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Kinematics of ambulatory runners with cerebral palsy: Class C5 to C8

by

© Karen Erika Natho

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ABSTRACT

To date, few studies have compared cerebral palsy (CP) running parameters. The purpose of this study was to identify and compare running patterns derived from biomechanical cinematography of subjects with CP athletically classed C5 to C8. The investigation focussed on between-class differences of lower limb temporal and kinematic variables. This study investigated whether there were significant differences between selected linear / angular variables during running in the four classes. Eight subjects were filmed, using four cameras, running 15 strides (right/ left limbs) over 25m. Non-parametric results did not illustrate between-class differences. However, when classes C5 & C6 and C7 & C8 were grouped, fifteen variables differed significantly (i.e., stance time, stride length, stance - swing ratio, hip ankle - maximum extension, trunk angle - maximum flexion / extension, left limb swing time). Trends also illustrated: stride length, swing percentage, trunk flexion and hip extension and flexion, knee flexion, hip and knee ROM all increased as the classes became more able.

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" All I really need is a song in my heart,
(Thanks Massawippi, Horizon, Northwood and Merrywood)
Food in my belly,
and love in my family" (Thanks Mom, Dad and Jamie - I will always love you better than M.C.I.C.)

- Raffi

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LIST OF ABBREVIATIONS

ABBREVIATION	WORD PHRASE
CP	cerebral palsy
CP-ISRA	Cerebral Palsy International Sports and Recreation Association
DF	dorsiflexion
IBSA	International Blind Sports Association
INSA-ID	International Sport Association for the Intellectually Disabled
IPC	International Paralympic Committee
ISMWSF	International Stoke Mandeville Wheelchair Sports Federation
ISOD	International Sports Organisation for the Disabled
PF	plantarflexion
ROM	range of motion
Std Dev	standard deviation

CHAPTER 1
Introduction

1.1 Introductory Statement

Classification is the fundamental system that differentiates Paralympic from Olympic sports. Years of hard work have lead to the creation of the Paralympic classification system, which has had continuous adjustments and revisions throughout the years. However, to date, an insufficient amount of research has been completed in ambulatory track events.

The tenth Paralympic Summer Games in Atlanta, Georgia was host to 3211 athletes making it the second largest sporting event in the world after the Olympic Games (Sherrill, 1997). These athletes represented five international sporting organizations: Cerebral Palsy International Sports and Recreation Association (CP-ISRA); International Stoke Mandeville Wheelchair Sports Federation (ISMWSF); International Sports Organisation for the Disabled (ISOD); International Sport Association for the Intellectually Disabled (INSA-ID), and the International Blind Sports Association (IBSA).

Prior to a sporting event, all Paralympic athletes are classified to ensure an equal playing ground (McClellan & Frogley, 1993). Modifications and improvements to the classification system have been rarely investigated and evaluated (Williamson, 1997). Regardless, organizers continue to strive for fair competition between groups of similar sporting potential. This responsibility is placed in the hands of classifiers who are qualified sport technicians, medical doctors, and other health care professionals, who are required to assess and assign athletes to classes. As classifiers, they consider impaired movement skills such as coordination, balance, and reflexes, evaluated in competitive settings.

To simplify administration during competition and to improve competition, organizers of international events are calling for a reduction in the number of classes (Cooper & Bedi, 1992). Reducing classes, by having different disabilities compete together, would simplify administration of the competition, create a larger competitive field, increase the credibility with the media and public, and prevent certain events from being deleted due to a lack of entries (Richter, Adams-Mushett, Ferrara, & McCann, 1992). Recently, the International Paralympic Committee (IPC) moved to promote events for athletes with disabilities in the Olympic Games (Steadward, 1992). Having many races for one event, (for example the 200-metre race had twenty events for both ambulatory and wheelchair participants at the Atlanta Games), makes it difficult to integrate events into the Olympic Games. A reduction in the number of competitive classes would be necessary for the Paralympic movement before Olympic participation is possible. Although the IPC is moving to merge disability sport into nondisability sport, the excessive amounts of events makes integration difficult.

In line with this initiative, CP-ISRA has streamlined the number of competitive groups into eight classes to represent all athletes with cerebral palsy (CP). The four most mobile classes C5, C6, C7, and C8 compete in athletic events without the use of assistive devices. The classes are based on a functional model versus the previously used medical model, with the level of disability and sport related tasks deciding classification. Sport specific skills, reflex activity, repetitive activities, and quick movements are tested by the classifiers (L. Holland, personal communication, June 22, 1998; CP-ISRA, 1997).

