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board as well as the Ethics Board in Benin.

Details of the study:

1.0 Objective of the study

The purpose of this study is to compare the loading and unloading techniques for load carriage on the head for pregnant and non-pregnant women in Benin. You will be considered for the study if you are physically active in daily tasks that include load carriage on the head.

2.0 Description of tests to be performed as part of the study:

During the visit, you will be asked to fill out questionnaires including questions on your daily activities and physical pain felt in the past. After the completion of these questionnaires, two inclinometers will be attached to your trunk using adjustable straps. More precisely, these two inclinometers will be placed at the levels of the sternum and the sacrum. You will then be filmed loading and unloading on your head a load that represents a typical load carried during your daily activities. The duration of this visit will be approximately two hours.

3.0 Risks

If you feel abnormal physical pain during or after the tests, please inform Dr. Lawani so that the state of physical pain can be evaluated.

4.0 Benefits

While you may not benefit directly from this study, results from this study will improve the knowledge on physical pain caused by physical tasks performed during pregnancy and these findings may benefit pregnant women in the future.
5.0 Exclusions

You will not be considered for this study if you suffer from physical pain that restricts your movements during physical tasks or if a member of medical staff forbids you to perform physical tasks with heavy loads.

6.0 Confidentiality

All information obtained during the course of this study is strictly confidential and your anonymity will be protected at all times. You will be identified using a special identification code. Data will be stored in locked files and will be available only to Dr. Lawani, Dr. Dumas and Erica Beaucage-Gauvreau. You will not be identified in any publication or reports and your photographs or video tapes will only be used in publication if you have given permission after blurring of the face.

7.0 Voluntary nature of study/Freedom to withdraw or participate

Your participation in this study is voluntary. You may withdraw from this study at any time and your withdrawal will not affect any future medical care.

8.0 Withdrawal of subject by principal investigator

The study investigators may decide to withdraw you from this study for safety and health reasons.

9.0 Liability

In the event that you are injured as a result of the study procedures, medical care will be provided to you until resolution of the medical problem. Minor injuries will be treated with the first aid kit available at all times during testing while more serious injuries will be treated at the local clinic.

8.0 Payment

You will be reimbursed for your travel expenses to and from the INJEPS or Déo Gratias clinic.

SUBJECT STATEMENT AND SIGNATURE SECTION:

I have read and understand the consent form for this study. I have had the purposes, procedures and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I chose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.
If at any time I have further questions, problems or adverse events, I can contact Dr. Lawani at 97440356 or 90942144.

If I have questions regarding my rights as a research subject I can contact Dr. Falola Jean-Marie, Laboratoire APS et Motricité INJEPS (UAC) au 97.88.00.76.

By signing this consent form, I am indicating that I agree to participate in this study.

_______________________  ________________________
Signature of Patient     Date

_______________________  ________________________
Signature of Witness    Date

STATEMENT OF INVESTIGATOR:

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study and demands, benefits, and risks involved to participants in this study.

_______________________  ________________________
Signature of Principal Investigator    Date
Title of project: Biomechanical and ergonomic assessment of the daily physical tasks performed by pregnant women in Benin.

Background information:

You are being invited to participate in a research study to evaluate the trunk movements of pregnant women during their daily tasks as well as during load carriage on their head. Moreover, this study has for goal to collect anthropometric data for pregnant women in Benin. This study is co-directed by Dr. Mohamed Lawani from l’INJEP in Benin and Dr. Dumas from Queen’s University in Canada. Erica Beaucage-Gauvreau, a Master’s candidate at Queen’s University, is also another investigator of this study. This study was made possible by the financial contribution of the International Society of Biomechanics. One of the three investigators will read through this consent form with you and describe the procedures in details and answer any questions you may have. This study has been reviewed for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board as well as the Ethics Board in Benin.

Details of the study:

1.0 Objective of the study

The purpose of this study is to determine which physical activities expose pregnant women to a greater risk of injury. Loading and unloading techniques for load carriage on the head will also be evaluated to identify movements that may cause injuries. You will be considered for the study if you are pregnant and that you are physically active in daily tasks that include load carriage on the head.

2.0 Description of tests to be performed as part of the study:

Two meetings will be necessary to complete your participation in this study. During the initial visit, you will be asked to fill out questionnaires including questions on your daily activities and physical changes felt during pregnancy. After the completion of these questionnaires, two inclinometers will be attached to your trunk using adjustable straps. More precisely, these two inclinometers will be placed at the levels of the sternum and the sacrum. You will then be filmed loading and unloading on your head a load that represents a typical load carried during your daily activities. The duration of this first visit will be approximately two hours.

For the second visit, only one inclinometer will be fixed at the sternum level for the duration of a whole day, approximately eight hours. Once again, the inclinometer will be attached to your trunk using adjustable straps. At the end of the day, after the removal of the inclinometer, reflective tape markers will be placed on your skin at different joint centers to identify the limits of the main body segments. Two photographs, frontal and sagittal, will then be taken simultaneously for digitization of the photographs that will be performed later on. Form fitting clothing will be required for this part of the study to
allow for better definition of the body segments. This second portion of the second meeting for the study will last approximately one hour.

3.0 Risks

If you feel abnormal physical pain during or after the tests, please inform Dr. Lawani so that the state of physical pain can be evaluated.

4.0 Benefits

While you may not benefit directly from this study, results from this study will improve the knowledge on physical pain caused by physical tasks performed during pregnancy and these findings may benefit other pregnant women in the future.

5.0 Exclusions

You will not be considered for this study if you suffer from physical pain that restricts your movements during physical tasks or if a member of medical staff forbids you to perform physical tasks with heavy loads, or if you suffer from any risk of pregnancy complication.

