GENDER DIFFERENCES IN WALKING WITH RESPECT TO MOVEMENT OF THE PELVIS

by

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ABSTRACT

Biological gender differences in walking and running have seldom been explored. Historically, women have been described as being less able to effectively perform the tasks of walking and running due to structural differences from men. The supposed "wide pelvis" of the female has been used as justification for women's exclusion from activity. The wider pelvis of the female has also been used to suggest that females are more prone to injuries in activity, especially at the knee because of a larger quadriceps angle (Q-angle). Social scientists have suggested that gender differences in walking, if indeed there are any, could possibly be explained by social and cultural factors as much as biological factors. By comparing men and women while walking and then introducing a mechanical factor which has a sociological influence and comparing them again, some answers may be found as to whether differences thought to occur between men and women while walking are actual biological differences or socially constructed differences.

This study evaluated whether kinematic differences existed between men and women during walking. Male (n=9) and female (n=9) subjects were recruited for this study. Both sexes walked barefoot on a treadmill at two different speeds, slow (0.89 m/s) and fast (1.45 m/s), while being video taped from the front, rear and sagittal views. The female subjects also walked a second time in high heeled shoes (heel height = 8.0 cm) following the same protocol. Reflective markers were placed over the following anatomical landmarks: 4th lumbar vertebrae, left shoulder, greater trochanter, lateral condyle of the femur, lateral malleolus, heel and fifth metatarsal, bilaterally on the iliac crests, anterior superior iliac spines, patellae, tibial

tubercles, posterior superior iliac spines and gluteal muscles. The dynamic Q-angle during the stance phase of walking was measured from the front view video. The mean area moved by each of the rear view markers was calculated from an in-house software program that analyzed the rear view video. Maximum and minimum hip, knee and ankle angles were calculated from the sagittal data. Nine anthropometric measures were measured from each subject. The static Q-angle, bi-iliocristal and bi-trochanteric widths, waist, thigh and bi-trochanteric circumferences, height and weight were all noted.

A two (speed)-by-two (gender) ANOVA was performed on all of the kinematic data with the significance level being set at $p < 0.05$. The results indicated that with an increase in walking speed there was an increase in marker movement for both the men and the women. Some structural and kinematic gender differences were found. Notably, the iliac crests of women moved more than the men's. The static and dynamic Q-angles for the women were greater than the men's. The high heels effected the ankle and hip angles but not the knee angle. The dynamic Q-angle significantly decreased when high heels were worn during walking.

The above results suggest that men and women do walk differently and biomechanical factors play a small role in perceived gender differences in walking. It is important that these differences are not used to negatively impact women in terms of their perceived abilities and the access they have to physical activity.

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INTRODUCTION

Although the walking and running abilities of men are often explored, the same abilities of women are less studied and possible biological gender differences have been less frequently addressed. Since men have traditionally been used as subjects in scientific studies rather than women, women's ability to participate in physical activity has often been judged in relation to the male "standard" or norm. Their structural anatomy, viewed as different and less efficient for movement than that of the male, has therefore been seen as less able to support vigorous physical activity whether it be walking, running or even cycling. Because women have not fully participated in sport and physical activity science has tended not to study their actual physical abilities but, make decisions about physical capabilities based on assumptions that they are disabled and less physically competent than men. For these reasons, it is possible that a biomechanical study assessing possible gender differences in walking might yield some interesting information. Social scientists have suggested that gender differences in walking, if indeed there are any, could quite possibly be explained by social and cultural as well as by biological factors. By comparing men and women walking and then introducing a cultural factor (high heeled shoes) and comparing them again, some answers may be found as to whether perceived differences between men and women while walking are actual biological differences or are based on cultural and social influences.

Pseudo-scientific beliefs and medical understandings have historically affected attitudes toward the nature of female physical activity (Vertinsky, 1990). Early representations of the differences between the male and female form and function drew support from the ideas of European anatomists and physiologists in the late 18th century. It was not until that time that the female anatomy was specifically illustrated as different from the male anatomy (Schiebinger, 1986). This interest in female form and function was socially significant, since drawings of the female skeleton portrayed the female skull as much smaller than the males, and the female pelvis as distinctly larger than the male's. The depiction of a smaller female skull was, of course, used to support the argument that females were intellectually inferior to men. Similarly, the wider pelvis illustrated on the female skeleton demonstrated to the medical community that women were not capable of running or walking efficiently like men and therefore, should be advised to abstain from strenuous activity. Thus, representations of the female body in the late 18th, throughout the 19th century and into the 20th century exaggerated possible real differences in women's anatomy and were clearly affected by cultural values, for example that women were solely reproductive beings and that men were the superior sex, both physically and mentally. The representation of 'natural' anatomical differences between the sexes has had significant long term implications for beliefs about women's health and physical activity. In particular the female's wide pelvis was long singled out by doctors and physical educators as an important reason why women are condemned to run less efficiently than men.

In some respects the supposed "wide pelvis" of the female is still being used as justification for women's poor walking and running ability, as well as their tendency toward injury during exercise, because of their perceived anatomical differences from men. Medical students are still largely taught the anatomy of the male form as the natural standard, and then told how the female anatomy differs from the male (Gray in Pick & Howden, 1992). For example, the section on the skeletal structure of the pelvis in Gray's Anatomy (1992) lists numerous female dissimilarities with respect to the male pelvis. Medical and kinesiology textbooks similarly continue to point out that the female is hampered by a wider pelvis (than the male) which disadvantageously alters the quadriceps angle (Q-angle) and hence affects and impairs her walking and running ability. Hence the language and practice of anatomy tends to validate the "essentialist" character of the female as disabled even though their claims can not necessarily be supported by existing biomechanical data.

A study using biomechanical methodology, trying to observe differences between men and women while walking, may shine some light onto the question of whether gender differences are real or socially constructed. However, the task is not so simple. If no social cues or evidence are present men and women may very well walk the same biomechanically. If this is the case why does the notion exist that the sexes do not walk or run similarly? To try and answer this question a cultural factor is introduced. For example, does the wearing of high heeled shoes influence how women walk? It may well be that the shoes do not elicit any biomechanical changes in walking. Women may consciously change their walking pattern in order to appear sexually attractive. Indeed, many women are socialized to behave differently than men. Gestures, movements and motions are ingrained from an early age. In our culture, girls are typically socialized to be graceful, less boisterous and less physically active than boys. Because high heels are generally thought to be "feminine" it may be that women do not normally walk or run differently than men, but when "dressing-up" they change the way they move to be more feminine by moving the hips more to appear sexually provocative. Another distinct possibility is that high heels, because of the structure of the shoe, actually cause women to walk differently. By adding a different component (or impediment) to the "natural" female walking pattern the female subjects' gait may be altered and some insight may be gained about the question of sex differences in walking being biological or sociological.

LITERATURE REVIEW

Biological Considerations

During walking the pelvis moves a great deal in many directions including, the medio-lateral, anterio-posterior and vertical. The motion of the bones of the pelvis is generally thought to be symmetrical. As the right foot lands at foot strike the right innominate is rotated in a posterior direction and the left innominate is rotated in the anterior direction. The trunk is rotated to the left with the anterior surface of the sacrum rotated to the left. During mid-stance of the right leg the innominate is in the process of rotating anteriorly and the sacrum is rotating right. Left heel strike occurs next with the left innominate beginning to rotate anteriorly. As the right foot toes-off the right innominate begins to rotate posteriorly (Greenman, 1990). The same description of motion can be given for the left side of the body. These motions however, are difficult to see with the human eye. Moreover, it is difficult to determine if these movements are performed in the same way by men and women. Few studies have addressed this issue and it would be interesting to see whether a kinematic analysis would help in addressing some of these issues such as, more movement of the pelvis laterally and vertically and perhaps different motion for the joint angles at the hip, knee and ankle. To perform a kinematic analysis the movement of bony landmarks of the region needs to be studied.

The bones of the pelvic region are largely covered with adipose tissue and large muscles. There are a few bony structures palpable at the surface that can help show the movement of the pelvis during activities. The anterior superior iliac spines (ASIS), the iliac crests and the posterior superior iliac spines (PSIS) are landmarks easily found on most people. With these landmarks a fair estimation of the movement of the pelvis during walking can be gained. Some problems with these landmarks have been noted however. For example, Williams et al. (1987) compared university students with distance runners and found that depending on the measure used, women distance runners have either a wider or narrower mean pelvic width than male distance runners. The bi-trochanteric width relative to leg length or stature suggested females have wider pelves, but this result could be attributed to more subcutaneous fat over the trochanters as is typical for females. More adipose tissue on women could confound the results. The ASIS measures relative to leg length and stature showed females to have narrower pelves compared to the males. Finally, the bi-iliac crest measures again indicated that females had wider pelves than males, although the difference was smaller than the bi-trochanteric measure. This variable could also be confounded by excess adipose tissue. With these inconsistent results in mind the notion that women are less efficient walkers and runners than men may be refuted on the basis that women are not structurally different than men.

Some anthropometric data have been gathered to try and differentiate biologically between men and women. Atwater (1990) took many anthropometric measures of females and males, one of the measures being pelvic width or bi-iliocristal breadth. This author found that the absolute pelvic width between men and women was the same. For college aged women the mean pelvic width was 28.4 centimetres (cm) and for the men, the average pelvic width was 28.4 cm as well. Differences were seen when relative measures were considered. The ratio of pelvic width to height indicated that women had a larger ratio than men suggesting that women had larger pelvic widths than men, but this is only because women tended to be shorter than men.

These results lead Atwater (1990) to state there may be a misconception that women have wider pelves than men. If indeed females and males have the same pelvic width then data and literature would be based on misconceptions and all the notions of female disability with respect to physical activity would prove inaccurate. Women as a group have been thought to be less competent than males in running events due to their wider pelves and greater femoral obliquity (Potera, 1986 in Williams). The supposed wide pelves of women have led some authors to claim that females are at a mechanical disadvantage in running (Rasch & Burke, 1978 in Cavanagh). This mechanical disadvantage is explained because the wider pelvis requires a greater lateral shift of the centre of gravity to keep the female's body weight over the supporting foot in each stride. It would be interesting to determine if males and females have different lateral movement of their pelves during walking to substantiate the claim of mechanical advantage possessed by males during gait.

The supposed differences in pelvic size have led many authors to believe that females have a different and less efficient walking and running style from men. Differences between the male and female pelvis have been noted. Male pelves are generally considered to be of one similar shape, while the female pelvis has been characterized as having one of four possible shapes.

1) The gynecoid type of pelvis has a round or broadly oval inlet with the long axis being the transverse axis.

2) The anthropoid pelvis which characteristically has an oval inlet with the long axis of the inlet being the anterior-posterior axis.

3) The android type of pelvis has a heart-shaped pelvic inlet which is similar to the male pelvis.

4) The platypelloid shape is described as being flattened anterior-posteriorly. (Young & Ince, 1939-40)

The female pelvis' distinctive characteristics as opposed to these of the male pelvis has been the reason given by many investigators as to why women are not efficient walkers and runners. The females' hips and legs are positioned differently from the males' due to different pelvic types. It has been pointed out that because of the wider pelvis, women have a greater Q-angle (Horton & Hall, 1989). The Q-angle is a structural variable that has been associated with gender differences in hip width. This angle is formed by a line from mid-patella to the ASIS, representing the pull of the quadriceps muscle and a line from mid-tibial tubercle to mid-patella, representing the pull of the patellar tendon. The acute angle between these two lines is defined as the Q-angle. The problem with a large Q-angle is that when the quadriceps contract the patella is more likely to be displaced laterally than if a small Q-angle is present.

The greater Q-angle is credited with making women less efficient walkers than men and therefore, more prone to injury. Because of a man's narrower pelvis he is able to walk with longer more "straight ahead" steps and this is naturally a more efficient gait, whereas a female's gait, with more genu valgum and knee hyperextension, is less efficient and predisposes women to knee injuries (Hutchinson & Ireland, 1995). Thus, these statements are just one more piece of evidence used to argue that women are not built for and can not participate as efficiently as men in sport or strenuous activities.

Some other less important differences in the male and female pelvis have been described. The entire female pelvic girdle is tilted forward as opposed to the male's (Van De Graff, 1988). This characteristic yields a stronger lordosis for women. People with a pronounced sway back are more prone to back problems, further validating the argument that women are less mechanically efficient in walking and running than men. Many anatomical text books describe the human body in terms of the male model and allot only small sections to the female body usually noting how it deviates from the males' (Gray in Pick & Howden , 1992). In general the bones of the pelvis are thinner and lighter for females than males. The outline of the obturator foramen is more triangular on females. As well the symphysis pubis is shallower in women than men. Finally, the female pubic angle is generally, wider and often more rounded than the males' (Van De Graff, 1988). Usually these descriptions use the male pelvis as the golden standard and compare the female pelvis to it. This method of comparison once again highlights the idea that women are deviant from the norm, i.e. the male.

The supposed anatomical differences between men and women has led at times to the exclusion of women from elite sport competition. The arguments that women are the weaker sex due to Q-angle, fragile bones and poorer physiological performance than men have been used to keep women from competing internationally in long distance running events. It was not until the 1980's that women were allowed to compete at a sanctioned track meet in distances over 1500 metres (m). The 3000 m and marathon for women were not allowed at the Olympic Games until 1984 in Los Angles (Williams et al., 1987).

Biological differences reported in the literature point out that women in general are weaker than men because of their biological make-up. Falls (1986) argues that when females participate in the same activities as males they show a higher incidence of knee injuries and this is probably due to the Q-angle. The same author further suggests that because of a woman's wider pelvis she has a smaller angle between the femur and tibia on the lateral aspect of the knee. Therefore, there is increased lateral displacement of the patella in females and hence greater incidence of knee pain. Falls (1986) quotes the average Q-angle for females to be between 9° to 11° while the average angle for males is between 5° to 7°. These angles are somewhat smaller than the average Q-angles quoted by other researchers. Horton and Hall (1989) found the average Q-angle for men to be 11.2° and for women 15.8°. This second set of angles seem to agree with more of the studies. The argument that women are more prone to injury due to the Q-angle is also supported by the Falls (1986) paper. The author says that women have a greater incidence of patella dislocation and subluxation than males. Shipman et al. (1985) also support the notion that because women possess a greater Q-angle than men they are not as efficient walkers and runners as men.

Females and males have been compared to each other with respect to distance running. Williams et al. (1987) did a biomechanical analysis of distance runners to try and dispel the notion that men were built and performed differently than women while running. They found that the when the width of the pelvis was measured as a percentage of stature between genders there was only a small difference (0.7%). This result needs some reference however. These measures were taken from distance runners and it was noted that both males and females from this sample had narrower relative pelvic widths compared to a general student population. Therefore, the normal population could show different results and many researchers would suggest this.

The pelvis and low back are areas of the body that according to Falls (1986) are prone to injury. It has been suggested that men and women have anatomical differences in these areas as well. The important differences are: men have more vertical ischial tuberosities than women; the ASISs on the men are inverted and on the women are everted; and finally the males are believed to have a backward pelvic tilt while the females have a forward pelvic tilt (Falls, 1986). The greater pelvic tilt seen in females causes some concern about injury as well. The acetabulum on females has a forward displacement away from the line of gravity. This thereby increases the force acting at the lumbosacral joint so the overall effect is greater stress on the low back and pelvis for equal loads in the female as opposed to the male.

Other authors have found sex differences in walking on different variables other than the ones examined in the previous study. Molen et al. in 1972 studied the step frequency, the mean velocity and mean step length of men and women walking at a self selected pace and compared the sexes. The differences found throughout this research were the following. Women had a higher step frequency than men. In other words, women walked with more steps over a given distance than men. This is not unexpected because women generally have shorter legs than men, thus to cover the same distance in the same time women would have to use more steps. Men generally chose a faster preferred walking speed than women. The step length of men is longer than that of women, again this is not unexpected because men generally have longer legs than women. Given these sex differences it is easy to assume that there may be sex differences on some other factors related to the movement of body parts during walking.

The initiation of gait has also been a criteria used to compare males and females. Nissan and Whittle (1990) studied this aspect of walking and found that most females unload their swing legs during the period between gait initiation and the first recorded vertical force and males do not. However, the same authors found the medio-lateral force components to be significantly higher in males indicating that they try to abduct their legs more than the females while walking. The female swing leg was found to move further and higher than the males' in the same study. As well the stance hip extended more in females. The movement of the knee showed no sex differences. The only sex difference at the ankle joint was during the swing phase when the ankle joint dorsiflexed more for females than males (Nissan & Whittle, 1990).