Biomechanics, one of the many sport-related sciences, has the potential to make a significant contribution to the continually growing area of sport. At this time, limited research has investigated the biomechanics of running in athletes with CP.

1.2 Statement of Problem

Over the years there has been ongoing discussion about combining disability groups and classes for competition. CP-ISRA has expressed great concern about the potential of having their athletes compete against others with different disabilities (L. Holland, personal communication, June 22). It is believed that an athlete with a spinal cord injury or amputee has a static disability that does not change, whereas an athlete with CP experiences physiological changes throughout an event putting them at a disadvantage (L. Holland, personal communication, June 22). Lina Faria, the past president of CP-ISRA, wrote to the IPC, that combining classes would greatly underscore the efforts of all the Paralympic athletes (L. Faria, personal communication, April 29, 1998).

Research has been completed, showing how certain classes within wheelchair racing and swimming events can be combined. (Higgs, Babstock, Buck, Parsons & Brewer, 1990; Brasile, 1990; Cooper & Bedi, 1992; Brookes & Cooper, 1987; Coutts & Schutz, 1988; Richter et al., 1992). To date, little initiative has been made to investigate different variables of ambulatory athletic events across different disabilities. In fact, only two running studies have researched biomechanical differences involved in running for individuals with CP (Pope, Sherrill, Wilkerson & Pyfer, 1993; Davids, Bagley, & Bryan, 1998). Pope et al. (1993) found variables differed between Class C6, C7, and C8 in hip range of motion (ROM) and velocity, knee and elbow ROM and trunk angle. Pope et al. (1993) recognized some differing variables with sprinting among the three classes but it focussed on comparisons with the nondisability literature. Davids et al. (1998) reported on running variables involved for children with CP. Subjects with spastic-diplegic CP were compared and contrasted with a control group without a disability. To date, no studies have investigated and compared the running parameters involved for healthy CP adults with various levels of disability.

1.3 Purpose of the Study

Based on the fact that few study has investigated the running patterns for Class C5 to C8 using healthy adults with CP, the following biomechanical study was undertaken to identify and compare running data derived from biomechanical cinematography from subjects classed C5 to C8 to supply the academic field with insight and a resource tool as well as provide the disability sporting community some insight on the kinematics for the ambulatory classes.

This study explored the differences between the running styles of the four CP ambulatory classes. The purpose was to identify linear and angular kinematic running variables of individuals with cerebral palsy Class C5, C6, C7, and C8, and distinguish kinematic differences between the classes.

The specific goal of this study was to answer the question: Were there significant differences between selected linear and angular variables during running for athletes in Class C5, C6, C7, and C8?

The main independent variable in this study was the four separate classes. Dependent variables were two sets of kinematic variables; 1) **Linear variables** including stride length, stride time, cadence, stance and swing ratio, and double float percentage, and 2) **Angular variables** of the ankle, knee, hip, and trunk.

1.4 Limitations of the Study

1. The CP ambulatory population in Edmonton was small. This affected the number of participants available and recruited. The sample size compromised the power and effect size within the study.
2. This two dimensional study eliminated the human movement in the third plane. Therefore all movements beyond the planes associated with the camera lens were either not measured or subject to perspective errors.
3. Systemic or equipment error exists with video analysis and impacts the collection of data. These errors lie in the lens optics, precision of the cameras, marker movement, and locating anatomical landmarks with surface markers. The researcher attempted to control these errors by using sensitivity tests throughout the study.
4. The manual digitizing process involves human intervention which introduced error. To control for human factor error the same digitizer was used throughout the study.
5. Markers had to be located during the cycle at times when they were not in view. This decreased the accuracy of marker identification during video digitizing.
6. The study was based on the assumption that the classification team could classify the participants accurately.

1.5 Delimitations of the Study

1. The study was delimited to:

A. Participants with CP;

B. Level of disability that would correspond to one of the four classes (C5, C6, C7, or C8) as decided by the classification team.

C. Subjects able to run 25m on a level runway without the use of external aids, such as braces, canes, walkers, orthotics, or crutches.

2. The biomechanical analysis was delimited to kinematic factors which is only one of the many areas that concern gait clinicians, classifiers, and athletes.

3. The background and experience each subject had with running was not taken into consideration.

4. The analysis was delimited to lower extremities of the body, excluding analysis of the upper extremities.

5. The analysis of the data was restricted to two dimensions in the sagittal plane of motion.

6. The participant sample was self-selected thus affecting generalizability (Keppel, 1973). Therefore, results would not represent and could not be compared to the general population but could only be generalized to other individuals of the same CP class with similar running mechanics and experience.