6.0 Confidentiality

All information obtained during the course of this study is strictly confidential and your anonymity will be protected at all times. You will be identified using a special identification code. Data will be stored in locked files and will be available only to Dr. Lawani, Dr. Dumas and Erica Beaucage-Gauvreau. You will not be identified in any publication or reports and your photographs or video tapes will only be used in publication if you have given permission after blurring of the face.

7.0 Voluntary nature of study/Freedom to withdraw or participate

Your participation in this study is voluntary. You may withdraw from this study at any time and your withdrawal will not affect your future medical care with your midwife or the prenatal classes taught by Dr. Lawani.

8.0 Withdrawal of subject by principal investigator

The study investigators may decide to withdraw you from this study for safety and health reasons for you and the fetus.

9.0 Liability

In the event that you are injured as a result of the study procedures, medical care will be provided to you until resolution of the medical problem. Minor injuries will be treated with the first aid kid available at all times during testing while more serious injuries will be treated at the local clinic.
10.0 Payment

You will be reimbursed for your travel expenses to and from the INJEPS or Déo Gratias clinic.

SUBJECT STATEMENT AND SIGNATURE SECTION:

I have read and understand the consent form for this study. I have had the purposes, procedures and technical language of this study explained to me. I have been given sufficient time to consider the above information and to seek advice if I chose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form. I will receive a copy of this consent form for my information.

If at any time I have further questions, problems or adverse events, I can contact

Dr. Lawani at 97440356 or 90942144

If I have questions regarding my rights as a research subject I can contact Dr. Falola Jean-Marie, Laboratoire APS et Motricité INJEPS (UAC) au 97.88.00.76.

By signing this consent form, I am indicating that I agree to participate in this study.

_______________________  ______________________
Signature of Patient       Date

_______________________  ______________________
Signature of Witness       Date

STATEMENT OF INVESTIGATOR:

I, or one of my colleagues, have carefully explained to the subject the nature of the above research study. I certify that, to the best of my knowledge, the subject understands
clearly the nature of the study and demands, benefits, and risks involved to participants in this study.

______________________________  __________________
Signature of Principal Investigator  Date
Appendix D: Original version of the three questionnaires

1) Demographic Questionnaire for pregnant subjects
2) Demographic Questionnaire for non-pregnant subjects
3) Oswestry Questionnaire for pregnant subjects
4) Oswestry Questionnaire for non-pregnant subjects
5) Pain drawing for both the pregnant and non-pregnant subjects
QUESTIONNAIRE DEMOGRAPHIE-P

COMMENTAIRES :

Les passages entre parenthèses en italique ne devraient être pris en considération que par l’examinateur. Leur but est d’obtenir des données relativement précises, par exemple si l’âge précis n’est pas connu par la sujette il est préférable de lui demander dans quelle classe d’âge elle se situerait.

En ce qui concerne la taille et le poids il est impératif de les mesurer car ils seront très importants pour la vérification de la numérisation des clichés pris lors des mesures anthropométriques avec la méthode de Jensen.

De manière générale, si des choix venaient à manquer dans les questions à choix multiples ou si les sujettes ne se reconnaissaient pas dans les réponses fournies, merci de collecter leurs remarques afin que l’on puisse analyser ces commentaires et enrichir le questionnaire.

INSTRUCTIONS :

Cette étude fait partie du projet de recherche sur l’évaluation biomécanique et ergonomique des tâches physiques et quotidiennes des femmes enceintes du Bénin, conduit à l’INJEPS.

Les informations que vous allez fournir vont être codées numériquement et entrées dans un ordinateur dans le but d’effectuer leur analyse. Afin de garantir l’exploitation de ces données, merci de ne valider qu’une seule réponse par question, à moins d’être spécifiquement invitée à faire autrement.
RESUME DES INSTRUCTIONS :

Ne cochez qu’une seule réponse, sauf si vous êtes invitée à en cocher plusieurs.

Répondez à toutes les questions de la meilleure manière possible.

Toutes les informations recueillies dans ce questionnaire sont strictement confidentielles.

Si vous décidez de ne pas répondre à ce questionnaire, veuillez en indiquer la raison au bas de cette page et nous le retourner.

Si vous avez des interrogations par rapport à cette étude, n’hésitez pas à nous en faire part:

Dr. Mohamed Lawani au 97440356 ou au 90942144

Merci de votre participation
INFORMATIONS DEMOGRAPHIQUES

1.1 Âge (remplacer peut-être par des tranches d’âge, si doutes sur la date de naissance)

1.2 Taille (à mesurer)

1.3 Poids avant la grossesse (si la sujette le connaît)

1.4 Poids actuel (à mesurer)

1.5 Nombre de grossesses (excluant la présente grossesse) :

1.6 Nombre de grossesses menées à terme :

1.7 Age de vos enfants :

1.8 Date des dernières menstruations : ________ Semaine de grossesse : ________
   (éventuellement déterminé d’après échographie ou palpation, si la sujette ne se souvient pas ou n’est pas sure).