Social and Cultural Considerations

It has been suggested by Thomas and French (1985) that many observed gender differences in motor performances are due to environment or cultural factors. Thus they suggest, that girls may be socialized to run differently, throw differently and jump differently than boys. These authors believe that due to early socialization and ingraining of the differences between boys and girls many gender differences do develop in physical performances. Thomas and French (1985) also note that most motor performance differences are small at the time children enter kindergarten, and that it is after this time that large discrepancies develop. Environmental factors are seen to be responsible for the increase in differences in motor performances during the elementary school years. Different standards are laid out for boys and girls and therefore, different expectations are held by teachers, parents and the children themselves for performance levels to be achieved. If the gender differences are biological then different standards might be appropriate. However, if gender differences are socially and culturally constructed then separate standards serve to intensify the perception that differences in motor performance exist between the sexes (Safrit et al., 1980).

On the same note, it could be suggested that women perhaps walk differently than men, out of perceived necessity or desire because of environmental or cultural factors. Women who wear tight fitting clothing and high heeled shoes will more than likely walk differently than their male counterparts, who wear pants and low heeled shoes. A tight fitting skirt might force a woman to take shorter strides, as would shoes with a substantial heel height. Women who wear this type of clothing may feel they are expected to walk differently and hence do so to perform. Some people believe that women walk differently than men willingly to create an erotic image. Nancy Henley (1977) claims that our society's beliefs about gestures and movement suggests that females wiggle their hips while men walk more smoothly. However, another author, Ray Birdwhistell (in Henley, 1977) suggests that just the opposite is true, and that men subtly wag their hips to the right and left involving a twist at the base of the ribs and ankles, while females present the length of their entire body as moving as a whole. This same author suggests that anatomy has little to do with these differences in walking. Rather these tertiary sex differences exist to emphasis a distinctiveness and sexuality. These comments by Birdwhistell, suggest that women are socialized to walk in a certain way, are expected to walk that way and therefore do. Perhaps the gender differences seen during walking are a self-fulfilling prophecy women create for themselves. Clinical literature has stated that when high heeled shoes are worn, the adjustments women must make to stay balanced while standing and walking are to thrust the buttocks backward and the chest forward. Statements like these help perpetuate myths that men and women walk and run differently and suggest that women search for ways to use their body to get sexual attention from males. However, if people have this perception, then they assume that women walk differently than men because of the postural changes the women had to make to stay balanced on the high heeled shoes. It could also be the case that women perform when wearing high heeled shoes because they feel glamorous or seductive and hence their walking style is somewhat changed.

A number of studies have examined women's gait while wearing high heeled shoes (Gehlsen et al. 1986, Snow et al. 1992 & Snow & Williams, 1994). There are also studies that have examined men wearing different heel heights while walking (de Lateur et al. 1991 & Opila et al. 1988). Most of these studies looked at kinematic differences between wearing heels and not wearing them while walking. None of these studies, however compared gender differences.

In 1986, Gehlsen and coworkers looked at the effects of heel height on knee rotation during gait. Their subjects wore heel heights ranging from 6.0 cm to 10.7 cm and walked on a treadmill with an electrogoniometer placed on their right knee. As well, each subject walked in bare feet and in running shoes (heel height 1.2 cm to 1.5 cm). The results indicated that knee flexion-extension and internal-external rotation during the swing phase of walking were significantly decreased. Interestingly, during the stance phase of walking no significant differences were noted for the amount of flexion-extension, internal-external or valgus-varus movements. Also significantly changed, were stride length and time with increased heel height. The authors concluded that high heeled walking is accommodated for by a shorter walking step, a quicker step with less range of motion at the knee joint during the swing phase. A few problems with this study are noted. Most obvious is the different heel heights worn by the subjects, and secondly only the knee joint was examined.

There are a few studies that suggest that high heeled shoes change one's posture (de Lateur et al. 1991 & Opila et al. 1988). This notion is then carried through to argue that a change in posture will effect gait. This argument essentially makes sense, however the trouble arises when the literature shows conflicting results as to how posture is changed due to high heeled shoes.

Opila et al. (1988) compared postural alignment in barefoot and high heeled shoe stance. These researchers used both men and women as subjects. Men wore shoes with a heel height of 7.0 cm, while the women wore their own shoes with an average heel height of 6.4 cm. The results found were interesting. Initially, there were some differences in posture, especially with the males or inexperienced heel wearers. The accommodation used by this group was to flex the knees, thereby moving posteriorly the centre of gravity of the trunk to re-establish the centre of gravity over the base of support. Eventually, after habituating to the heels, this flexed knee position disappeared. The authors found differences between the two stances, barefoot and high heeled. At the ankle joint the differences were obvious; in heels the ankle was more plantar flexed, as well as externally rotated. At the hip there were no differences between the trials in the position of the line of gravity. In the lumbar-pelvic region there were some significant changes noted while wearing high heels. When the heels were worn the subjects flattened their lumbar spine, the pelvis rolled backwards and the legs became more vertical (knees extended as they became used to wearing the high heeled shoes). These results generally contradict what most authors observed with respect to the lumbar curvature. It is generally assumed that while wearing high heels the lumbar lordosis is increased and the pelvis is tilted more anteriorly. It should be noted though, that these results were from static measurements, not during walking. Perhaps if lumbar lordosis were studied in a dynamic situation, the results would be different.

De Lateur and coworkers (1991) followed up on the idea of varied posture in different heels heights and looked at both the static and dynamic components. These authors examined the effects of heel height on the lumbar spine and lower limb joint kinematics in the sagittal plane. They looked at both sexes as had Opila and co-workers in 1988, and they also measured the effect negative heels had on posture. For static posture these authors found no significant differences with the various heel heights. During the dynamic part of the study great changes in the ankle angles and lesser changes at the more proximal joints from shoe to shoe were noted. Interestingly, significant differences toward decreasing lumbar lordosis were only seen among the male subjects with increasing heel height rather than the expected increase lordosis. For the female subjects no trend was seen in either direction. The conclusion drawn by these investigators was that the compensation for heel height occurs distally, or at the ankle joint, and is factored out by the time the trunk is viewed, meaning that walking appears to be the same at the upper body whether wearing high heeled shoes or not.

When women are wearing high heeled shoes, the experience these women have walking in these shoes may effect their style of walking. A study addressing this issue was conducted by Opila (1990). In this study the researcher examined the differences between experienced and non-experienced wearers of high heeled shoes at two different heel heights (low heels averaged 1.6 cm and high heels averaged 6.1 cm). At the low heel height there were no differences between experienced and non-experienced heel wearers. At the high height some significant differences were found. The stride lengths of the inexperienced group were significantly greater than the experienced group. As well, in high heeled shoes the experienced wearers had significantly greater increases in knee flexion during stance. The intrasubject variability in the inexperienced group was greater for knee flexion. The movement of the pelvis was different between the two groups. At toe-off the pelvis was lower on the stance leg side in experienced wearers and higher in inexperienced wearers. As well the pelvis was less level or had more exaggerated motion at toe-off during high heeled gait in experienced wearers. Overall the inexperienced heel wearers showed a more cautious gait style and this instability was quantified in the inexperienced walkers by a decreased internal-external rotation of the lower limb during the high heeled gait. So this study concluded that there are differences between experienced and inexperienced walkers in high heels.

The most comprehensive study on the effect of high heeled shoes on gait is a recent study conducted by Snow and Williams (1994). These authors looked at a number of variables including lumbar curvature, pelvic tilt during standing and sagittal lower extremity kinematics, ground reaction forces and rearfoot motion during walking. Three heel heights (1.91 cm, 3.18 cm, 7.62 cm) were worn by women walking at 1.4 m/s. There were no significant differences between heel heights found in lumbar curvature or pelvic tilt. Significant increases in the vertical and anterio-posterior forces during walking were found with increased heel height. As well, the kinematics showed a number of significant differences during walking. The angle of the ankle throughout the gait cycle showed increases in plantar flexion with an increase in heel height. The maximum knee angle during swing and the knee extension velocity decreased with increased heel height. These authors, as have others, noted from casual observation that a high heeled shoe is less stable than a low heeled shoe during walking. Although a number of studies have been conducted more thorough research is still warranted.

As shown in the preceding studies there seems to be some general misconceptions about the female's ability to perform comparably with men during walking, running and in sport in general. Much of the evidence given in the literature about biological differences is unsubstantiated with biomechanical research, therefore a pilot study was undertaken to determine whether there were indeed biomechanical differences between males and females during walking. To try and find an answer to this problem the movement of the skeleton, more specifically the pelvis was examined along with the Q-angle. The pilot project is discussed in the next section of the thesis.

The tension between socio-cultural and biological differences in gender renders it impossible to pull apart these two perspectives and attribute differences in gender to either one or the other. It is difficult to know what to attribute to either category. However, the question proposed by the current study is whether kinematic differences exist between men and women during walking. If differences in the movement of the skeletal system are seen between men and women during walking then a step towards support for true biological differences in movement is taken. However, if no kinematic differences are noted then perhaps the argument that differences are culturally induced is warranted. Support for this may be found by controlling the clothing that women wear while walking. How this problem is addressed in the current study is discussed later in the methods.

PILOT PROJECT

From the above literature review it can been seen that there are a number of issues. Reading in this area provoked the interest of this author and therefore a pilot study was undertaken to try and answer some questions. The pilot project conducted in 1994 examined the differences of movement of the pelvis between females and males while walking at a slow and fast speed. Eight subjects were used; four women and four men. The outcome indicated that for most bony landmarks there were no differences between men and women while walking. No statistical analyses were carried out on these data. Conclusions were based on the visual inspection of kinematic data in line graph format.

The data that were examined were the movement of the right and left iliac crests, ASISs, patellae, tibial tubercles, PSISs, the gluteal muscles and the lumbar vertebra (L4). The vertical movement of all the variables was the only movement inspected.

The Q-angles in the study yielded inaccurate results because they were calculated for the entire gait cycle, thereby incorporating the swing phase as well as the stance phase of walking. The important information to know is the Q-angle during the stance phase only. The Q-angle for men was larger than that of women in the study, when considering the minimum Q-angle throughout the gait cycle. When the maximum Q-angle was examined the results agreed with the literature in that women have larger Q-angles than men. The average women's Q-angle was larger than the men's at both speeds and for both legs as seen in Table 1.

Table 1. Q-angles of men and women walking at two speeds.

	Women			Men		
	Min. Ang	Max. Ang	Avg. Ang	Min. Ang	Max. Ang	Avg. Ang
0.98 m/s R	0.99 °	13.74°	11.13°	-12.60°	6.80°	-0.74°
0.98 m/s L	-8.29°	8.71°	2.95°	-12.41°	5.67°	0.48°
1.94 m/s R	-0.28°	43.34°	11.80°	-14.30°	8.47°	-0.29°
1.94 m/s L	-21.57°	11.79°	0.85°	-13.76°	8.69°	0.97°

After completing the pilot project and examining the data a number of problems with the study became evident. First of all, the subjects walked at two speeds on a treadmill in bare feet, 0.98 m/s was the slow speed and 1.94 m/s the fast speed. The second speed was quite fast for all of the subjects. Many of the subjects complained of sore feet during the second trial at the fast walking speed. In the future, these speeds should be reduced to ensure all subjects are comfortable at the slow and fast walking speed in bare feet.

Probably the most significant problem with this study was that foot switches were not used. This lack of equipment created a problem because the timing of each subject's walking pattern could not be examined. Furthermore, subjects could not be compared against one another because the data could not be time and stride normalized. All the data were therefore, looked at on an individual basis and hence the conclusions that have been drawn are not that strong. Examining the data across subjects would yield much stronger and convincing arguments.

Statistical analyses were not performed on these data. The study was used to determine if a larger project on the same topic was feasible and worthwhile, therefore statistical analyses were not deemed necessary. Again if this had been done more convincing arguments and stronger conclusions could be made. As it stands the data only suggest certain conclusions. In the future more definite answers to the questions asked in this paper are necessary.

Another factor that was neglected during the data collection was the use of a reference point in the field of view while video taping. Had such a point been digitized in each frame more relevant information might have been gained by examining the X component movements of each marker. The resultant component could also have been examined had a reference point been used. The resultant component probably would have yielded the most valuable information of any of the components.

Measurement of the Q-angle in this study provided little useful information. A static measure of Q-angle would have helped in the gender comparisons. The use of foot switches in another study would enable the researcher to look only at the Q-angle during the stance phase of walking. This measure is much more valuable than the measure of Q-angle throughout the entire walking cycle.

Sagittal joint angle data could have produced some more meaningful results. Also an experienced heel wearer could perhaps provide some important information to this study. With this in mind some more pilot data were collected. One experienced female high heeled shoe wearer was recruited to walk in varied heel heights. This subject wore heels of 6.6 cm and 10.4 cm in height and also walked in bare feet. The subject could not walk at the designated fast speed of 1.94 m/s in either set of shoes, hence the fast speed used for this subject was 1.56 m/s. The results yielded by this subject are interesting. The horizontal movement of the markers seems not to yield any useful information, however the vertical movement of the markers did. As well, a side view of the subject was filmed to enable the investigator to examine the joint angles of the subject while walking in bare feet, 6.6 cm (moderate) and 10.4 cm (high) heels.

The data from this experienced heel wearer show not too may differences between heels and bare feet. More data however, needs to be collected to draw conclusive results. A more detailed description of the pilot project is given in appendix A.

RATIONALE

In light of all the questions that still remained unanswered from the pilot project conducted by this author, and the controversies in the literature, the present study was proposed. A study with many variables and subjects needed to be undertaken to try and dispel some of the misconceptions about gender differences in human movement. A biomechanical study examining movement of the pelvis during walking placed in a social science setting would have great significance in the literature. Some anthropometric data were also needed to lay to rest issues remaining in the current literature. The first issue being, do women really have wider pelves than men? This naturally leads to the issue of the Q-angles of men and women. The current study measured static Q-angle as well as the Q-angle during the stance phase of walking. Second, was whether skeletal movement is truly different between men and women during walking. The purpose of this study was to kinematically look at the movement of a number of bony landmarks from the front, rear and side of the subjects while walking to give an overall picture of what is really happening. Thirdly, if there were differences between men and women during walking the question to be answered was are they structurally or socially manifested.

LIMITATIONS

The limitations related to the current study were the following. The first limitation of the study was the shoes worn by the women during the high heel trials. Even though these women may have had experience walking in high heels the shoes worn in the study were not be their own and hence, the subjects may not have been completely comfortable in the shoes. This could effect the subjects' walking style. Another biomechanical limitation was the speed that the women could walk on the treadmill while wearing the high heeled shoes. Because the surface of the treadmill was smooth as well as the soles of women's shoes there was not much traction for the subjects, hence the fast speed these subjects could walk at was limited.

The socio-cultural make-up of the subjects used in this study limited the application of results to a larger population. Both the male and female subjects used in this study were, white, middle-class, western students. This is a small representation of each of the gender groups. Men and women of different ethnic backgrounds may yield different biomechanical results, therefore, this study is limited in the way in which the results can be used. Inferences cannot be made to different groups about the way in which they walk.

DELIMITATIONS

The delimitations for this study were the following. The group of people selected to walk were as slender as possible to eliminate the confounding factor of marker movement due to soft adipose tissue. However, elite athletes were not accepted as subjects. Recreationally fit adults were used. Further, these subjects were selected from the university environment, therefore only people who saw the recruitment postings participated. As well, only women who were willing to walk in high heeled shoes and scarce clothing could be subjects. The men participating in the study had to be willing to walk in tight fitting clothing and bare chested.

HYPOTHESES

A number of hypotheses were tested in the study.

1) The skeletal movement of the pelves of men and women during walking in bare feet would not be different at the slow walking speed of 0.98 m/s nor the fast speed of 1.45 m/s.

2) The pelvic width of men and women would not be significantly different on an absolute scale.

3) The Q-angles of men and women would not be significantly different while standing and while walking.

4) Joint angles would not be significantly different between men and women walking in bare feet.

5) There would be no statistical differences on any of the joint angles variables between the women walking in heels and women in bare feet at either speed.

METHODS

Subjects

The study used twenty-three subjects, eleven women and twelve men between the ages of twenty and thirty-five years. These subjects were recruited from the faculty, staff and students at the University of British Columbia. The subjects were not elite athletes nor from any particular athlete population. Moderately active people were the ideal subjects to try and limit body fat and extraneous subcutaneous tissue. The inclusion criteria for the study were: male and female, 18-35 years, recreational athletes, healthy with no musculoskeletal injuries, females, non-experienced high heel wearers and females with 7 1/2, 8 or 9 shoe size. The exclusion criteria were: elite athletes from any sport, recent musculoskeletal injury, ectomorph or endomorph body type, females with experience walking in high heeled shoes, or obvious visual anatomical malignment e.g. over-pronation, genu valgum. In accordance with university regulations, all subjects signed an informed consent.

Anthropometry

Multiple variables were measured on each subject before the data collection procedures began. These measures were taken to try and ensure subjects were of the same approximate morphological type, to screen out any subjects predisposed to an extreme body type which might effect the results of one of the gender groups and also to substantiate the assumption of bilateral symmetry. The height, weight and static standing Q-angle of each person was measured. An attempt was made to match the male and female subjects on height and weight as much as was possible. To try to obtain an indication as to the structural characteristics of the subjects used the standing posture of the subjects was examined and some things were noted. The bi-iliocristal and bi-trochanteric widths were measured for each subject. Segment lengths of the lower leg were measured as follows: foot width from the ground to the lateral malleolus while standing in bare feet and in heels (in the case of the women), shank length from the lateral malleolus to the head of the fibula and the length of the femur from the lateral condyle to the greater trochanter. The thigh circumference was measured on all subjects as an indicator of body type of the subjects. This measure was obtained by placing a steel tape measure around the thigh horizontally with the top edge of the tape just under the fold of the buttock. Two other circumference measures that were taken were the bi-trochanteric and waist. As well, if present, the amount of genu varum or genu valgum of each subject was noted. Finally, the degree of pronation or supination of the feet was noted from a general visual inspection while the subjects stood bare foot in the anatomical position.

Data Collection

Each subject walked on a Quinton Instruments Clinical-Research treadmill barefoot while being video taped for four minutes. The subjects walked at two speeds, 0.98 m/s and 1.45 m/s for two minutes each. The walking speeds chosen in this study, are different enough that differences in walking due to a change in speed were expected. Oberg et al. (1994) suggested that a normal, self selected walking speed for subjects in the age range of 10 to 79 years is approximately 1.19 m/s. The same authors suggested that 1.54 m/s is a fast walking speed for subjects in the same age category. The slow speed in this study, being slower than a normal walking speed was then a valid speed to have used. As well, the fast speed utilized in this study fell just short of the fast speed used by Oberg et al. (1994) however in this case it was warranted because the high heeled shoes used in this study limited the fast speed at which the female subjects could walk.

Markers were placed on bony landmarks. Subjects were asked to wear either a bathing suit or cycling shorts and a short top. Male subjects wore no shirt. Reflective markers were placed on the anterior, posterior and sagittal sides of the subjects. The anterior view showed markers over the left and right iliac crests, the left and right ASIS, the left and right patellae and the left and right tibial tubercles. The markers placed on the back were placed over: the lumbar vertebra 4 (L4), the left and right PSIS, and centred on the greatest prominence of the left and right gluteal muscles. As well, the markers on the left and right iliac crests were visible from the rear (Fig. 1).

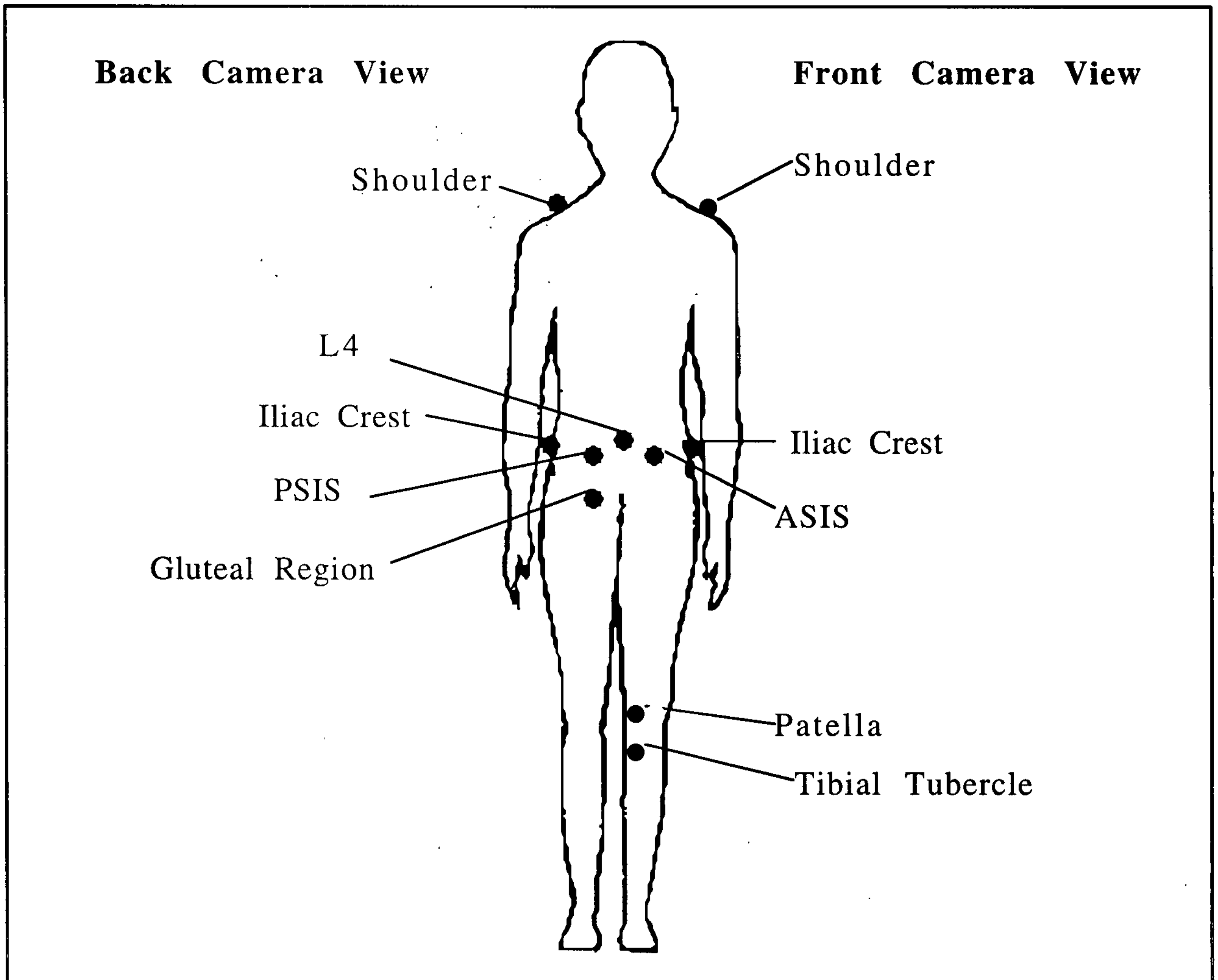

Figure 1. Marker placement on the front and rear view of each subject.

Markers for the sagittal view were placed on the left side of the subjects over the superior aspect of the shoulder, the greater trochanter, the lateral condyle of the femur, the lateral malleolus, the heel (centred on the calcaneus) and the lateral aspect of the head of the fifth metatarsal. The markers on the skin were the shoulder, the patellae, the tibial tubercles, L4, the knee and the ankle. The iliac crests, ASISs, PSISs, the gluteal and the greater trochanter markers were placed on a single layer of clothing. The heel and fifth metatarsal markers were placed on the shoe worn by the subject. Although having markers on clothing is not ideal it could not be helped and the amount of movement of the markers due to clothing was negligible.

Each subject also wore two foot switches while walking in bare feet. The switches were places under the right heel and ball of the foot. The switches were placed on the sole of the foot slightly lateral to the centre of the heel and the medial side of the sole under the toes. These switches were used to determine when heel strike and toe-off occurred for each subject. This information allowed normalization of the gait cycle across subjects. It was not possible to put foot switches on the heels of the high heeled shoes, therefore during those trials, in which shoes were worn, the foot switches were worn between the shoe and the foot.

Three video cameras were used, one placed 6.57 m in front of the subject, one placed 6.58 m behind the subject and one placed 5.5 m to the left of the subject to record the sagittal view while walking on the treadmill. The bottom of each of the camera lenses was 1.19 m from the floor therefore, the cameras were situated so that the subject was only seen from the neck down to the treadmill, to insure the anonymity of the subjects. The video taping rate used was at 60 Hertz.

All of the women subjects were asked to walk again wearing a pair of high heeled shoes. The heel height of the shoe was substantial in the spectrum of heels worn by women today. The total heel height was 8.0 cm. The heels had a base of support at the heel of approximately 2.0 cm^2. The shoes worn in this part of the study were provided by the researcher to insure continuity between subjects.

The female subjects again walked at the slow (0.98 m/s) and fast (1.45 m/s) speeds for 2 minutes each. The same reflective markers described earlier in the study were once again used in this part of the study. The markers remained in place for both sets of trials. This part of the study was undertaken to determine if differences did exist between men and women whether they were biologically or socially manifested.

Data Analysis

Once all the data were collected Peak Performance Technologies computer software was used to condition the data. The video tapes were digitized automatically and edited in the Peak 5 program. The raw data were filtered using a Butterworth filter at 6 Hz. The data were then normalized to three walking strides, a stride being defined as the time from one heel-strike to the consecutive heel-strike of the same foot. Once all of the data were conditioned they were downloaded to a PC computer for further analysis. Microsoft Excel, a spreadsheet program was used to manipulate the data.

From the sagittal view the hip, knee and ankle angles were calculated in the Peak program and then downloaded to Excel. These angles are defined as follows: the hip angle was the angle between the left horizontal and the anterior aspect of the left thigh, the knee angle was the angle between the posterior left shank and the left thigh and the ankle angle was the angle between the left foot segment and the left shank segment see Figure 2.

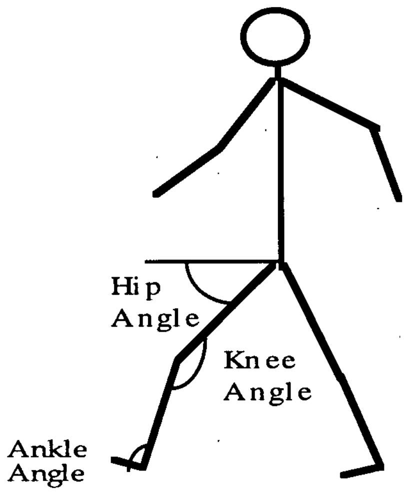

Figure 2. Definition of sagittal joint angles

In-house software was used to normalize the data to one stride cycle from left heel strike to left heel strike. Another in-house program was used to look at pelvic movement. This program calculated the total area each rear marker moved throughout the gait cycle. These data were compared between men and women in bare feet, men and women in heels and women in heels and bare feet.

The data from the front and rear camera views were examined through graphical analysis. Each variable (marker on a landmark) was compared across the three conditions. The patterns of movement, timing of the movements and distance moved were explored. Because the pelvis is considered to move as one bone and the right and left side to move opposite of one another, it was assumed that the markers on the front of the pelvis would mimic the corresponding rear markers. For example, the ASIS and PSIS markers on the same side of the body were assumed to have the same movement patterns and therefore, the area of marker movement for the ASIS markers was not examined. The front view yielded the dynamic Q-angle which was only calculated on the left leg because symmetry between sides was assumed. As well the dynamic Q-angle for the purpose of this study was calculated during the stance phase of one stride during the gait cycle.

STATISTICAL ANALYSIS

Statistical analyses were performed using in-house software. The independent variables tested were gender, speed and footwear. The dependent variables examined were dynamic Q-angle, the minimum and maximum hip, knee and ankle angle, the resultant movement of markers for the PSISs , iliac crests and gluteal markers. Analysis of Variances (ANOVAs) were run to determine any significant differences between the three groups of walkers. The variables that were examined were the mean dynamic Q-angle, bi-trochanteric width, bi-trochanteric circumference, bi-iliocristal width, thigh circumference, height, weight and static Q-angle. As well the means of the resultant marker movement of each marker from the rear view camera were examined to see which if any landmarks showed gender differences during walking. The significance level was set at $p<0.05$.

RESULTS

Subject Descriptions

Twenty-three subjects volunteered for the study. Two female and three male subjects were excluded from the study, therefore nine men and nine women were used to test the hypotheses. The subjects excluded were not used for two reasons: (1) technical difficulties in data collection due to video tape problems or computer problems and (2) an inability to walk at the required speeds on the treadmill. The data from the remaining eighteen subjects, nine males and nine females, were used for analysis. The average age (standard deviation) of the 9 male subjects was 25.9 (± 2.7) years and 9 female subjects was 26.3 (± 1.1) years.

Visual inspection while the subjects stood relaxed with feet shoulder width apart indicated that most of the men (five subjects) exhibited a mild degree of genu varum and none of them showed any signs or genu valgum. Four men appeared to have relatively straight alignment. Three women displayed a mild amount of genu varum and two women had mild genu valgum. Four women appeared to have straight lower limb alignment. Six men pronated with three of these subjects having substantial over pronation. Three men appeared to exhibit mild supination while standing relaxed. Seven women pronated a mild amount and one female subject supinated. One female subject appeared to have normal foot alignment. Out of all of these variables, pronation was the only one to be exhibited in large quantities and for males only. No subjects were excluded at this point due to any obvious malignment problems. The pronation, supination, genu varum and valgum exhibited by all of the subjects was within normal limits. All subjects were normal healthy individuals that met the inclusion criteria and had no significant anatomical malignment characteristics that would effect their gait.

Anthropometric Data

The anthropometric data are presented in Table 2. There were no significant differences between the right and left side on the men or women for the static Q-angles or thigh circumferences. Bilaterally the women had a larger Q-angle than the men. The absolute waist circumference of the women was smaller than that of the men. The men weighed significantly more than the women and were taller. The female subjects had significantly smaller bi-iliocristal widths than the male subjects. The thigh circumference compared across gender was not significantly different. Finally, the bi-trochanteric width and circumference was no different for men than it was for women.

Table 2. Anthropometric Data. Mean and standard deviation for each group
*Indicates statistical significance across gender ($p<0.05$)

Anthropometric Measure	*Men*	*Women*	
Height	179.6 cm (6.91)	169.5 cm (3.6)	*
Mass	74.1 kg (8.0)	64.1 kg (4.6)	*
Waist Circumference	78.0 cm (3.2)	68.4 cm (4.5)	*
Bi-Trochanteric Circumference	92.3 cm (4.5)	95.4 cm (1.8)	
Bi-Trochanteric Width	31.2 cm (2.4)	32.1 cm (1.0)	
Bi-iliac Width	26.5 cm (1.6)	23.9 cm (2.1)	*
Right Thigh Circumference	55.6 cm (3.1)	57.5 cm (2.8)	
Left Thigh Circumference	55.3 cm (3.1)	57.2 cm (2.3)	
Right Static Q-Angle	13.6 ° (3.0)	21.7 ° (8.0)	*
Left Static Q-Angle	13.8 ° (3.3)	20.7 ° (7.5)	*

Gender

Only a few of the variables examined in this study yielded significant results with respect to the condition of gender. The dynamic Q-angle (Table 3) was significantly different ($p < 0.05$) for men and women with the women having a larger angle. The only gender difference discovered was in the amount of movement of the iliac crest markers. The left and right iliac crests of men moved significantly less ($p < 0.05$) than that of the women. See Table 4 for results.

The joint angle data yielded only a few significant gender differences. The ankle angle conveyed no differences between men and women when compared on the maximum and minimum joint angle. There were no gender effects for the knee maximum or minimum joint angles as seen in Figure 3. The pattern of the knee angle as it moved through flexion and extension during the stance phase of walking was almost identical for the men and women.

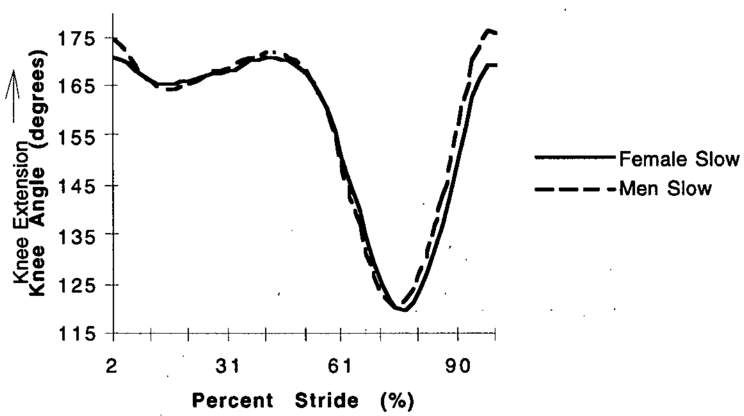

Figure 3. Knee angle vs. percent stride for men and women at the slow walking speed.

The maximum hip angle, or hip extension, showed a significant gender effect during the stance phase of walking. The hip was the only joint angle to show a significant gender effect. Men had more hip extension than women during the stance phase of the gait cycle. Below Table 3 shows the significant differences in each of the joint angles examined in the study.

Table 3. Average joint angle in degrees throughout one stride. *Indicates significant difference between gender ($p<0.05$).†Indicates significant speed effect ($p<0.05$).

	Ankle Dorsi-flexion Angle	*Ankle Plantar-flexion Angle*	*Min. Knee Extension Angle*	*Max. Knee Extension Angle*	*Hip Flexion Angle*	*Hip Extension Angle*
Female Slow	108.3	124.0†	155.5†	174.6	68.9†	101.0*†
Female Fast	110.0	129.8†	147.0†	173.9	67.4†	103.6*†
Male Slow	107.0	123.6†	156.5†	177.1	70.8†	102.5*†
Male Fast	107.7	126.6†	148.3†	175.8	68.1†	105.9*†

Speed

Most variables in all three conditions showed a significant speed effect. The variables that were not effected by changes in speed were: the left iliac crest, the minimum ankle angle, the maximum knee angle, and the maximum ankle angle.