1.9 Niveau scolaire (n’entourer qu’une seule réponse)
   a. Non scolarisée
   b. Éducation scolaire sans complétion du primaire
   c. alphabétisation
   d. Primaire
   e. Collège
   f. Lycée (sans diplôme)
   g. Baccalauréat
   h. Niveau licence (sans diplôme)
   i. Licence
   j. Niveau maîtrise (sans diplôme)
   k. Maîtrise
   l. Doctorat

1.10 De quelle main écrivez-vous ?
   a. Gauche
   b. Droite
   c. Les deux

1.11 Origine ethnique :
   a. Fon
   b. Adja
   c. Yoruba
1.12 Laquelle des phrases suivantes décrit le mieux votre expérience avec le tabac
   a. Je n’ai jamais pris de tabac
   b. Je prends du tabac occasionnellement
   c. Je prends du tabac régulièrement

1.13 Etes-vous ?
   a. Employée
   b. Votre propre employeur
   c. Etudiante
   d. Femme au foyer

1.14 Si vous avez répondu « employée » ou « votre propre employeur », veuillez établir la liste des emplois que vous avez occupé depuis le début de cette grossesse :

<table>
<thead>
<tr>
<th>Intitulé de l’emploi</th>
<th>Employeur</th>
<th>Date de début</th>
<th>Date de fin</th>
<th>Nombre d’heures par semaine</th>
<th>Travail en équipe/horaire décalé (O/N)</th>
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1.15 Avec combien de personnes vivez-vous : ____________

1.16 Nombre d’enfants vivant avec vous (indiquer l’âge) :
   _______ _______ _______ _______ _______ _______

1.17 Vous occupez-vous d’un enfant de moins de deux ans de façon régulière sinon constante ?
   a. Oui
   b. Non

1.18 Si oui, le portez-vous sur le dos et combien d’heures par jour environ ?
   ___________

1.19 Statut marital
   a. Célibataire
   b. Vivant avec quelqu’un (maritalement)
   c. Mariée (monogame)
   d. Mariée(polygame)
e. Divorcée
f. Veuve

1.20 Veuillez indiquer dans laquelle de ces fourchettes se situe votre revenu familial mensuel (incluant toutes les sources de revenu) :

a. 15.000 francs et moins
b. entre 15.001 francs et 30.000
c. entre 30.001 et 50.000 francs
d. plus de 50.001 francs

1.21 Combien de personnes de votre foyer ont un revenu : ______

1.22 Votre religion :
a. Religion traditionnelle
b. Chrétienne
c. Musulmane
d. Autre : _____________

TACHES DOMESTIQUES, TRAVAIL ET ACTIVITE PHYSIQUE

Indiquez toutes les tâches domestiques que vous avez effectuées pendant la dernière semaine. Répondez à toutes les questions (répondez « 0 » si vous ne faites pas cette activité)

<table>
<thead>
<tr>
<th>Activité</th>
<th>Nombre de fois par semaine</th>
<th>Durée moyenne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allaiter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porter un enfant</td>
<td></td>
<td></td>
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<tr>
<td>Faire la cuisine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piler</td>
<td>Le mil/le maïs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L’igname</td>
<td></td>
</tr>
<tr>
<td>Sécher les aliments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moudre</td>
<td>Les condiments</td>
<td></td>
</tr>
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<td></td>
<td>Les céréales</td>
<td></td>
</tr>
<tr>
<td>Faire les courses/aller au marché</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cueillir</td>
<td>Les fruits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Les légumes</td>
<td></td>
</tr>
<tr>
<td>Laver la vaisselle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nettoyer</td>
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<td></td>
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<tr>
<td>Faire la lessive</td>
<td>Debout</td>
<td></td>
</tr>
<tr>
<td></td>
<td>À genoux</td>
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</tr>
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<td></td>
<td>Assise</td>
<td></td>
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<tr>
<td>Faire les lits</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

185
Donner des soins personnels à un enfant ou à un adulte handicapé (*habiller, faire manger, changer, laver, etc.*)

Raccommodage de vêtements
Jardinage
Entretien extérieur de la maison
Aller chercher du bois
Aller chercher de l’eau
Aller aux champs

Faire de l’élevage  
- De bovins
- D’ovins
- De caprins
- De volailles

Autre, spécifier

---

**QUESTIONS SUR LE PORT DE CHARGES**

1.23 Combien de fois par jour en moyenne levez-vous une charge à porter sur la tête ? ________________________________

1.24 Pour quelle durée moyenne, en heures et/ou minutes, portez-vous une charge sur la tête par journée ? ________________________________

1.25 Y-a-t-il une variation de la durée moyenne du port de la charge pour les différentes journées de la semaine ?
   a. Oui
   b. Non

1.26 Si oui, précisez (incluant le maximum et minimum):

   ________________________________

1.27 Est-ce que le port de la charge est plus difficile pendant la grossesse ?
   a. Oui
   b. Non

1.28 Est-ce que le soulèvement de la charge est plus difficile pendant la grossesse ?
   a. Oui
   b. Non

1.29 Est-ce que le dépôt de la charge est plus difficile pendant la grossesse ?
   a. Oui
1.30 Si oui, est-ce à cause
   a. Du ventre
   b. De douleurs physiques au dos
   c. D’autres douleurs physiques,
      précisez :______________________________________
   d. Autres :___________________________________________________________

1.31 Avant la grossesse, leviez-vous la charge ?
   a. Individuellement
   b. En équipe

1.32 Depuis la grossesse, levez-vous la charge ?
   a. Individuellement
   b. En équipe

1.33 Êtes-vous une marchante
   a. Ambulante
   b. Fixe

1.34 Quel est le poids typique que vous transportez ?
   a. 0-5 kg
   b. 5.1-10 kg
   c. 10.1-15 kg
   d. 15.1-20 kg
   e. Plus de 20 kg

1.35 Est-ce que les charges que vous transportez varient pendant la semaine ?
   a. Oui
   b. Non

1.36 Si oui, précisez la variation (incluant la charge maximale et minimale) :
   _________________________________________________________________

1.37 Quelle est la nature de la charge que vous transportez ?
   a. Fruits et légumes
   b. Poissons et viandes
   c. Textiles et bijoux
   d. Conserves et produits manufacturés
   e. Pétrole et huile
   f. Eau (seau et bassine)
   g. Autres :__________________________________________________________
1.38 Avant la grossesse, combien d’arrêts volontaires quotidiens incluant une décharge afin de vous reposez comptez-vous ?
   a. Moins de 5 arrêts
   b. 6 à 10 arrêts
   c. Plus de 10 arrêts