As speed increased from 0.98 m/s to 1.45 m/s the dynamic Q-angle significantly decreased for both men and women. The dynamic Q-angle was smaller than the static Q-angle for both the men and women. The footwear trials were also effected by the speed of walking. The increase in speed had an inverse relationship with dynamic Q-angle for the barefeet and high heeled shoe trials. The results for all three groups at both the slow and fast speed are shown below in Table 4.

Table 4. Mean and standard deviation static and dynamic Q-angle for the left leg during stance. *Indicates statistical difference for speed of walking ($p<0.05$).

Walking Speed	*Men*	*Women*	*Women Heels*
Static	13.8* (3.3)	20.7 * (7.5)	-----
0.98 m/s	6.2 * (3.5)	14.6 * (9.1)	12.0 (7.1)
1.45 m/s	4.9 * (3.6)	12.9 * (8.4)	10.8 (8.3)

An in-house software program was used the calculate the average area each of the rear markers moved throughout one stride of walking. The markers examined bilaterally were the iliac crests, the PSISs and the gluteal markers. The L4 marker was used as a reference point for the software program. The software program, although it did not separate the horizontal and vertical movement of each of the markers, was a useful tool in determining the total area covered by each marker throughout the walking cycle. This computer program also showed a graphical display of the movement of each marker throughout a number of step cycles. The patterns displayed by the program suggested some gender differences. From visual inspection the male subjects, displayed a smaller movement pattern at the PSIS markers than the women. The iliac crest marker movement for the women seemed to be more vertical than horizontal and for the men the opposite was true. Finally, the markers on the gluteal muscles were observed to move in a larger pattern for the women than the men.

The movement of the markers on the back of the subjects was influenced by the speed of walking. As the speed increased the total area the marker moved increased for the: right crest, left PSIS, right PSIS, left gluteal and right gluteal, as can be seen in Table 5. The left gluteal marker also showed a significant interaction between gender and speed. Although from the slow to fast speed both the men and women had a significant increase in movement in the area covered by the left gluteal marker for the women it changed much more than that of the men. All of the landmarks moved significantly more with an increase in walking speed during the footwear trials as well. No interactions were found in this set of data.

Table 5. Mean area of marker movement in mm^2. * Indicates significant difference on gender ($p<0.05$) . † Indicates significant difference on speed ($p<0.05$).

Marker	*Men Slow*	*Men Fast*	*Women Slow*	*Women Fast*
Left Crest	136.81*	168.31*	207.30*	317.14*
Left PSIS	64.81†	93.06†	128.18†	227.64†
Left Gluteal	600.83†	947.12†	783.81†	1567.10†
Right Crest	121.30*†	145.49*†	195.30*†	289.02*†
Right PSIS	86.64†	128.05†	148.02†	292.31†
Right Gluteal	686.46†	1107.9†	874.75†	1370.24†

Many of the joint angles were effected by an increased walking speed as well. Flexion and/or extension increased with and increase in walking speed. The hip, knee and ankle angles were examined for the left leg during walking. The minimum and maximum angle for each joint throughout the stance phase of the gait cycle was considered for each of the three conditions (men, women and women in heels). In one gait cycle, stance usually occurred over the first 60% of the cycle. The maximum ankle angle increased significantly when speed increased meaning that the maximum ankle angle reached at the fast speed was greater than the maximum ankle angle reached at the slow speed of walking. Figure 4 shows a smaller minimum ankle angle at approximately 30% of the stride, or mid-stance, at the fast walking speed. A larger maximum ankle angle was seen for the fast walking speed at 60% of the stride, or toe-off. Just before heel-strike at approximately 90% of the stride cycle the ankle once again dorsiflexed more at the faster walking speed. Statistical analyses were not conducted on the swing phase of the gait cycle, therefore the maximum amount of plantar flexion that occurred throughout the entire stride was not considered here. It is the difference in the two curves at 60% of the stride that was of interest as this was where the statistical significance occurred. It was seen from the graph that at this point significantly more ankle plantar flexion was achieved at the fast speed than the slow.

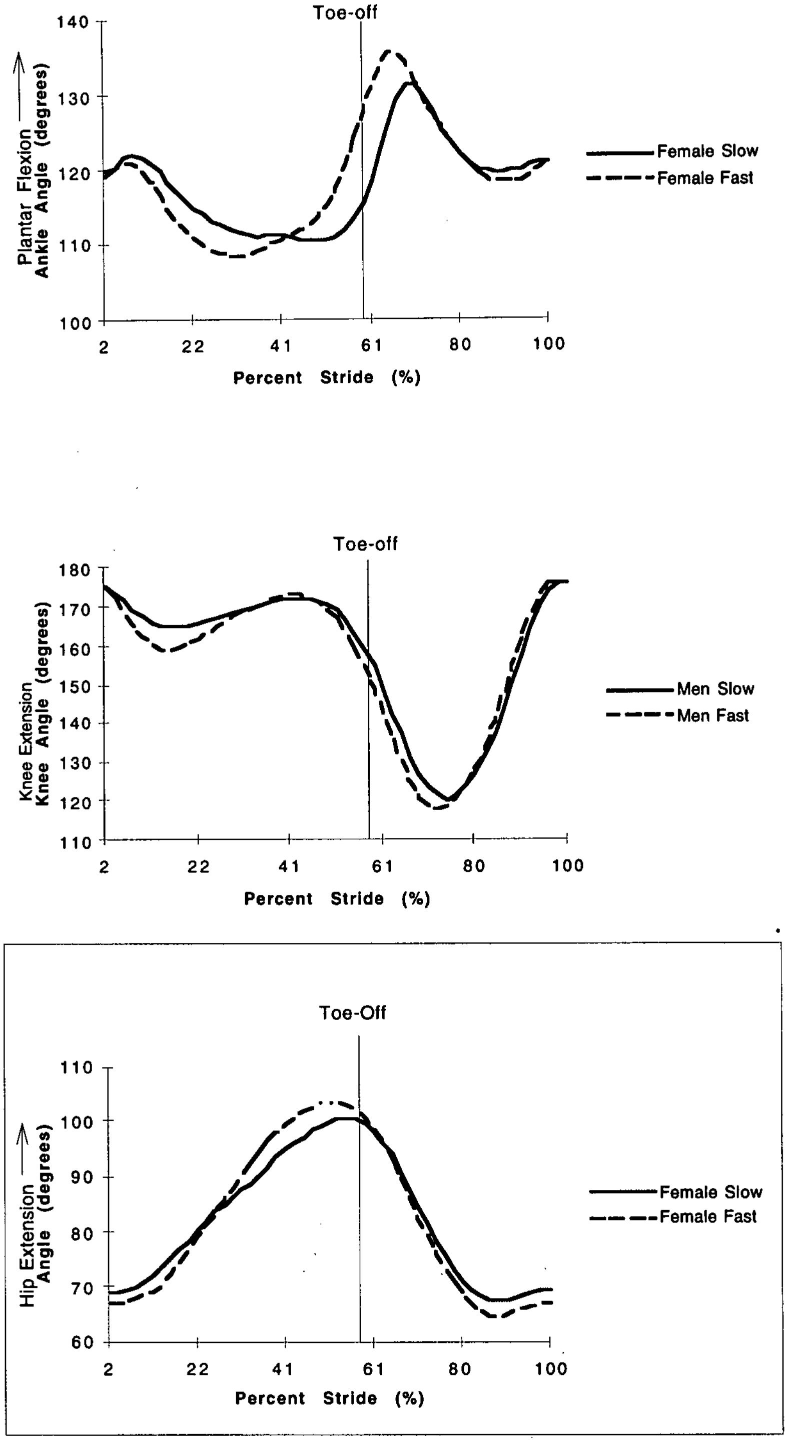

Figure 4. Typical joint angle graphs for the ankle, knee and hip.

The minimum knee angle decreased as the walking speed increased indicating that knee flexed more in the fast trials and Figure 4 uses the male subjects to illustrate this finding. During the stance phase of the walking cycle at fast speed of walking the minimum knee angle reached was significantly smaller than the minimum angle obtained during the slow walking speed. The minimum knee angle for the fast speed was 148.3° and occurred immediately before toe-off. The minimum knee angle for the slow speed was 156.5° and occurred right before toe-off as well. The graph below shows that throughout most of the stance phase the knee is flexed more at the fast speed than at the slow speed. The graph also shows that in the swing phase the knee was flexed more during the first part and flexed less in the second part at the fast walking speed.

The minimum hip angle decreased significantly with an increase in walking speed which suggested that the hip flexed more at the faster speed. This is seen in Figure 3 at heel strike where the curve for the fast speed of walking was lower than for the slow speed. The maximum hip angle increased significantly as the walking speed increased meaning that the hip also extended more during stance at the fast speed as can be seen in Figure 4. Maximum hip extension in Figure 5 was reached just prior to toe-off, at the fast speed the hip extended to 103.6° and at the slow speed the hip extended to 101.0°. The hip moved through a greater range of motion during one stride at the fast speed of walking than at the slow for the women as shown in Figure 4.

No significant speed effect occurred at the ankle during the footwear condition. The minimum knee angle changed significantly during the stance phase as a result of a change in speed of walking during. As the speed of walking increased the knee flexed significantly more. When the female subjects walked in the high heels both the minimum and maximum hip angles, during stance, were significantly changed by the speed of walking. The hip flexed and extended more at the faster speed than at the slower speed of walking with respect to the footwear trials as shown by Figure 6. The maximum hip extension for both speeds occurred just prior to toe-off and this was where the significant difference between the two curves occurred. Graphs of the hip for women walking in barefeet and in high heeled shoes looked almost identical across the speed condition. By comparing these two graphs it was easy to see that footwear had no influence on the hip angle.

Footwear

Comparing the high heel shoe trials against the barefeet trials for the women showed unexpected results. There were no significant differences in the dynamic Q-angle between the footwear condition and barefoot condition for the women.

Women walking a second time in heels did not elicit significant changes on the rear marker movement patterns of the subjects used in this study. The only marker to demonstrate a footwear effect was the right gluteal marker. In bare feet the total area this marker moved was less than when the same subject walked in heels.

The joint angle data suggested some differences between women walking in high heeled shoes versus barefeet. The ankle angle showed a significant difference when the women walked in bare feet versus when they walked in heels. This was to be expected because the structure of the shoe held the ankle in a plantar flexed position.

Neither the minimum nor the maximum knee angle were significantly affected by the footwear. Figure 5 shows the same knee angle pattern whether the women walked in heels or bare feet.

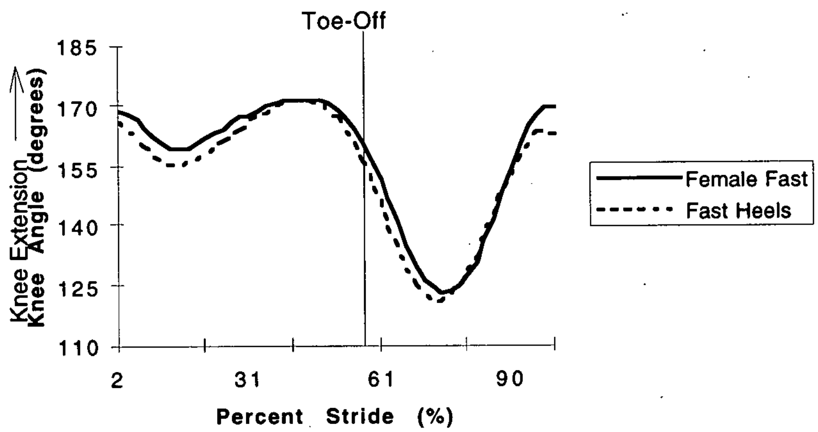

Figure 5. Knee angle footwear comparison for the fast walking speed.

The hip angle was significantly effected by footwear. The hip flexed more throughout one stride cycle with an increase in heel height of the footwear. This can be seen in Figure 6 where the females walking at the slow speed were compared across footwear types. Just after heel strike and just prior to heel strike the hip reached maximum flexion. The minimum angle reached by the women in bare feet was 68.9 degrees and the minimum hip angle reached by the women walking in heels was 68.2 degrees.

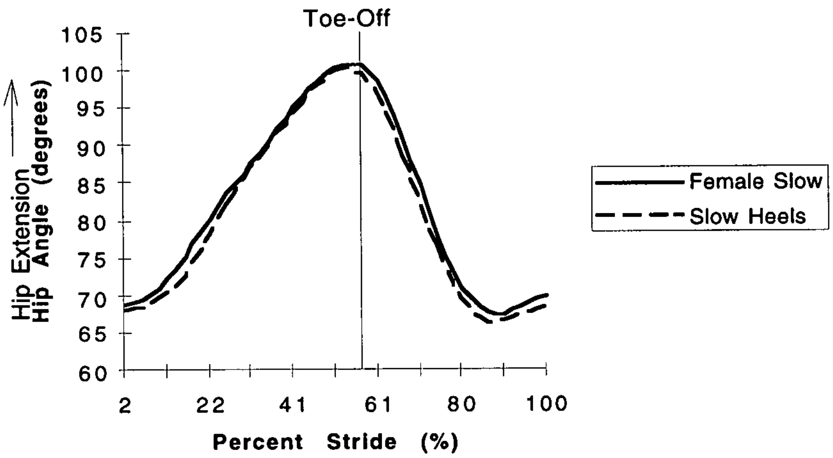

Figure 6. Hip angle vs. percent stride for females walking at the slow speed in bare feet and heels.

DISCUSSION

Anthropometric Data

From the data presented here, men and women were differentiated structurally. Anthropometric data indicates that there are certain characteristics that consistently are different between the two genders. This study measured a number of anthropometric variables and found some to be significantly different for men and women. Some anthropometric variables also showed no differences between the genders. It was no surprise that the men were significantly heavier and taller than the women. As no screening of subjects was done on these two variables anyone who met the inclusions criteria was accepted into the study. The waist circumference showed a significant difference between gender indicating that the women subjects were smaller than the male subjects. Surprisingly the bi-iliocristal width measures were significantly larger for the men than the women. Most literature (Falls, 1986 and Hutchinson & Ireland, 1995) suggests that women have larger pelves than men and uses the bi-iliocristal width to support these claims. However, it can be argued quite reasonably that the men are larger in height and weight than the women and therefore, the pelvic width is larger due to the simple fact that the men have a larger skeletal frame than the women.

The static Q-angle measure also indicated that the male and female subjects used in this study were structurally different than one another ($p<0.05$). This study found that the women had larger Q-angles than men. These results agree with the literature that suggests that men and women are different physically (Heyward et al. 1986, Wells, 1991, and Wells & Plowman, 1983). This measure, Q-angle, is linked to the pelvis and therefore the hypothesis that men and women are not inherently built differently was rejected. However, it was difficult to explain why the women had larger static Q-angles than men when the men had wider pelves at the iliac crests. Perhaps the alignment of the patella and the femur, and not the width of the pelvis, greatly influences Q-angle. Women are often described as having "squinting patellae" that is, patellae that are positioned more medially and internally rotated (Hutchinson & Ireland, 1995). Some common alignment situations are often seen in women such as; medially and internally rotated patellae, increased external rotation of the tibia and over pronation at the feet, these malalignment scenarios are said to increase the Q-angle.

The variables that indicated no significant differences between the genders tell us some interesting things as well. The bi-trochanteric width another measure used to describe pelvic width, bi-iliac width being the other, was not significantly different between gender. This finding was somewhat unexpected since this measure was used to describe pelvic width it was expected that the women would have been larger at this landmark. The bi-trochanteric circumference and thigh circumferences also were similar for the male and female subjects.

The question arose as to which measure should have been used to describe pelvic, bi-iliocristal or bi-trochanteric width. It should be considered that the bi-iliocristal measures are taken at the top of the pelvis and the other measure is taken at the bottom of the pelvis, the bi-trochanteric. However, this is not a true measure of the pelvis since the two landmarks used to calculate the measure are the greater trochanters, not any part of the pelvis. At best this measure could be used to suggest pelvic width but can not be used as the true indicator. Too much depends on the positioning and size of the femurs for this measure to be valid and reliable. Since the bi-trochanteric width is not actually taken from landmarks on the pelvis the measure that should be considered a more accurate indication of pelvic width is the bi-iliocristal width. It is difficult to know whether the bottom of the female pelvis is any different from the male pelvis since the true bony landmarks of the bottom of the pelvis are extremely difficult to palpate.

The anthropometric results and the rear view camera data comparing the right and left sides of the men and women indicated that the assumption of symmetry when walking was indeed a valid one. None of the variables measured bilaterally indicated any differences between the right and left side of the body. The anthropometric symmetry found in this study can be transferred to the motion of walking and it can be suggested that walking is a symmetrical movement, therefore only examining the left side for the sagittal and front view camera data was valid. Symmetry of walking has been found to be the case for normal, healthy subjects in many studies (Zatsiorky et al., 1994).