1.39 Pendant la grossesse, combien d’arrêts volontaires quotidiens incluant une décharge afin de vous reposez comptez-vous ?
   a. Moins de 5 arrêts
   b. 6 à 10 arrêts
   c. Plus de 10 arrêts
QUESTIONS SUR LA GROSSESSE ET LES DOULEURS PHYSIQUES

1.40 Avez-vous réduit vos activités physiques depuis le début de votre grossesse ?
   a. Oui
   b. Non

1.41 Si oui,
   précisez pourquoi:____________________________________________________
   Et comment :__________________________________________________________

1.42 Suivez-vous des cours de gymnastique prénatale ?
   a. Oui
   b. Non

1.43 Nommez dix (10) activités physiques ou tâches, que vous trouvez plus difficiles à exécuter depuis le début de votre grossesse. Coter la difficulté de ces tâches à l’aide la réglette. Inclure le port de charge sur la tête pour comparaison.

<table>
<thead>
<tr>
<th>Activités</th>
<th>Cote de difficulté</th>
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<tbody>
<tr>
<td>1._____________________________________</td>
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<td>10.___________________________________</td>
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COMMENTAIRES :

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En ce qui concerne la taille et le poids il est impératif de les mesurer car ils seront très importants pour la vérification de la numérisation des clichés pris lors des mesures anthropométriques avec la méthode de Jensen.

De manière générale, si des choix venaient à manquer dans les questions à choix multiples ou si les sujettes ne se reconnaissaient pas dans les réponses fournies, merci de collecter leurs remarques afin que l’on puisse analyser ces commentaires et enrichir le questionnaire.

INSTRUCTIONS :

Cette étude fait partie du projet de recherche sur l’évaluation biomécanique et ergonomique des tâches physiques et quotidiennes des femmes enceintes du Bénin, conduit à l’INJEPS.

Les informations que vous allez fournir vont être codées numériquement et entrées dans un ordinateur dans le but d’effectuer leur analyse. Afin de garantir l’exploitation de ces données, merci de ne valider qu’une seule réponse par question, à moins d’être spécifiquement invitée à faire autrement.
RESUME DES INSTRUCTIONS :

Ne cochez qu’une seule réponse, sauf si vous êtes invitée à en cocher plusieurs.

Répondez à toutes les questions de la meilleure manière possible.

Toutes les informations recueillies dans ce questionnaire sont strictement confidentielles.

Si vous décidez de ne pas répondre à ce questionnaire, veuillez en indiquer la raison au bas de cette page et nous le retourner.

Si vous avez des interrogations par rapport à cette étude, n’hésitez pas à nous en faire part:

Dr. Mohamed Lawani au 97440356 ou au 90942144

Merci de votre participation
INFORMATIONS DEMOGRAPHIQUES

1.1 Age (remplacer peut-être par des tranches d’âge, si doutes sur la date de naissance)

1.2 Taille (à mesurer)

1.3 Poids actuel (à mesurer)

1.4 Nombre de grossesses:

1.5 Nombre de grossesses menées à terme :

1.6 Age de vos enfants :
   1 _____  2 _____  3 _____  4 _____  5 _____  6 ____

1.7 Niveau scolaire (n’entourer qu’une seule réponse)
   a. Non scolarisée
   b. Éducation scolaire sans complétion du primaire
   c. alphabétisation
   d. Primaire
   e. Collège
   f. Lycée (sans diplôme)
   g. Baccalauréat
   h. Niveau licence (sans diplôme)
   i. Licence
   j. Niveau maîtrise (sans diplôme)
   k. Maîtrise
   l. Doctorat

1.8 De quelle main écrivez-vous ?
   a. Gauche
   b. Droite
   c. Les deux

1.9 Origine ethnique :
   a. Fon
   b. Adja
   c. Yoruba
   d. Bariba
   e. Goun
   f. Dindi
   g. Autre : ____________
1.10 Laquelle des phrases suivantes décrit le mieux votre expérience avec le tabac
   a. Je n’ai jamais pris de tabac
   b. Je prends du tabac occasionnellement
   c. Je prends du tabac régulièrement

1.11 Etes-vous ?
   a. Employée
   b. Votre propre employeur
   c. Etudiante
   d. Femme au foyer

1.12 Si vous avez répondu « employée » ou « votre propre employeur », veuillez établir la liste des emplois que vous avez occupé dans les six derniers mois:

<table>
<thead>
<tr>
<th>Intitulé de l’emploi</th>
<th>Employeur</th>
<th>Date de début</th>
<th>Date de fin</th>
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</table>

1.13 Avec combien de personnes vivez-vous : ____________

1.14 Nombre d’enfants vivant avec vous (indiquer l’âge) :
   _______ _______ _______ _______ _______ _______ _______

1.15 Vous occupez-vous d’un enfant de moins de deux ans de façon régulière sinon constante ?
   a. Oui
   b. Non

1.16 Si oui, le portez-vous sur le dos et combien d’heures par jour environ ?
   __________

1.17 Statut marital
   a. Célibataire
   b. Vivant avec quelqu’un (maritalement)
   c. Mariée (monogame)
   d. Mariée(polygame)
   e. Divorcée
   f. Veuve

1.18 Veuillez indiquer dans laquelle de ces fourchettes se situe votre revenu familial mensuel (incluant toutes les sources de revenu) :
   a. 15.000 francs et moins
b. entre 15.001 francs et 30.000

- entre 30.001 et 50.000 francs
- plus de 50.001 francs

1.19 Combien de personnes de votre foyer ont un revenu : _____

1.20 Votre religion :
- Religion traditionnelle
- Chrétienne
- Musulmane
- Autre : ____________

**TACHES DOMESTIQUES, TRAVAIL ET ACTIVITE PHYSIQUE**

Indiquez toutes les tâches domestiques que vous avez effectuées pendant la dernière semaine. Répondez à toutes les questions (répondez « 0 » si vous ne faites pas cette activité).

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<thead>
<tr>
<th>Activité</th>
<th>Nombre de fois par semaine</th>
<th>Durée moyenne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allaiter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porter un enfant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faire la cuisine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piler</td>
<td>Le mil/le maïs</td>
<td></td>
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<tr>
<td></td>
<td>L’igname</td>
<td></td>
</tr>
<tr>
<td>Sécher les aliments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moudre</td>
<td>Les condiments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Les céréales</td>
<td></td>
</tr>
<tr>
<td>Faire les courses/aller au marché</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cueillir</td>
<td>Les fruits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Les légumes</td>
<td></td>
</tr>
<tr>
<td>Laver la vaisselle</td>
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<td></td>
</tr>
<tr>
<td>Nettoyer</td>
<td></td>
<td></td>
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<tr>
<td>faire la lessive</td>
<td>Debout</td>
<td></td>
</tr>
<tr>
<td></td>
<td>À genoux</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assise</td>
<td></td>
</tr>
<tr>
<td>faire les lits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Donner des soins personnels à un enfant ou à un adulte handicapé (<em>habiller, faire manger, changer, laver, etc.</em>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raccommodage de vêtements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jardinage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entretien extérieur de la maison</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### QUESTIONS SUR LE PORT DE CHARGES

1.21 Combien de fois par jour en moyenne levez-vous une charge à porter sur la tête ? __________________________

1.22 Pour quelle durée moyenne, en heures et/ou minutes, portez-vous une charge sur la tête par journée ? __________________________

1.23 Y-a-t-il une variation de la durée moyenne du port de la charge pour les différentes journées de la semaine ?
   a. Oui
   b. Non

1.24 Si oui, précisez (incluant le maximum et minimum):
   ____________________________________________

1.25 Levez-vous la charge ?
   a. Individuellement
   b. En équipe

1.26 Êtes-vous une marchante ?
   a. Ambulante
   b. Fixe

1.27 Quel est le poids typique que vous transportez ?
   a. 0-5 kg
   b. 5.1-10 kg
   c. 10.1-15 kg
   d. 15.1-20 kg
   e. Plus de 20 kg
1.28 Est-ce que les charges que vous transportez varient pendant la semaine ?
   a. Oui
   b. Non

1.29 Si oui, précisez la variation (incluant la charge maximale et minimale) :

1.30 Quelle est la nature de la charge que vous transportez ?
   a. Fruits et légumes
   b. Poissons et viandes
   c. Textiles et bijoux
   d. Conserves et produits manufacturés
   e. Pétrole et huile
   f. Eau (seau et bassine)
   g. Autres :_____________________________________________

1.31 Combien d’arrêts volontaires quotidiens incluant une décharge afin de vous reposez comptez-vous ?
   a. Moins de 5 arrêts
   b. 6 à 10 arrêts
   c. Plus de 10 arrêts
Questionnaire Oswestry Version 2.0 - P

(Oswestry Disability Index 2.0)

Veuillez répondre à chacune des sections suivantes. Dans chaque section, n’encerclez que la réponse qui décrit le mieux votre pire épisode de mal de dos depuis le début de cette grossesse. Nous avons conscience que vous pouvez penser que deux affirmations d’une même section convenaient à votre situation, mais veuillez tout de même sélectionner celle qui décrivait le mieux votre situation. Merci de répondre du mieux que vous pouvez, en tenant seulement compte des conséquences de la douleur.

Section 1 – Intensité de la douleur
☐ Je n’ai pas souffert
☐ La douleur était très peu intense lors de mon épisode de maux de dos.
☐ La douleur était modérée lors de mon épisode de maux de dos.
☐ La douleur était assez sévère lors de mon épisode de maux de dos.
☐ La douleur était très sévère lors de mon épisode de maux de dos.
☐ La douleur était la pire imaginable lors de mon épisode de maux de dos.

Section 2 – Soins personnels (se laver, s’habiller, etc.)
☐ Je pouvais m’occuper de moi-même normalement et sans que cela ne fasse empirer la douleur.
☐ Je pouvais m’occuper de moi-même normalement mais cela était très douloureux.
☐ M’occuper de moi-même était douloureux et je le faisais lentement et avec précautions.
☐ J’ai eu besoin d’aide, mais je pouvais presque tout faire moi-même.
☐ J’avais besoin d’aide quotidiennement pour la plupart de mes soins personnels.
☐ Je ne pouvais pas m’habiller, je me lavais avec difficultés et je restais au lit.

Section 3 – Levage
☐ Je pouvais lever des poids importants sans douleurs supplémentaires.
☐ Je pouvais lever des poids importants mais cela augmentait la douleur.
☐ La douleur m’empêchait de lever des poids importants à partir du sol, mais je pouvais les transporter s’ils étaient correctement positionnés ou s’ils m’étaient remis.
☐ La douleur m’empêchait de lever des poids importants à partir du sol, mais je pouvais transporter des charges légères ou modérées si elles étaient correctement positionnées.
☐ Je ne pouvais lever que des charges légères.
☐ Je ne pouvais transporter ou lever aucune charge.