Biomechanical Considerations

A general statement can be made in light of the results indicated above that there are biomechanical differences between men and women during walking. Although some of the variables examined in the study suggested no gender differences one must consider the number of variables examined in the study and the main concern, being the movement of the pelvis. For this particular piece of anatomy gender differences can be noticed during walking at different speeds.

Gender Condition

When analyzing the frontal plane data, marker movement of each individual marker was not calculated. The important data gathered from the front view was that of the dynamic Q-angle during stance. As stated previously in the results section, the left Q-angle indicated gender differences in walking at both the slow and fast walking speeds. This was not a surprise because the anthropometric data showed gender differences and if this was so in an anatomical position it should have carried over into gait. This was found to be the case in this study. Gender differences were seen in the static and dynamic Q-angle. As stated previously these results were somewhat surprising in that the pelvis of the women was not larger than that of the men. Most literature on Q-angle (Falls, 1986 & Hutchinson & Ireland, 1995) specifies that a wide pelvis is the primary factor in determining whether a person will have a large Q-angle. The results of this study did not lead this author to believe that Q-angle is strongly influenced by the width of the pelvis. Other factors that may have influenced the Q-angle in this study were the width of the ASISs, genu valgum, patellar squint, external tibial rotation and over pronation. All of these factors could have increased the Q-angle. but unfortunately were not measured in this study.

The only variable in the sagittal plane to show a gender difference during walking was the maximum hip angle and this occurred just prior to toe-off. At the hip joint, men move through a greater range of motion than the women did during gait. That is, the hip extended more for the men than it did the women. Greater hip extension in men can be explained because the men had longer legs -as indicated from the anthropometry data that showed the men to be significantly taller than women- and in order for the men to clear the ground in the swing phase of gait their legs had to start the swing phase at a greater distance away from the body. It is unimportant that men's hips flexed more than the women's in the context of this study. This is one small component in the movement of walking and therefore, cannot be used to argue gender differences in walking. Furthermore, hip extension is linked to the structural difference of leg length in men and women, men having the longer lower limbs. It was expected and hence, not surprising that one factor in the sagittal plane was different between the genders.

The rear view data contrasts the anthropometric data which showed men to have wider pelves than women based on the bi-iliocristal width. The mean area each marker moved tells generally how the pelvis moved during walking. As stated previously the right and left iliac crest marker movement was significantly different for men than it was for women. Since the men had wider hips than the women it would stand to reason that more motion during walking would be seen at the iliac crest markers. This was not the case in this study. The women's pelvis, at the iliac crest markers, moved more throughout the gait cycle than the men's did. If one considers that walking consists of rotational and linear movement and that each side of the body rotates around a fixed point when walking then increased pelvic movement of the wider pelvis would be expected. While walking the two sides of the body work around the centre of gravity. On a continuous line, the further two points are away from the centre of rotation the further linear distance they will travel. This explanation can be described by using a wheel as an example. When a wheel rotates a point on the outside of the wheel travels a greater distance than a point near the centre of rotation. So men's hips are wider than women's therefore the vertical distance the men's pelves move around an axis of rotation should be greater than that for women's pelves. However, this was not evident from the data collected in the current study. Perhaps the shape of the movement patterns affected the area enough to show a significant differences between the men and women. The female's pattern of movement at the iliac crest was much more vertical than the male's. The iliac crest markers on the men tended to follow a more circular path than the women. This vertical movement at the iliac crests was enough to significantly change the area moved by each marker throughout the walking cycle.

The PSIS and gluteal markers bilaterally did not show any significant differences between men and women while walking. That is, the range of motion each of these markers moved during walking was the same for men and women. The lack of difference between the PSISs of men and women is what was expected from the data of this study. This can be easily explained by the illustration used earlier of walking being a rotation of two sides around an axis. The PSISs are situated much closer to the centre of line than the iliac crests are. The PSISs are very close to L4 which was the reference point used to calculate the movement of each marker. The oscillation of the PSIS markers was dramatically smaller than that of the wider situated iliac crests. Since the pelvis works as one bone, even though it is comprised of three, it is expected that the part of the bone situated closer to the centre of rotation would move less whether it was on a male pelvis or female pelvis.

The results of the movement of the gluteal markers were a surprise. It is a commonly held notion that women walk differently than men because they have more soft tissue in the gluteal region and therefore this soft mass moves more during walking. Although no significant difference was found in the size of the gluteal soft tissue mass, on average the females did have a larger bi-trochanteric circumference than the male subjects used in this study. The notion that women have more soft tissue in the gluteal region and therefore move more while walking has been contradicted by the results of this thesis. One possible explanation for these data was that the subjects used in this study were slender enough that soft tissue movement was not an issue. Perhaps another explanation could be that the soft tissue mass in the gluteal region was relatively firm for the subjects used in this study because they were physically active people. The soft tissue in this area was constituted of more muscle and relatively little adipose tissue because these subjects were physically active people. This is a reasonable explanation. Another explanation could be that there truly were not differences in the movement here, but that people perceive differences. This notion will be discussed later in the paper.

The front, anthropometric and some of the rear view data suggested that there were gender differences in walking. The sagittal data indicated that no differences were found between men and women while walking. Perhaps if the rear data were looked at in another way or more in-depth more gender differences would emerge. If the movement of the pelvic markers was broken down into vertical, horizontal and anterio-posterior movement more information related to the notion that women move their hips more in walking could be gained. As indicated in this study women had a larger static and dynamic Q-angle than men. Maybe the variables that need to be assessed during walking are lower on the body than examined in this study. If one was to examine the stride width and perhaps the width at the knees during walking differences may be discovered between men and women while walking. The orientation of the lower limbs is related to the width of the pelvis which leads one to naturally conclude that the width of the lower limbs would be related to the width of the pelvis. Since women tend to have a larger Q-angle than men this may also effect the width of the stride. Women with unusually large Q-angles may have a wider stance than men because their feet would be forced the situate laterally to compensate for the genu valgum. Conversely it could be said that someone with a great deal of genu valgum also has a large Q-angle out of necessity because the feet need to be situated side-by-side and not cross over. If the tibias were aligned at the same angle as the femurs the feet would end up being criss-crossed, not an efficient way of walking.

Speed Conditions

It was intriguing how the dynamic Q-angle changed with changes in speed. Because the Q-angle is linked to the unvarying skeletal structure of the pelvis it could be assumed that this would an consistent variable. This was not the case in this study. As the speed of walking increased the dynamic Q-angle decreased. This phenomenon was difficult to explain, however, one possibility could be that at a faster walking pace the patella moved in a different path. Since the patella is the only landmark in the Q-angle measurement that is variable the decrease in Q-angle at a faster walking speed must be related to the position of the patella.

The rear markers were all affected by a change in walking speed except the left crest marker. With an increase in walking speed all of the other markers moved more. It was expected that these markers would cover a lager area at the faster walking speed because the body in general must move through a greater range of motion to achieve a faster walking speed. For example, to walk faster an increase in stride length and frequency was needed. Increasing stride length similarly increases the amount of motion produced by the entire body. This effects other landmarks on the body in the same way. The increased range of movement in the joints with increasing speed was expected because with increasing speed it has been reported that step length increases (Winter, 1991) and velocity is the product of step length and step frequency, hence an increase in velocity must elicit an increase in step length and step frequency.

Each of the joint angles studied the hip, knee and ankle revealed a significant speed effect during walking. This agrees with some data presented by Oberg et al.

(1994). These authors analyzed the walking of two hundred and thirty-three subjects and studied their hip and knee angles. The speeds used in the Oberg et al. study (0.91 m/s for slow walking and 1.54 m/s for fast walking) were fairly similar to the speeds used in the current study (0.89 m/s for slow walking and 1.45 m/s for fast walking). Oberg et al. (1994) found that both the hip and knee angles moved through a greater range of motion with increasing speed. The current study suggested that the hip, with an increase in speed flexed more. At the knee an increase in the speed of walking increased the amount of knee flexion during walking. The ankle joint movement in this study was also effected by speed with more plantar flexion occurring at the faster walking speed.

The speed effects found in this study were expected and therefore, uninteresting. Changes in speed were included as part of the protocol of the study to perhaps elicit gender differences in walking. At the outset of the study it was thought that perhaps at normal walking speeds no differences would be apparent between men and women while walking. However, if subjects were forced to walk at a faster speed maybe some changes in walking would occur and yield gender differences. This nonetheless, was not the case, the speed condition did not bring about a gender difference in walking.

Footwear Condition

Some authors have suggested that women walk differently when wearing high heeled shoes as opposed to low heeled shoes or no shoes. Zatsiorky et al. (1994) stated that women in high heeled shoes take shorter steps than women in low heeled shoes. In the current study high heeled shoes affected some aspects of gait but not others. When the same subjects were compared in bare feet and high heeled shoes with respect to the dynamic Q-angle, shoes had a significant effect. The Q-angle decreased significantly when the female subjects walked in heels at both speeds of walking. This was probably due to the women taking a wider stance when wearing heels to maintain balance because they are on a narrower base of support. If the distance between the feet is wider the femur will sit at a less acute angle than when the feet are spaced approximately shoulder width apart. Q-angle may also have decreased in the high heeled shoes because of the structure of the shoe. When wearing high heeled shoes people are not able to pronate at the foot as much as in barefeet or running shoes. If the foot does not move through it's normal range of motion then another structure will have to compensate for this. The tibia quite possibly will align differently thus changing the positioning of the patella. If the patella is pulled more laterally the Q-angle decreases. High heeled shoes change the alignment of the lower limbs thereby, decreasing the dynamic Q-angle.

The sagittal data indicated that two of the three joint angles investigated were affected by the high heeled shoes. Obviously the ankle angle changed throughout the entire gait cycle when high heeled shoes were worn. The ankle was held in a more plantar flexed position by the shape of the shoe. However, the range of motion that the ankle actually moved through was no different whether the female subjects were in high heeled shoes or barefeet. The differences found at this joint were not important because on an absolute scale no differences were found. The knee angle was not affected by the change in heel height however, the hip joint was affected. In the heels the hip flexed more throughout the gait cycle then when the women walked in bare feet. This was attributed to women having to bring the leg higher to clear the ground while wearing the high heeled shoes.

The only rear view variable to be affected by a change in footwear was the right gluteal marker. With an increase in heel height the movement of the marker also significantly increased. These results were somewhat unexpected. It was thought that perhaps the heels would make the subjects walk differently. It was hypothesized that the most noticeable place for the perturbation of high heeled shoes to take effect would be in the movement of the rear view markers. This proved not to be the case for five of the six markers considered in this view. This finding suggests that the differences seen between the men and women at this view were probably true biomechanical differences because a perturbation of the walking style of women did not effect their movement patterns.

Social and Cultural Considerations

This thesis was based on the assumption that men and women walk differently. This general statement inherently has two issues that must be addressed. The first is the general categorization of men and women into two separate groups. The second issue is the idea of difference and what this means.

By comparing men and women one assumes that "all men" and "all women" are the same biologically, socially and culturally. This is clearly not the case as women are not a universal category; they come from many different ethnic and economic groups. Generally, the women used when describing stereotypes of physically active females are heterosexual, western white women neglecting Asian and black women (Hargreaves, 1994). The group of women used in this study were young, white, middle-class, North American students. Women from different cultures may not have the same opportunities or motivations as the group used in this study in terms of physical activity (Vertinsky et al., 1996). Hence since women can not be discussed as a homogenous group it is difficult to draw sweeping conclusions as to whether men and women walk differently.

The second issue, the idea of difference, is intrinsically involved with the first issue. What is the purpose of studying differences between men and women, and by studying difference do we exaggerate the notion of difference between the sexes by trying to categorize and illustrate it? Unfortunately, difference must be studied to negate it. This study found that there were differences biomechanically between men and women while walking. Having found this, it can not be used as an argument that women are less able physical beings than men. The danger in finding differences between the sexes is the use to which assumptions are put. Gender differences in walking need not be applied to running or any other physical activity to promote the idea that women are less able to perform these physical tasks than men. All that can be said is that some women perform these activities differently than some men.

In light of the biomechanical findings earlier presented in this paper, it could be stated that the possibility exists for the differences in walking between men and women to be perceived rather than biomechanically manifested. Guthrie (in McArthur & Baron, 1983) has proposed that some morphological characteristics may signal dominance and because men are thought to be the dominant gender it can be argued that if a man possesses these morphological characteristics and a woman does not she will be perceived as different and weaker than the man. Because women primarily walk the same, biomechanically, as men as shown by the results of this study, socio-cultural factors are a plausible explanation for gender differences in walking. However, even one slight biomechanical difference in walking, such as the centre of moment, is enough for most people to perceive the gender identity of the walker (McArthur & Baron, 1983). This information indicates how strong social perception is. Having watched the video tapes of the subjects used in this study it made sense to suggest that we are culturally trained to perceive gender differences in walking. On the video tapes the women appeared to sway more horizontally and move more vertically than the men, however, the biomechanical analyses used did not suggest any biological differences. A possible explanation for this is a subconscious assumption that when a woman is seen walking she moves her hips more laterally than a man. This assumption could be ingrained in our consciousness from early childhood when we are taught how boys and girls should behave.

The results of the footwear trials made it difficult to surmise that gender differences in walking may be caused by socio-cultural factors. It was expected at the onset of the study that the shoes the women wore for the second set of trials would affect the gait of the women as seen from the rear camera and that this information could then be used to argue that the perceived differences between men and women during walking were indeed that, perceived. The only variable at the rear to suggest walking differences due to footwear was the right gluteal marker. The other five markers did not show an increased amount of movement while in high heels. The argument that socio-cultural factors affect women's gait is not supported by the findings of this study. Women did not appear to "wiggle" more when a cultural variable (high heeled shoes) was introduced into the equation.

The sagittal and frontal data did indicate that some differences were elicited by the high heeled shoes. The ankle and hip angles were affected by the shoes. The Q-angle was affected by the shoes as well. The footwear condition changed the stance of the women by decreasing the Q-angle. With the differences these variables indicated with a change in heel height it might be suggested that social factors are at play and do affect women's gait. The results from the front and sagittal data were unexpected. Ten variables were examined with only four indicating any differences in walking between barefoot and shoe trials. This led the author to state that social factors were not responsible for the perceived gender differences in walking.

The question originally posed was; are perceived differences in walking between men and women biological or socially constructed? This question was somewhat more difficult to answer than originally thought. There seemed to be some biomechanical differences between men and women while walking, however the similarities in walking between the genders seemed to out weigh the differences. Can we say that the differences are biological? Yes. Can we say that the differences are constructed? Yes. Where does this leave us?

The human mind is extremely perceptive. As noted by McArthur and Baron (1983), it can queue into the slightest abnormality and notate a difference. A study found that perceivers were able to detect a walking or running man when viewing film for only 200 msec. This information suggests that people are attuned to extract information dealing with the invariances in the environment and that only kinematic stimuli are needed to perceive human motion. Biomechanically, men and women probably walk equally efficiently. There are small differences between the genders when walking that make us appear to walk differently. These subtle differences are more a factor of identifying gender than of efficiency in walking. Perhaps we have evolved this way to allow the human race to distinguish between one another. Since walking is a primary activity of human beings it is efficient to evolve into slightly different movers.

CONCLUSIONS

The results of this study led the author to suggest that there are gender differences in walking with respect to movement of the pelvis. Although non-significant differences were found for some of the variables in this study, overall it can be said with some confidence that men and women walk differently. A large number of variables were examined in this study, some of them more important than others. The real issue was pelvic movement during walking, however some variables used in this study were only indirectly related to the pelvis. These variables were used to give an overview of men's and women's gait, a general boundary in which the issue of gender differences with respect to the movement of the pelvis was placed on the study. The variables that indicated gender differences in walking were the important variables to consider. The rear view camera data were meaningful data. Originally the study was undertaken because of the popular stereotypes that women walk differently from men, and that this is evident in the sway of the pelvis as seen from behind. The first notion to be addressed was whether the buttocks and hips moved more on women than men during walking. This was indeed the case for the iliac crests of the women which moved more than those of the men. The gluteal region, however, did not appear to move more for either of the genders. The front view camera data supported the rear view camera data by again showing a gender difference during walking related to the pelvis. This difference was seen in the dynamic Q-angle which was larger for women than men. The sagittal data were auxiliary data used in the study to support the results gained from the rear view camera data. The number of variables investigated in this study was large therefore, it stands to reason that some similarities would be seen by gender because men and women are the same species and should move somewhat alike.

The increased Q-angle for the female subjects in this study could have affected an increased risk of injury in walking and running. Since it's been suggested in this thesis that the increased Q-angle was not directly related to pelvic width there must be another explanation for it. As stated earlier, the increased Q-angle was probably related to the positioning of the tibias and therefore, the tibial tubercles and the patella. If the patellae were situated more medially and the tibia externally rotated then more strain would be placed on the lateral aspect of the knee leading to an increased risk of injury at the knee joint.

Based on the results of this study, the following specific conclusions were made. It was hypothesized that the skeletal movement of the pelves of men and women during walking in bare feet would not be different at either a slow or fast walking speed. This hypothesis was supported by the results of this study. Of the four pelvic markers studied, bilaterally the iliac crests and PSISs, the iliac crests were the only markers to show significant gender differences. The ASIS markers on the front of the pelvis were assumed to move in the same way as the PSIS markers since these landmarks are on the same bone. With this in mind a total of six pelvic markers were assessed. Only two of the six markers indicated differences between men and women while walking.

The pelvic width of men and women was hypothesized to be the same on an absolute scale. There are two measures used in the literature to evaluate pelvic width: bi-iliocristal width and bi-trochanteric width. Both of these measures were used in this study. The bi-trochanteric width indicated no difference in pelvic width between men and women. The bi-iliocristal width, however did indicate a difference between men and women in pelvic width with men having wider iliac crests. As a result of the findings of this study, this author considers the bi-iliocristal width to be a truer measure of pelvic width and therefore, the hypothesis as stated at the being of this paragraph would not be supported by the findings of this study.

The third hypothesis was not supported by the results of this study. It was hypothesized that the Q-angles of men and women would not be significantly different while standing or walking. In both instances the hypothesis was rejected. The right and left standing Q-angles were significantly different by gender. The left dynamic Q-angle was also significantly different by gender.

Joint angles, it was hypothesized, between men and women during walking would not be significantly different. Six variables were considered in this part of the study; the minimum and maximum angle reached for the ankle, knee and hip angles during the stance phase of walking. The only variable to suggest a gender difference was the maximum hip angle. The other five variables indicated no gender differences. With these results in mind it can be stated that the fourth hypothesis was found to be correct.

With regards to the differences in women walking in high heeled shoes and bare feet, it was hypothesized that no differences at any of the joint angles would be found other than the obvious change in ankle angle with an increase in heel height, which was the case. This hypothesis was supported for the knee angle but not for the hip angle. Both the minimum and maximum hip angle was significantly affected by the increase in heel height.

Because some differences were elicited by making the female subjects walk in high heeled shoes it could be suggested that perceived gender differences in walking are due to cultural and social factors such as the way Western women dress. High heeled shoes force women to walk differently to maintain their balance. These differences are not a factor of women's skeletal structure, but of the clothing they wear and possibly the context in which they move.

It is important to realize that not all women can be grouped into one category as a "universal" woman. This study only included white, western, middle-class, university students hence, the results found here can not be applied to women as a whole. The biological differences between men and women while walking are important because they influence our notions of gender differences but so too, do cultural differences which affect the way we think about how women walk. On the basis of this study, it can be said that there are indeed structural differences between the sexes that influence their biomechanics of walking. These movement differences between men and women should not, however, be used to deny women certain physical activity experiences since they are only differences and not impairments.

RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

There were some limitations as to the data collection and analyses carried out in this study. These limitations could have affected the results as stated here. Firstly, due to time constraints imposed by biomechanical analysis, many variables were not addressed that could have yielded useful and meaningful information. The movement of the rear markers was only assessed in terms of the total area moved. A more meaningful approach could have been to break down the movement into components and examine the vertical and horizontal movement of each marker. It could be suggested the horizontal movement of the pelvic markers would have been greater for men than women.

In terms of more useful data collection procedures, a 3D kinematic analysis would also have imparted much more relevant information. Rotational movement at the hip joint could have then be analyzed and again perhaps gender differences could have been detected with this method of data analysis. The movement of the tibial tubercles and patellae could have been tracked better as well.

Another factor that affected the results is the sample size. It is difficult in biomechanics to process large amounts of data in a relatively short amount of time. If more time had been available then more subjects should have been used to get a better sense of the true population. Experienced high heeled shoe wearers could have been used as subjects to see if there were any differences in walking between this group and non-experienced wearers.

Perception was not addressed in this study. The next step in this process would be to have a group of men and women walk while being video taped wearing the same clothing with all social queues stripped away. Another group of subjects would watch these video tapes and try and determine the gender of the walker by viewing only the motion at the pelvis since this is the one area that seems to illicit differences in gender while walking.

The important information gained from this thesis was that in the sagittal plane gender differences in walking were not found, however they were noticed in the coronal plane. In biomechanical gait studies, 3D and coronal plane research must address gender.

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APPENDIX A

Results of Pilot Study

The results of the pilot project gave interesting and important information in terms of whether males and females walk differently. Basically, no differences were seen between men and women during walking with respect to the kinematics of the pelvis. Some differences seemed to exist when comparing the kinematics of the lower limbs between men and women. This makes sense when one considers that the legs have more degrees of freedom of movement than the pelvis, therefore it was expected that the legs would show more variability than the pelvic region. Some differences were noted between men and women for Q-angle, however because this was looked at over the whole walking cycle and not just during stance some errors were incurred due to the distortion of the camera (the knee moves through a large range of motion, therefore, as it moves towards and away from the camera the information gained from the markers may be misleading).

When one looks at the individual graphs of each subject similarities across subjects can be seen. As well similarities across males and females respectively can be seen. Subjects 1, 2, 4, 7 and 9 were the female subjects with subjects 1 and 2 being the same female; subject 1 wearing heels and subject 2 in bare feet. Subjects 3, 5, 6 and 8 were the male subjects. Subjects 2, 3, 8 and 9 have full data sets, meaning that each marker at each speed was examined. After examining the resultant coordinate for subjects 2 and 3 it was decided to examine only the vertical (Y) component of marker movement, therefore all other subjects have only vertical movement data. The horizontal (X) component was not reliable because of subject drift on the treadmill. Subjects 2 and 3 were the leanest female and male respectively and subjects 8 and 9 the heaviest and more fleshy. These subjects represent the extremes in body type of the sample population their data was analyzed first to determine if gender differences could be seen. For the remaining subjects 1, 4, 5, 6, and 7 a decision was made to only examine some of the variables. The landmarks that were looked at for the remaining subjects were the right crest from the front view, the right ASIS, the right patella, the left patella, the right tibial tubercle, L4 and the right gluteal muscles. Because the pelvis is essentially one bone it was deemed that one crest would represent what both sides were doing assuming symmetry. As well, the right ASIS would represent well enough what the left ASIS was doing as well as the right and left PSISs. Both the right and left patellae and tibial tubercles were examined because symmetry could not be assumed for these landmarks because they are completely different bones. The movement patterns of the iliac crests, ASISs and PSISs indicated no differences in movement between the sexes, see Figures 7 and 8.

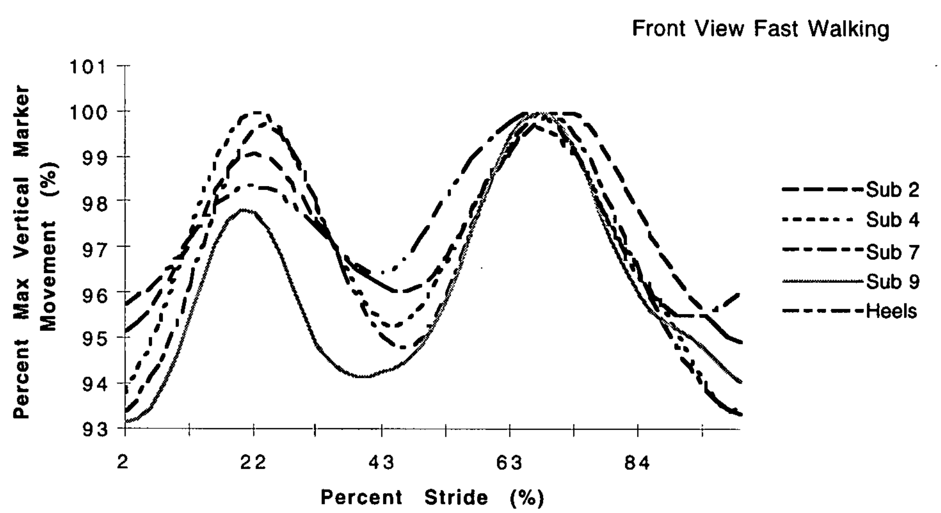

Figure 7. Female subjects ASIS vertical movement at 1.94 m/s.

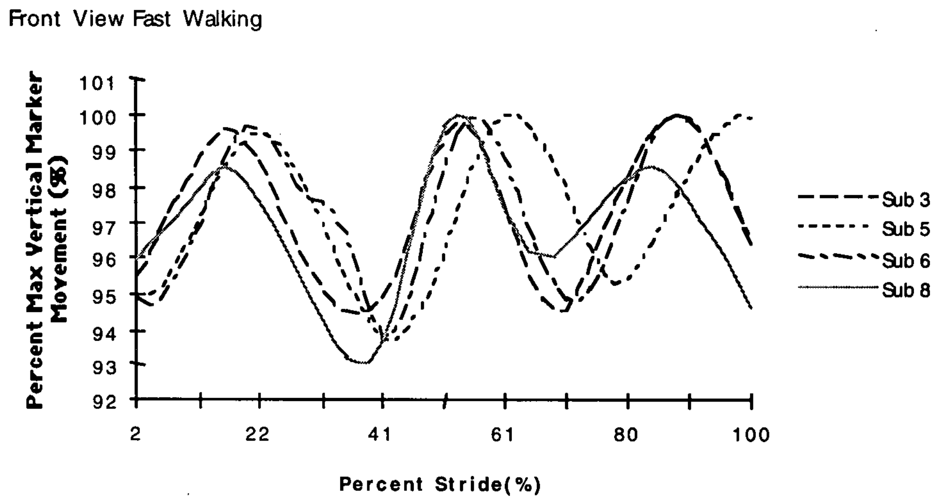

Figure 8. Male subjects ASIS vertical movement at 1.94 m/s.

The patellae and tibial tubercles sometimes showed gender differences, but not in all cases. Figures 9 and 10 show cases where gender differences are seen during walking for the tibial tubercle markers.

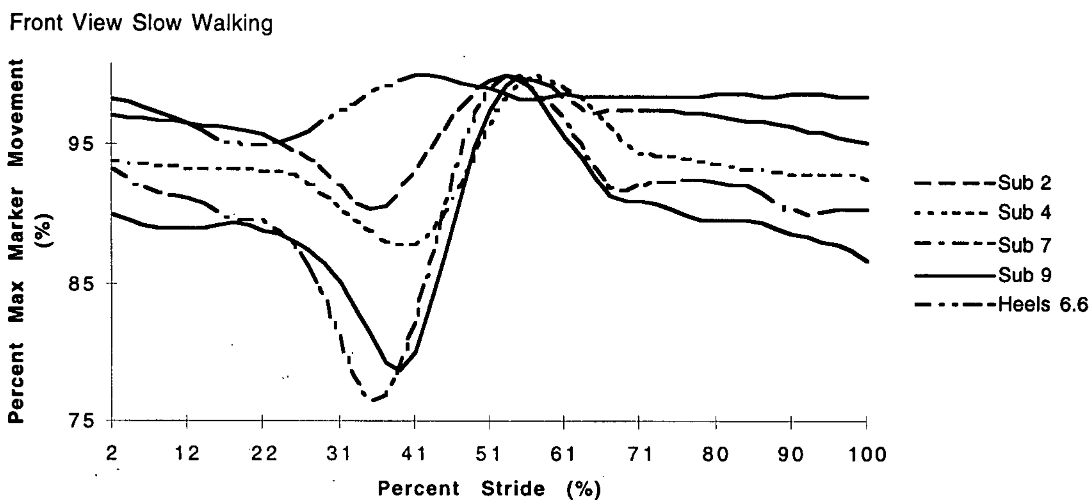

Figure 9. Female subjects tibial tubercle vertical movement at 0.98 m/s.

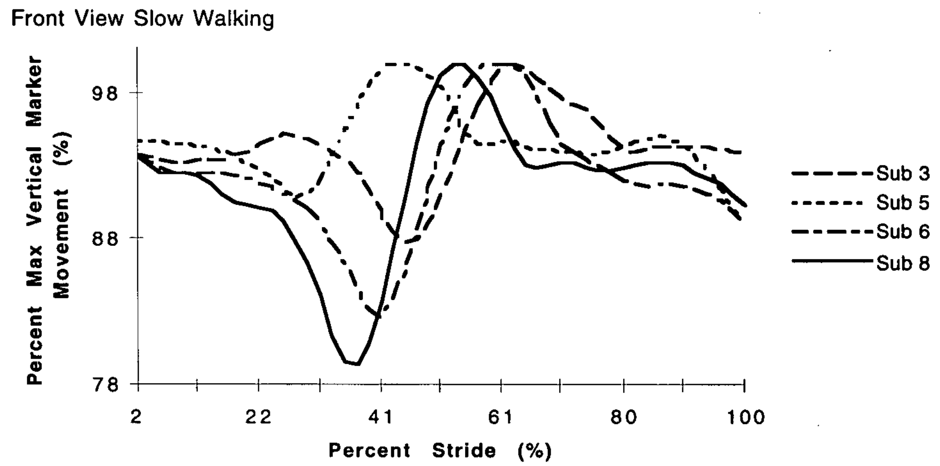

Figure 10. Male subject tibial tubercle vertical movement at 0.98 m/s.

As well, the gluteal muscle markers usually showed gender differences, but not consistently. Surprisingly, the L4 vertebra marker did yield gender differences during walking. Different results might be indicated, should the horizontal or resultant component data be considered.

Resultant Component Data

All the variables will be discussed for the subjects which have a complete set of data. For the slow speed, the right crest resultant data seems to show no gender differences however, only subjects 2 and 3 are used to make this conclusion. A pattern of two peaks is seen with the first being a small peak and the second being relatively larger. Although foot switches were not used in this study, it is assumed that heel strike occurs at the first peak and the second peak represents toe-off.

As suggested earlier the right ASIS pattern looked very similar to the right crest pattern with two peaks for both subject 2 and 3 (female and male respectively). The difference between these landmarks being that the first peak was almost as high as the second peak for the ASIS, whereas for the right crest the first peak was noticeably smaller than the second. Gender differences did not seem evident for this variable.

The right patella was one of the variables that did show gender differences. The patterns between the male and female almost suggest that one was completely backward from the other. The female subject had two sharp peaks followed by a gradual, smoother maxima, whereas the male subject showed a gradual increase to a peak with a smooth peak first and then a sharp second peak.

The right tibial tubercle of the female showed no real set pattern, possibly due to movement of the subject on the treadmill. The male's right tibial tubercle did show a pattern, however it was not that consistent. The large peaks were assumed to occur during the stance phase, while the small bumps indicate the swing phase of walking.

The left crest during slow walking for the male and female again showed no gender differences. The patterns are very similar to the patterns seen for the right crest. One interesting point is that the male pattern seemed somewhat more stable than the pattern for the female. These results possibly stem from the fact that the female subjects in general carried more subcutaneous tissue.

As seen previously between the right crest and ASIS, the patterns of the left crest and ASIS were virtually the same, especially for the male. Again as in the crest pattern, the male's pattern seemed to be more consistent than the female subject's walking pattern. The male's pattern seemed to go through a greater range of motion than the counterpart female pattern.

Again the left patella patterns of the male and female were quite different although they did resemble the patterns shown by the right patella for each subject.

The same is true for the left tibial tubercle, the male and female patterns were different. The female pattern seemed to be opposite of the male pattern. The female tibial tubercle showed a gradual rise to a peak, whereas the male pattern showed a peak and then a gradual decrease.

At the fast speed the movement of the left crest for the female differed significantly from the movement of the same landmark for the male subject. The movement of the female subject did not seem to travel through as great a range of motion as did the left crest of the male subject. Other than the difference in amplitude of the two graphs, the general pattern of movement appeared similar between the genders. The left ASIS seemed to show some slight gender differences during the fast speed of walking. The female subject showed a more pronounced movement at heel strike, while the male showed a more pronounced movement at toe off.

The left tibial tubercle and left patella showed huge gender differences during walking at the fast speed. The pattern of the female's patella is unlike that of any other patella pattern seen in this study. There was a repeatable pattern however, so the researcher does have faith in this variable. The graph showed a very fast increase at heel strike, with a sharp decrease following that and then another small sharp increase dropping off quickly at toe-off. This is very different from the male subject's pattern, which resembles other patella movement patterns exhibited by the other subjects in this study. A sharp increase to a peak at heel strike with a gradual decrease in vertical movement to toe-off. The tibial tubercle movement for the female subject does not really show a repeatable pattern. This subject 's movement pattern resembled that produced by other subjects. However, this subject's pattern was not all that stable either.