Section 4 – Marche
☐ La douleur ne réduisait pas mon périmètre de marche.
☐ La douleur m’empêchait de marcher plus d’un mile (≈ 1,6 km).
☐ La douleur m’empêchait de marcher plus d’un demi mile (≈ 800 m).
☐ La douleur m’empêchait de marcher plus de 100 mètres.
☐ Je ne marchais qu’à l’aide d’une canne, de béquilles, ou d’une autre personne.
☐ Je passais la plupart de mon temps au lit et devait ramper jusqu’aux toilettes.
Section 5 – Position assise
□ Je pouvais m’asseoir dans n’importe quel fauteuil/chaise/tabouret aussi longtemps que je le souhaitais.
□ Je pouvais m’asseoir dans mon fauteuil/chaise/tabouret favori aussi longtemps que je le souhaitais.
□ La douleur m’empêchait de rester assise plus d’une heure.
□ La douleur m’empêchait de rester assise plus d’une demi-heure.
□ La douleur m’empêchait de rester assise plus de 10 minutes.
□ La douleur m’empêchait complètement de m’asseoir.

Section 6 – Position assise par terre
□ Je pouvais m’asseoir par terre aussi longtemps que je le souhaitais.
□ Je pouvais m’asseoir par terre sur une natte aussi longtemps que je le souhaitais.
□ La douleur m’empêchait de rester assise plus d’une heure.
□ La douleur m’empêchait de rester assise plus d’une demi-heure.
□ La douleur m’empêchait de rester assise plus de 10 minutes.
□ La douleur m’empêchait complètement de m’asseoir.

Section 7 – Position debout
□ Je pouvais me tenir debout aussi longtemps que je le voulais sans causer de douleurs supplémentaires.
□ Je pouvais me tenir debout aussi longtemps que je le voulais mais cela provoquait des douleurs.
□ La douleur m’empêchait de me tenir debout plus d’une heure.
□ La douleur m’empêchait de me tenir debout plus d’une demi-heure.
□ La douleur m’empêchait de me tenir debout plus de 10 minutes.
□ La douleur m’empêchait totalement de me tenir debout.

Section 8 - Sommeil
□ Mon sommeil n’était pas perturbé par la douleur.
□ Mon sommeil était occasionnellement perturbé par la douleur.
□ À cause de la douleur je dormais moins de 6 heures.
□ À cause de la douleur je dormais moins de 4 heures.
□ À cause de la douleur je dormais moins de 2 heures.
□ La douleur m’empêchait totalement de dormir.

Section 9 – Vie sociale
□ Ma vie sociale était normale et ne provoquait pas de douleur supplémentaire.
□ Ma vie sociale était normale mais augmentait l’intensité de la douleur.
□ La douleur n’avait pas d’effet significatif sur ma vie sociale mis à part qu’elle limitait mes activités les plus intenses.
□ La douleur restreignait ma vie sociale et je ne sortais plus aussi souvent.
□ La douleur limitait ma vie sociale à celle que j’avais dans mon foyer.
□ Je n’avais plus de vie sociale à cause de la douleur.
Section 10 - Déplacements

□ Je pouvais voyager partout sans douleurs.
□ Je pouvais voyager partout mais cela provoquait des douleurs supplémentaires.
□ La douleur était importante mais j’arrivais à voyager pendant plus de 2 heures.
□ La douleur limitait mes déplacements à ceux nécessitant moins d’une heure de voyage.
□ La douleur limitait mes déplacements à ceux qui étaient nécessaires et qui duraient moins de 30 minutes.
□ La douleur m’empêchait de me déplacer de chez moi sauf pour recevoir des soins.
Questionnaire Oswestry Version 2.0 -NP
(Oswestry Disability Index 2.0)

Veuillez répondre à chacune des sections suivantes. Dans chaque section, n’encerclez que la réponse qui décrit le mieux votre pire épisode de mal de dos dans les six derniers mois. Nous avons conscience que vous pouvez penser que deux affirmations d’une même section convenaient à votre situation, mais veuillez tout de même sélectionner celle qui décrivait le mieux votre situation. Merci de répondre du mieux que vous pouvez, en tenant seulement compte des conséquences de la douleur.

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☐ À cause de la douleur je dormais moins de 2 heures.
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☐ Ma vie sociale était normale et ne provoquait pas de douleur supplémentaire.
☐ Ma vie sociale était normale mais augmentait l’intensité de la douleur.
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☐ La douleur limitait mes déplacements à ceux qui étaient nécessaires et qui duraient moins de 30 minutes.
☐ La douleur m’empêchait de me déplacer de chez moi sauf pour recevoir des soins.
CARTE DE DOULEUR

Veuillez indiquer à l’aide de la réglette les sites et l’intensité de l’inconfort que vous avez ressenti lors du soulèvement, dépôt et port de la charge dans les cases indiquées. Utilisez la réglette pour obtenir l’intensité de l’inconfort pour chaque zone dans laquelle vous avez ressenti de l’inconfort. Vous pouvez utiliser autant de zones que nécessaire.

Poids de la charge soulevée : ___________________________ kg
Appendix E: Raw data for trunk postures and postures of the head relative to the trunk
Flexion-Extension trunk angles for the VC at C7 for pregnant subjects

Figure A.1. Flexion-Extension trunk angles during walking for the VC at C7 for pregnant subjects.
Flexion-Extension trunk angles for the VC at C7 for pregnant subjects

Subject 7-p

Subject 8-p

Subject 9-p

Subject 10-p

Subject 11-p

Subject 12-p

Mean-No Load
Mean-Load
Walking Angles-No Load
Walking Angles-Load
Flexion-Extension trunk angles for the VC at C7 for pregnant subjects

subject 13-p

subject 14-p

subject 15-p

subject 16-p

subject 17-p

subject 18-p

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension trunk angles for the VC at C7 for pregnant subjects

subject 19-p

subject 20-p

subject 21-p

subject 22-p

subject 23-p

subject 24-p

Percentage of walking portion of trial (%)

Angles (°)

Mean-No Load

Mean-Load

Walking Angles-No Load

Walking Angles-Load
Flexion-Extension trunk angles for the VC at C7 for pregnant subjects

subject 25-p

subject 26-p

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension trunk angles for the VC at C7 for non-pregnant subjects