The back view of the subjects at the slow walking speed again produced some conflicting results. Some variables suggested gender differences in walking while others did not. The lumbar vertebra landmark produced a fairly repeatable, steady pattern for both the male and female subjects. The left crest marker from the rear view however, suggested that gender differences may be present. The male subject showed a nice steady pattern not that different from the pattern displayed by the L4 landmark. The female's movement pattern was unsteady and not repeatable.

The left PSIS showed similar results in that the male's movements seemed much steadier than the female subject's movements. Although neither pattern was highly reproducible because of the fact that neither was repeated with much consistency. The left gluteal muscles showed huge gender differences although this was expected because of the soft tissue underneath these markers.

At the fast walking speed the L4 marker indicated some gender differences while walking. The male subject had a nice steady pattern, while the female subject did not seem to exhibit any repeatable movement pattern. The same can be said for the left crest marker, that the male subject showed a nice pattern, while the female subject did not. The left PSIS variable for the female subject was unsteady as well. The male subject once again showed an invariable movement pattern. Interestingly enough, the one variable which seemed to be steady for the female was the left gluteal muscle, it varied from the pattern displayed by the male subject, but this is the first time at this walking speed (1.94 m/s) that a repeatable pattern was exhibited by the female subject. The male's pattern once again was steady and repeatable.

It is interesting to note that for subjects 8 and 9, the heavier subjects, there were little spikes in the graphs at the beginning of each peak. This could possibly be attributed to movement of the extra flesh and adipose tissue that these subjects carry. In cases where no repeatable pattern was found this was attributed to the subject shifting laterally on the treadmill while walking.

Y (vertical) component

For the remaining subjects the Y component will be the only component discussed. A decision was made to only study this component because as stated earlier, the X component and therefore the resultant component were unreliable because of the subjects' movement laterally on the treadmill during the walking trials. No reference point was used in the filming process and therefore this lateral movement could not be factored out of the data during the data conditioning. The certain anatomical landmarks that were studied were chosen because of reasons stated previously. The variables that were examined for the rest of the subjects were the following: the right crest, the right ASIS, the right and left patellae, and the right and left tibial tubercles from the front view. The rear view variables discussed were L4 and the right gluteal muscles. The remainder of the subjects will not be discussed individually as done earlier in this paper. The results of the females and males in general will be viewed as two groups respectively and thus discussed as one entity as opposed to individually.

Not surprisingly, the right crest and ASIS for the females looked similar. These findings were also noted for subject 2. There was a distinct pattern of a two peak cycle during the slow walking trials. Although the heaviest female subject, number 9 showed a slightly different pattern than the rest of the females, the differences were probably not significant. The male subjects as well, showed the same patterns as the females on both of these variables. Over all it could be said that the information gained through the iliac crest and ASIS variables showed no gender differences in the movement of these bones of the pelvis during walking please see Figures 11 and 12.

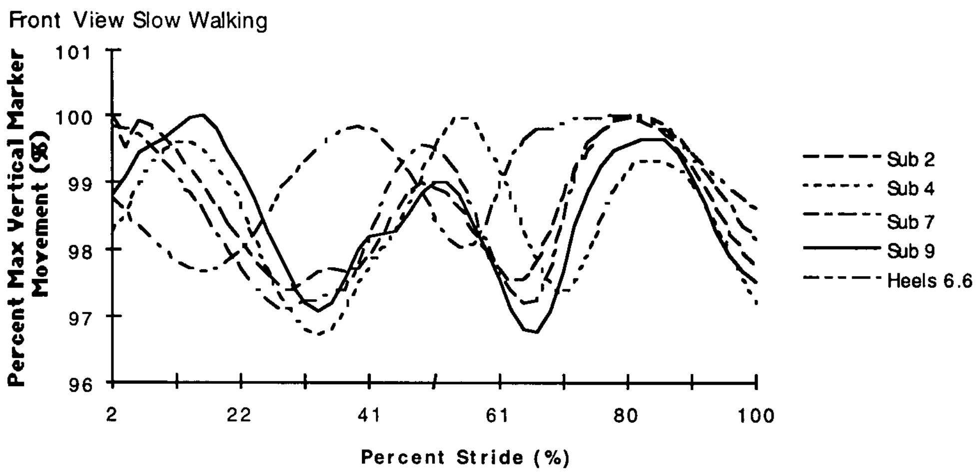

Figure 11. Female subjects iliac crest vertical movement at 0.94 m/s.

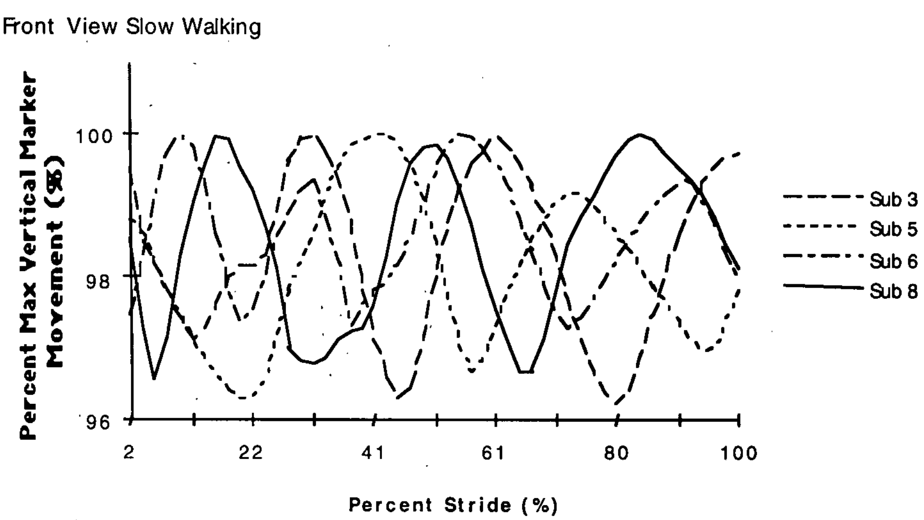

Figure 12. Male subject iliac crest vertical movement at 0.98 m/s.

The right and left patellae for both men and women appeared to have the same movement pattern. The pattern being a sharp rise to a point, with a gradual decline of the curve incorporating two or three smaller peaks and then a sharp drop-off. It is assumed that the first sharp increase was heel strike and the final drop-off was toe-off. This pattern appears very consistent after the X component had been factored out.

The movement of the left and right tibial tubercle did not seem as consistent as the patellae variables, however as with the patellae, the tibial tubercles look much better with the horizontal component of movement factored out. There are no distinct gender differences on these variables. It is interesting to note that for both the men and women some asymmetry does exist between the tibial tubercles.

The front fast trials of walking for men and women yielded still more interesting results. Yet again, the right crest and right ASIS for both the males and females were very similar while walking at this fast speed. The patterns were the same as those of the slow walking trials only the timing is much quicker during the fast walking trials. As previously seen the heavier subjects have more inconsistent movements in their patterns. This is possibly due to the movement of soft tissue and not the actual skeletal movements.

The movement patterns of the left and right patellae during fast walking again produce no gender differences. The pattern of these landmarks seemed to be tighter and more consistent at the fast speed, than at the slow speed.

The graph of the tibial tubercles showed some exciting results, the second peak of the cycle was more accentuated for both the male and female subjects while walking at this fast speed than at the slow speed. Here also, the movement pattern tightened up as speed increased. It is interesting to note that both groups of subjects showed the same response to increasing the speed of walking, showing yet again evidence of gender similarity in the walking movement.

Turning now to the rear view of the subjects while walking at the slow speed, some gender differences in the movement of the L4 vertebra were seen. This result must be interpreted with caution however, because it was only one female subject that was different from the rest of the female subjects. This one set of data did skew the results. If this subject (7) was taken out of the analysis for this variable no gender differences would have been noted.

The right gluteal muscles did show some gender differences. This was expected due to the movement of the soft tissue under the reflective markers. It is difficult to characterize a specific male and female pattern as each subject seemed to have a unique pattern. It is interesting that although there was no set female or male pattern, each individual has a repeatable pattern, see below Figures 13 and 14.

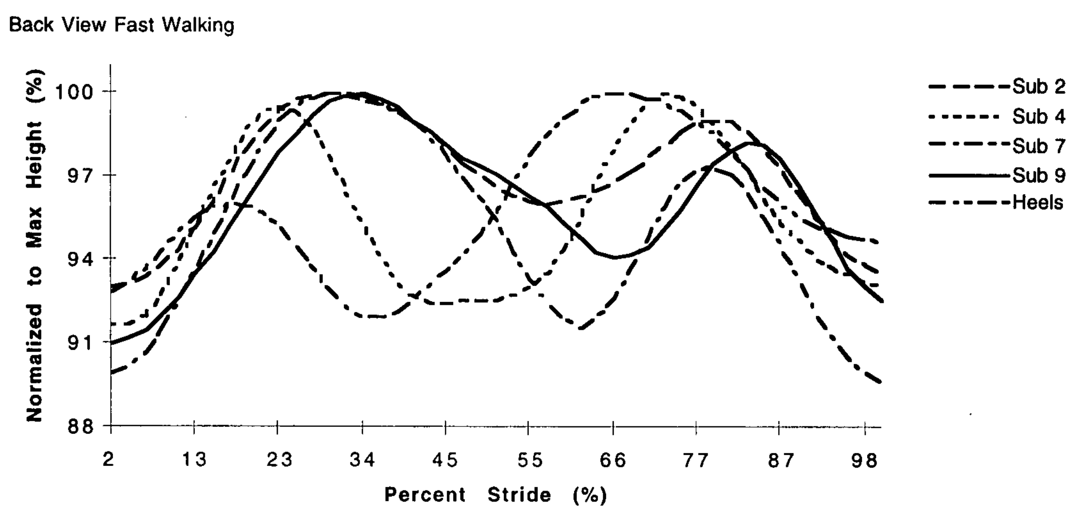

Figure 13. Female subjects gluteal muscle vertical movement at 1.94 m/s.

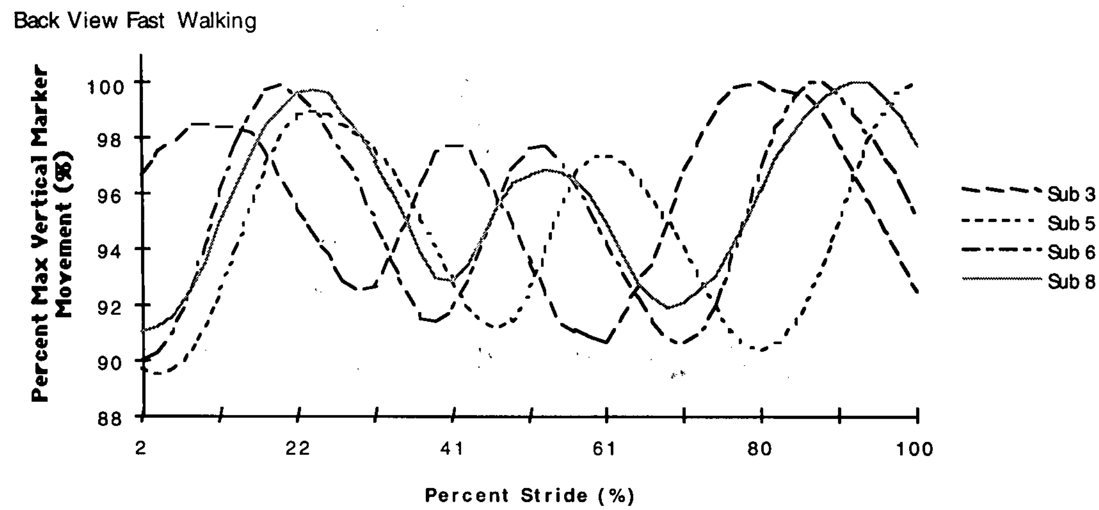

Figure 14. Male subjects gluteal muscle vertical movement at 1.94 m/s.

Although the slow walking trials showed no consistent gluteal muscle movement patterns the fast speed trials did. This was concordant with the other variables that showed a tighter movement pattern at the fast walking speed than at the slow walking speed. There was once again no gender differences on this variable.

The front view of this subject indicated some interesting trends. The right crest marker showed the same movement pattern for all three conditions, however, the two shoe conditions indicate that the vertical movement of this marker moved with greater articulation than in bare feet. Heel strike and toe-off are greatly accentuated in high heeled shoes. The same comments could also be made with respect to the right ASIS at the slow walking speed. In fact the two graphs look very much the same. This is not unexpected when one considers bone and that the markers are situated close together see Figure 15.

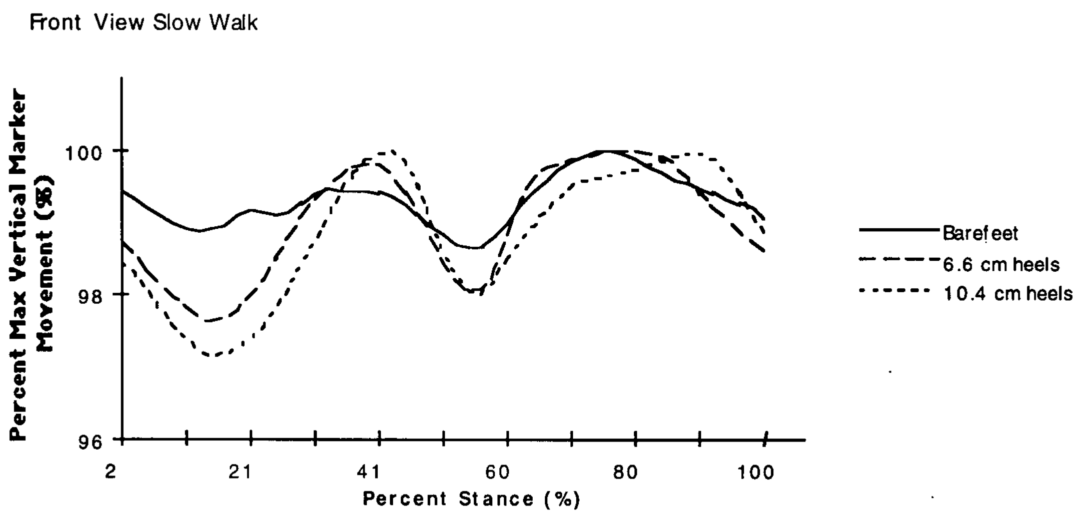

Figure 15. Vertical right crest movement of experienced heel wearer.

The front view slow walking graph of the three conditions for the right patella show interesting points. Again the two shoe condition patterns mimic each other. What is interesting is the pattern for the patella while the subject is wearing no shoes. At heel strike the graph continues in the opposite direction than the other two curves, see Figure 16.

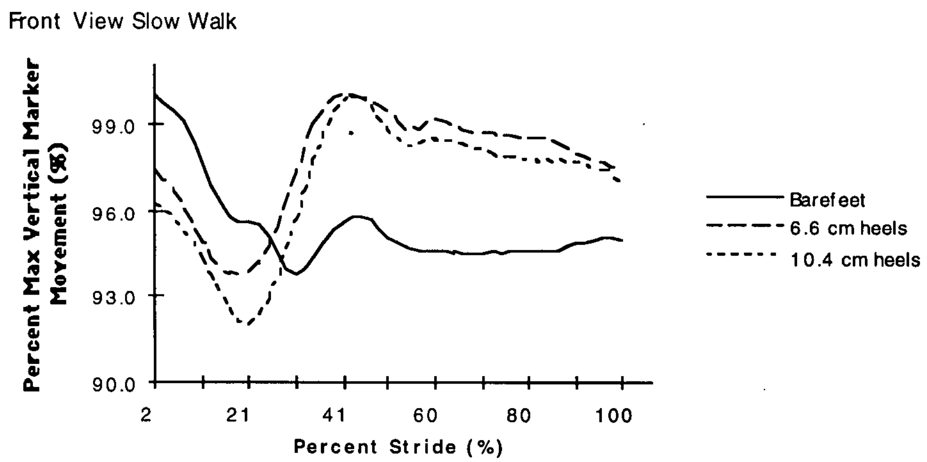

Figure 16. Vertical movement of the right patella of experienced heel wearer.

This indicates that at heel strike in bare feet the subject continues to flex the knee, whereas in high heels this would not be the case. Because the ankle is plantar flexed, the subject must extend the knee immediately at heel strike to propel the body forward.

The tibial tubercle marker is similar to the patella in this slow walking trial. The two shoe condition patterns follow one another closely, except the high heel condition is occurring higher up that the moderate heel condition, which is expected.

The fast walking condition show virtually the same patterns for each marker as the slow condition. Once again the only difference being more accentuated patterns. The meaning of this can be seen in the graph of the tibial tubercle, see Figure 17.