Figure A.2. Flexion-Extension trunk angles during walking for the VC at C7 for non-pregnant subjects
Flexion-Extension trunk angles for the VC at C7 for non-pregnant subjects

(subject 7-np)

(subject 8-np)

(subject 9-np)

(subject 10-np)

(subject 11-np)

(subject 12-np)

---

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension trunk angles for the VC at C7 for non-pregnant subjects

- Subject 13-np
- Subject 14-np
- Subject 15-np
- Subject 16-np
- Subject 17-np
- Subject 18-np

Graphs showing the percentage of walking portion of trial (%) against angles (°) for each subject under different conditions.
Flexion-Extension trunk angles for the VC at C7 for non-pregnant subjects

subject 19-np

Angles (°)

Percentage of walking portion of trial (%)

subject 20-np

Angles (°)

Percentage of walking portion of trial (%)

subject 21-np

Angles (°)

Percentage of walking portion of trial (%)

subject 22-np

Angles (°)

Percentage of walking portion of trial (%)

subject 23-np

Angles (°)

Percentage of walking portion of trial (%)

subject 24-np

Angles (°)

Percentage of walking portion of trial (%)

---

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension trunk angles for the VC at C7 for non-pregnant subjects

Subject 25-np

Percentage of walking portion of trial (%)

Angles (°)

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Lateral bending trunk angles for the VC at C7 for pregnant subjects

Figure A.3. Lateral bending trunk angles during for walking for the VC at C7 for pregnant subjects.
Lateral bending trunk angles for the VC at C7 for pregnant subjects

Subject 7-p

Subject 8-p

Subject 9-p

Subject 10-p

Subject 11-p

Subject 12-p
Lateral Bending trunk angles for the VC at C7 for pregnant subjects

subject 13-p

subject 14-p

subject 15-p

subject 16-p

subject 17-p

subject 18-p

Percentage of walking portion of trial (%)

Angles (°)

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Lateral Bending trunk angles for the VC at C7 for pregnant subjects

Subject 19-p

Subject 20-p

Subject 21-p

Subject 22-p

Subject 23-p

Subject 24-p

Mean-No Load, Mean-Load, Walking Angles-No Load, Walking Angles-Load
Lateral Bending trunk angles for the VC at C7 for pregnant subjects

subject 25-p

subject 26-p

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Lateral Bending trunk angles for the VC at C7 for non-pregnant subjects

Figure A.4. Lateral Bending trunk angles during walking for the VC at C7 for non-pregnant subjects.
Lateral Bending trunk angles for the VC at C7 for non-pregnant subjects

Subject 7-np

Subject 8-np

Subject 9-np

Subject 10-np

Subject 11-np

Subject 12-np

Mean-No Load  mean-load  Walking Angles-No Load  Walking Angles-Load
Lateral Bending trunk angles for the VC at C7 for non-pregnant subjects
Lateral Bending trunk angles for the VC at C7 for non-pregnant subjects

subject 19-np

subject 20-np

subject 21-np

subject 22-np

subject 23-np

subject 24-np

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Lateral Bending trunk angles for the VC at C7 for non-pregnant subjects

subject 25-nc

Percentage of walking portion of trial (%)

Angles (°)

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Figure A.5. Flexion-Extension trunk angles during walking for the VC at S1 for pregnant subjects.
Flexion-Extension trunk angles for the VC at S1 for pregnant subjects

Subject 8-p

Subject 10-p

Subject 11-p

Subject 12-p

Subject 13-p

Subject 14-p

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension trunk angles for the VC at S1 for pregnant subjects

subject 15-p

subject 16-p

subject 17-p

subject 18-p

subject 19-p

subject 20-p

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension trunk angles for the VC at S1 for pregnant subjects

- Subject 21-p
- Subject 22-p
- Subject 23-p
- Subject 24-p
- Subject 25-p
Flexion-Extension trunk angles for the VC at S1 for non-pregnant subjects

Figure A.6. Flexion-Extension trunk angles during walking for the VC at S1 for non-pregnant subjects.
Flexion-Extension trunk angles for the VC at S1 non-pregnant subjects

(subjects 7 to 13)
Flexion-Extension trunk angles for the VC at S1 non-pregnant subjects

subject 14-np

subject 15-np

subject 16-np

subject 18-np

subject 19-np

subject 20-np

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension trunk angles for the VC at S1 non-pregnant subjects
Lateral Bending trunk angles for the VC at S1 for pregnant subjects

Figure A.7. Lateral Bending trunk angles during walking for the VC at S1 for pregnant subjects.
Lateral Bending trunk angles for the VC at S1 for pregnant subjects

subject 8-p

subject 10-p

subject 11-p

subject 12-p

subject 13-p

subject 14-p

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Lateral Bending trunk angles for the VC at S1 for pregnant subjects

subject 15-p

subject 16-p

subject 17-p

subject 17-p

subject 19-p

subject 20-p

---

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Lateral Bending trunk angles for the VC at S1 for pregnant subjects

subject 21-p

subject 22-p

subject 23-p

subject 24-p

subject 25-p

Mean-No Load  ——— Mean-Load  ——— Walking Angles-No Load  ——— Walking Angles-Load
Figure A.8. Lateral Bending trunk angles during walking for the VC at S1 for non-pregnant subjects
Lateral Bending trunk angles for the VC at S1 for non-pregnant subjects

subject 7-np

subject 8-np

subject 9-np

subject 10-np

subject 12-np

subject 13-np

Mean-No Load    Mean-Load    Walking Angles-No Load    Walking Angles-Load
Lateral Bending trunk angles for the VC at S1 for non-pregnant subjects

- Subject 14-np
- Subject 15-np
- Subject 16-np
- Subject 17-np
- Subject 18-np
- Subject 19-np
- Subject 20-np