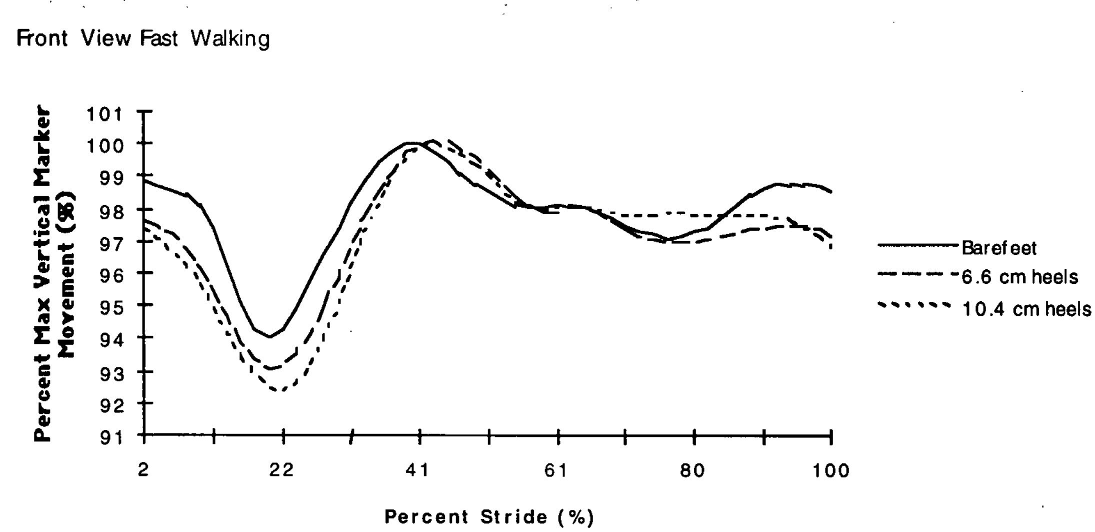

Figure 17. Vertical movement of right tibial tubercle of experienced heel wearer.

All three conditions follow the same movement pattern and the important events in the gait cycle seem to stand out slightly more than in the slow walking trials. The only differences that can be seen between the slow and fast walking speeds are that the slow speed the barefoot condition seemed to diverge from the two shoe conditions at the patella and tibial tubercle, whereas at the fast speed the patella and tibial tubercle patterns seemed to follow each other during each condition.

For the back view the data gathered were limited. Data were only collected at the fast speed and only two conditions were completed, bare feet and high heels. The graphs examined were of the left side of the body as opposed to the right side as in the front view. This was done to try and get an overall picture as to the movement of this subjects while walking. The fourth lumbar vertebra (L4), left crest, left PSIS and left gluteal marker all looked very similar between the two conditions, see Figure 18.

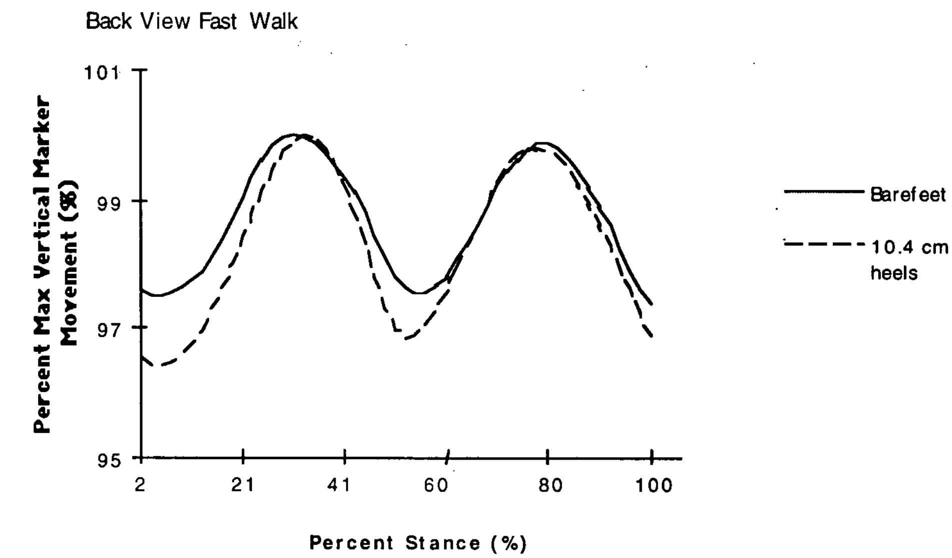

Figure 18. Vertical movement of the fourth lumbar vertebra experienced heel wearer.

Surprisingly the gluteal marker even represented closely what the bony markers were doing.

The sagittal view of this subject yielded joint angles which suggest some interesting things. As can be seen from the slow walking trials, the ankle and foot angles showed similar patterns, see Figure 19.

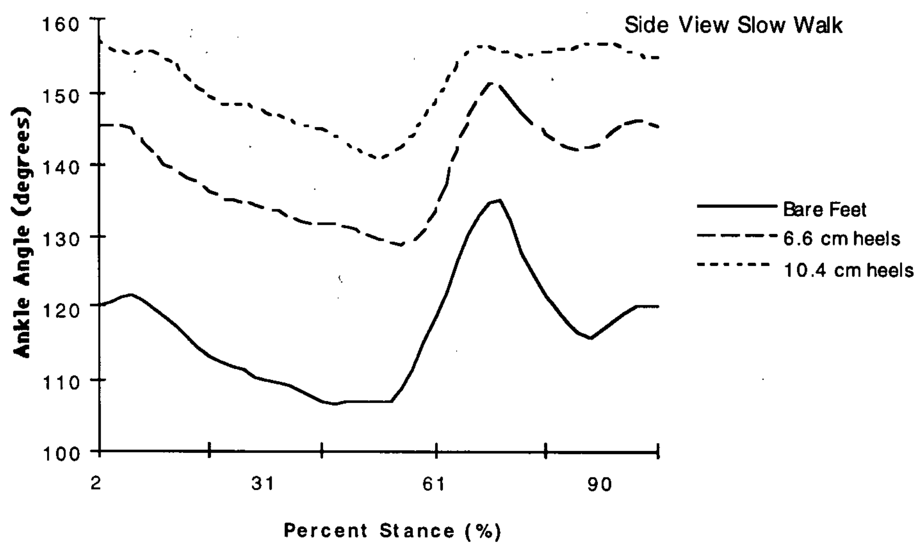

Figure 19. Ankle angle during slow walking for experienced high heel wearer.

The only differences seems to be that in bare feet these angles move through a greater range of motion which is what is expected. In the shoes the foot and ankle are fixed in a plantar flexed position. Thus decreased range of motion at this joint is expected and makes sense.

The slight difference that exists between trials at the foot and ankle seem to be factored out by the time they reach the knee and hip as can be seen in Figure 20.

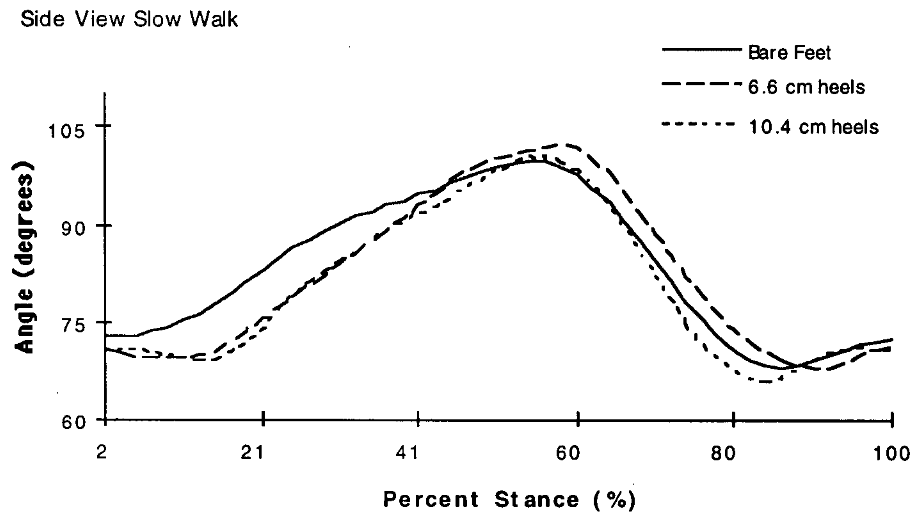

Figure 20. Hip angle during slow walking for experienced high heel walker.

All conditions follow a tight movement pattern. Although the hip angle for the barefoot trial does wander slightly in the first phase of the gait cycle the differences are not large. The hip seems to extend slightly earlier than in the two shoe conditions, possibly because in heels, heel strike happens earlier due to the shoe and therefore there is some lag time before the hip must extend.

The fast speed of walking shows joint angles closely related to the ones seen at the slow walking speed. The patterns of the ankle and foot are slightly different between conditions, but the differences are factored out when the knee and hip angles are examined see Figure 21.

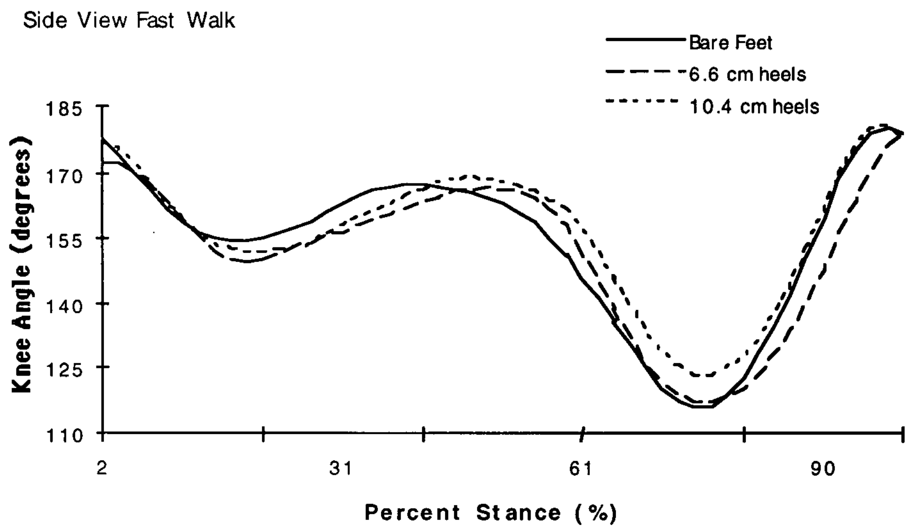

Figure 21. Knee angle during fast walking experienced heel wearer.

As can be seen from the above discussed results most variables showed no differences in skeletal movement between men and women during walking. Although some variables did indicate that walking might be different between men and women the overall picture suggests not.

Female Subject Walking in Heels

The subject that walked in heels for the study was subject 2 who had earlier walked under the normal conditions that all subjects were given. This subject came back on a different day, wore the same clothing (except for the 5.2 cm high heeled shoes) and walked again at 0.89 m/s and 1.94 m/s for two minutes each.

The patterns of the right crest and right ASIS while walking at the slow speed for subject 1 appeared relatively similar to that of the patterns the same subject with no heels. There was a slight difference in the movement patterns in that subject 1 appeared to have a less steady pattern, especially for the iliac crest movement. The right and left patella movements did not seem to be effected by the high heels the subject was wearing. The patterns are very similar to those of the same subject walking while in bare feet. The tibial tubercle variables seemed to be somewhat effected by the heels. The left tibial tubercle in particular showed quite a different pattern between the non-heels trial and the heels trial. The heel strike and toe-off phases of gait were more pronounced when the subject was wearing heels. The back view of the subject in heels was slightly different than the subject in bare feet. As seen with other variables, the L4 movement pattern was somewhat unsteady as opposed to the pattern produced by the same subject with no shoes. The gluteal muscles pattern was significantly different while wearing heels versus no heels. However, in this instance the trials where the subject was wearing heels seemed to be smoother than the trials with no shoes worn.

The fast walking speed for subject 1 showed that the right crest seemed to move the same whether heels were worn or not, this is interesting in light of the results of the slow walking speed indicating that there were differences between the heels and non-heels trials. The right ASIS showed some small differences between heels and non-heels. One difference was that the heels trial went through a greater amplitude of movement than the non-heels trial did. The heels trial moved through 70 mm vertically, while the non-heels trial moved through 50 mm. Also there seemed to be a greater distance travelled vertically between the heel strike and toe-off of the non-heels trial than the heels trial. The right and left patellae looked virtually the same for the trials with or without heels. The tibial tubercles looked somewhat different between the two trials There was a sharper peak at toe-off during the non-heels trials than during the heels trials.

Overall, there did not really seem to be a difference in the movement pattern for the same subject wearing heels and not wearing heels. Some variables showed differences, however the majority did not. Considering it was the same subject walking with and without heels these results are reliable.

Quadriceps Angle

The Q-angle was calculated for all subjects as this measure is often used when comparing differences between men and women during walking and running. The results yielded some interesting information. Referring to charts 1 and 2, one sees that the average Q-angles for men and women found in this study agree with those found in the literature. Atwater (in Cavanagh, 1990) states that most men have a Q-angle of about 10 degrees while women's Q-angles generally measure about 15 degrees. She goes on to say that a Q-angle of greater than 20 degrees is considered abnormal. The men in the current study had smaller Q-angles for all walking speeds and all legs than did the women.

Q-angle was calculated throughout the entire walking cycle. So the average Q-angle for each subject includes the angle while the leg was in swing phase. Chart 1 and 2 have negative Q-angles as well. A negative Q-angle represents the direction of the quadriceps pull. The minimum and maximum Q-angles for men and women were calculated as well. Charts 1 and 2 shows these figures. As can be seen, at both speeds the men had larger minimum Q-angles than the women. This is interesting, in that the literature states that women have larger Q-angles than men. This concept was reinforced however when the maximum Q-angles were examined for both men and women. The maximum Q-angles indicated that the women had larger Q-angles than the men. Again from charts 1 and 2 it was seen that women have on average a larger Q-angle than men at both speeds and for both legs. When these results are considered simultaneously one sees that the women's Q-angles covered a broader range of the spectrum. A surprising result was found when looking at the speed effect on Q-angle. For both the males and female there seemed to be no effect of speed on Q-angle. Also there did seem to be large leg differences in Q-angle for the women, but not the men.

Discussion

As is seen from the above discussed data, it is with some confidence that this author states there are indeed gender differences in walking with the delimiter being only on certain variables. In some instances there indeed does seem to be differences due to sex. In many circumstances no gender differences occur between the male and female subjects. The effect of speed had no recognizable effect on the data, as well the high heels worn by one female subject did not yield any definite information about the gender differences of movement of certain bony landmarks.

The iliac crest and ASIS variables basically did not indicate that gender differences occur during walking. The patellae and tibial tubercles sometimes showed gender differences, however not in all cases. The L4 vertebrae unexpectedly indicated differences between the genders. Finally, the gluteal muscles usually showed differences between the men and women but not on a consistent basis.

As discussed earlier, the resultant component data was unpredictable as was the X component data. It would be interesting to see whether the X component truly does show differences between the genders or whether the differences see were due to movement of the subjects on the treadmill. If these components are unpredictable then more validity is given to this study in only examining the Y component.

The Q-angles calculated for the study are skewed somewhat because they incorporate the swing phase. During the swing phase the Q-angles would be distorted due to the flexion of the knee. This part of the walking cycle would better be left out and only the stance phase Q-angle calculated.

One subject walked twice in the study once following the same protocol as the other subjects and once on a different day wearing 5.2 cm heeled shoes. This variable was introduced in the study to try and determine whether a social influence played a role in gender differences in walking. Women dress differently then men, wearing tight clothes and often high heeled shoes. If differences seen they could be due to the environment or due to biology. Determining if there are gender differences in walking or whether women truly do walk differently than men is an important and interesting question. If the same subject walked with the same pattern in both conditions the social influence could be ruled out. If there were indeed differences between men and women during waking seen then the differences would truly be due to body type. The data from this study suggests that when conditions are similar for men and women differences are not generally seen during walking.

The men and women used in the pilot study were slender. These types of subjects were used to try and be as accurate as possible in marker placement on the skeletal system. The movement of the pelvis was what is sought in this study thus, monitoring the skeleton is the most effective way to do this. Even so, much of the movement of the markers must be attributed to the movement of skin and soft tissue and clothing in some cases. However, no better options are available other than having the subjects walk nude. This is not practical for obvious ethical reasons.

Some differences were seen between the men and women, but the reliability and validity of these results is somewhat questionable. A more in depth look at the averages and perhaps some statistical analysis would yield more relevant information. More subjects as well would lend more confidence in the study. For the one subject that wore high heels it is interesting to note that only some variables show differences between heels and no heels for the same subject. Gender differences in walking are slight but some do seem to exist. The slight differences that do exist probably do so because of environmental factors as opposed to anatomical deviations between the sexes.

Some of the results of this study agree with the literature. The differences in Q-angle between the men and women in this particular study support other results obtained in many other research studies. The Q-angles found for both the men and women were very close to those previously stated in the literature. The kinematics examined in this study do not support the notion that men and women walk differently. In general, the variables examined for this project showed no sex differences during two different speeds of walking. One could argue that although there seems to be differences between the Q-angle of men and women, the conclusion can not be made that they walk differently from one another. The statement that men are more efficient walkers mechanically, than women is not valid in light of the kinematic data examined in this study.