Diagram showing the percentage of walking portion of trial (%).
Lateral Bending

trunk angles for the VC at S1 for non-pregnant subjects

subject 22-np

subject 23-np

subject 24-np

subject 25-np

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension Trunk Angles at C7 for the three loaded trials for pregnant subjects

Figure A.9. Flexion-Extension Trunk Angles at C7 for the three loaded trials for pregnant subjects
Flexion-Extension Trunk Angles at C7 for the three loaded trials for pregnant subjects

subject 7-p

subject 8-p

subject 9-p

subject 10-p

subject 11-p

subject 12-p

Trial 1-Load  Trial 2-Load  Trial 3-Load
Flexion-Extension Trunk Angles at C7 for the three loaded trials for pregnant-subjects

subject 13-p

subject 14-p

subject 15-p

subject 16-p

subject 17-p

subject 18-p

Trial 1-Load  Trial 2-Load  Trial 3-Load
Flexion-Extension Trunk Angles at C7 for the three loaded trials for pregnant subjects

- Subject 19-p
- Subject 20-p
- Subject 21-p
- Subject 22-p
- Subject 23-p
- Subject 24-p

Graphs showing the angles in degrees (%) for each subject across the percentage of the trial.
Flexion-Extension Trunk Angles at C7 for the three loaded trials for pregnant subjects

(subject 25-p)

(subject 26-p)

Trial 1-Load  Trial 2-Load  Trial 3-Load
Flexion-Extension Trunk Angles at C7 for the three loaded trials for non-pregnant subjects

Figure A.10. Flexion-Extension Trunk Angles at C7 for the three loaded trials for non-pregnant subjects
Flexion-Extension Trunk Angles at C7 for the three loaded trials for non-pregnant subjects
Flexion-Extension Trunk Angles at C7 for the three loaded trials for non-pregnant subjects

subject 13-np

subject 14-np

subject 15-np

subject 16-np

subject 17-np

subject 18-np

Trial 1-Load  Trial 2-Load  Trial 3-Load
Flexion-Extension Trunk Angles at C7 for the three loaded trials for non-pregnant subjects

subject 19-np

subject 20-np

subject 21-np

subject 22-np

subject 23-np

subject 24-np

Trial 1-Load | Trial 2-Load | Trial 3-Load
Flexion-Extension Trunk Angles at C7 for the three loaded trials for non-pregnant subjects

subject 25-np

Percentage of trial (%)

Angles (°)

Trial 1-Load  Trial 2-Load  Trial 3-Load
Flexion-Extension Head Angles with respect to the trunk for pregnant subjects

Figure A.11. Flexion-Extension Head Angles with respect to the trunk during walking for pregnant subjects
Flexion-Extension Head Angles with respect to the trunk for pregnant subjects

subject 17-p

subject 18-p

subject 19-p

subject 20-p

subject 21-p

subject 22-p

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension Head Angles with respect to the trunk for pregnant subjects

subject 23-p

subject 24-p

subject 25-p

subject 26-p

---

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension Head Angles with respect to the trunk for non-pregnant subjects

Figure A.12. Flexion-Extension Head Angles with respect to the trunk during walking for non-pregnant subjects
Flexion-Extension Head Angles with respect to the trunk for non-pregnant subjects

subject 11-np

subject 12-np

subject 13-np

subject 14-np

subject 15-np

subject 16-np

subject 17-np

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Flexion-Extension Head Angles with respect to the trunk for non-pregnant subjects

---

- Subject 18-np
- Subject 19-np
- Subject 20-np
- Subject 22-np
- Subject 23-np
- Subject 24-np

---

Legend:
- Mean-No Load
- Mean-Load
- Walking Angles-No Load
- Walking Angles-Load
Flexion-Extension Head Angles with respect to the trunk for non-pregnant subjects

subject 25-np

Percentage of walking portion of trial (%)

Angles (°)

-60
-40
-20
0
20
40

Mean-No Load  Mean-Load  Walking Angles-No Load  Walking Angles-Load
Appendix F: Correction equation for the electrogoniometer
The electrogoniometer was affixed to the wooden device and moved in a range of angles in $5^\circ$ increment from $-130^\circ$ to $140^\circ$. The angles measured by the electrogoniometer were compared to those reported by the goniometer. The electrogoniometer was tested in three different sets of trials where it was detached and reattached to the wooden device. Within each set of trial, the electrogoniometer was moved in the range of motion three times. Following these steps, all the measurements were combined to obtain a correction equation for the electrogoniometer data through the curve fitting tool in Matlab 2007B. The angles measured by the electrogoniometer were corrected using the following equation with a correlation of 0.9994:

$$f(x) = 3.909 \times 10^{-8} x^4 + 6.75 \times 10^{-7} x^3 + 8.927 \times 10^{-5} x^2 + 1.029x -0.3123$$

The measurements and corrected measurements from the three sets of trials are shown in Table A.1, Table A.2, and Table A.3. The angular errors and corrected angular errors between the values measured by the goniometer and electrogoniometer for the three sets of trials are shown in Figure A.14, Figure A.15, Figure A.16, Figure A.17, Figure A.18, and Figure A.19.
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Figure A.14. Angular errors for the first set of trials

Figure A.15. Angular errors after corrections for the first set of trials
Table A.2. Second set of three trials for the electrogoniometer against the goniometer

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Figure A.16. Angular errors for the second set of three trials

Figure A.17. Angular errors after correction for the second set of three trials.
Table A.3. Third set of three trials for the electrogoniometer against the goniometer

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Angular errors for the third set of three trials

Figure A.18. Angular errors for the third set of three trials.

Angular errors after correction for the third set of three trials

Figure A.19. Angular errors after correction for the third set of three trials.