1.6 Definition of Terms

Anatomical position: a person standing upright, with feet together, arms by the sides and palms forward.

Absolute angle: the angle formed by two vectors in which one represents an axis in space (vertical or horizontal).

Ankle plantar/dorsiflexion: maximum joint angle of flexion and extension found at the ankle, defined by a relative angle between the foot and ankle segments, plantarflexion was recorded during toeoff and contact phases, and dorsiflexion during midstance and midswing phases.

Ankle neutral position: was an ankle angle of 70 degrees. This ankle angle was defined when the dot product between the vectors representing the shank and foot was equal to 90 degrees (Winters, 1979).

Ashworth Scale: widely used scale in clinical setting to measure spasticity.

Ataxic: loss of coordination, a lack of sense of balance and position in space.

Athetosis: continual uncoordinated movement of the limbs. Limbs have involuntary, purposeless movements and purposeful movements are contorted. There is a marked persistence of primitive motor reflexes.

Cadence: numbers of steps in one minute.

Cerebral palsy: neurological disorder with spasticity and incoordination caused by brain damage around time of birth. Cerebral palsy (literally, paralysis of the brain) is a non-progressive disorder of movement that begins in childhood (prenatal, perinatal or postnatal) and is caused by malfunctioning of or damage to the brain. It results in a loss of selective control of muscles by the motor cortex and emergence of spasticity (Bleck & Nagel, 1982).

Classification criteria for Class C5, C6, C7, and C8: Classification requirements for Class C5, C6, C7, and C8 (Table 1.1)

Table 1.1

Classification Guidelines for Class C5, C6, C7, and C8

Class	*Guidelines*
C5	Symmetric or asymmetric moderate diplegic; a slight change in centre of gravity leads to loss of balance; grade 3 spasticity in lower extremities.
C6	Moderate athetoid or ataxic; ambulates without aids; some spasticity present.
C7	Ambulant hemiplegic; spasticity grade 2 to 3.
C8	Minimally affected diplegics with spasticity grade 1 to 2; hemiplegics with spasticity grades 1 to 2; monoplegics; minimal athetoids.

Note. Reprinted from "Classification Guide:", Medical Science Sub-Committee & Organizing Committee, 1994, FESPIC Beijing '94 p. 7-9.

Contracture: a reduction in ROM due to restriction by inelastic connective tissue.

Diplegia: paralysis of both arms or both legs.

Double float: a percentage of the gait cycle in which both feet are not contacting the ground.

Double support: a percentage of the gait cycle in which both feet are in contact with the ground.

Gait: manner or style of walking/running.

Gait cycle: interval between two successive occurrences of one of the repetitive events of running, which includes four phases (Vaughan, Davis & O'Connor, 1992):

1) Contact phase : from terminal swing to initial stance including when the foot makes contacts the ground
2) Midstance phase: from initial stance to terminal stance including when the foot is in contact with the ground and the leg is perpendicular to the ground
3) Toeoff phase: from terminal stance to initial swing including when the foot comes off the ground
4) Midswing phase: from initial swing to terminal swing including the midpoint of time between toeoff and contact.

Hemiplegia: complete paralysis affecting one side of body.

Hip flexion/extension: maximum angle of flexion/extension found at the hip defined by the absolute angle of the horizontal axis and thigh segment. Maximum hip flexion in this study was found within the contact phase and maximum extension during the toeoff phase.

Kinematics: describes motion but without reference to forces involved.

Knee flexion/extension: angle of flexion/extension at the knee defined by a relative angle formed between the thigh and shank segments. In this study, flexion was recorded during midswing and midstance phases, and extension was during toeoff and contact phases.

Less able: a group which is more severely disabled than the group to which it is being compared.

Marker: an object fixed to a point on skin or clothing that is visible to an optical measurement system; typically a small sphere covered in reflective tape.

Mixed involvement: most commonly a combination of spasticity and athetosis usually characterized by deficient balance reactions.

Monoplegic: one limb is involved.

More able: a group which is less severely disabled than the group to which it is being compared.

Multidisability system: having different disabilities compete against one another.

Paralysis: loss of ability to contract a muscle voluntarily due to damage or lesion to the central or peripheral nervous system.

Quadriplegic: four limbs are involved.

Reference system: a right-handed orthogonal triad, XYZ, fixed in the ground. The axes for a person standing in an anatomically defined neutral position was defined as:

X pointing forward (anteriorly)

Y pointing upward (superiorly)

Z pointing rightward.

Relative angle: the angle formed by two vectors represented by two body segments.

Run: ability to ambulate faster than a walk but slower than a sprint.

Sagittal axis: the plane dividing the body into left and right parts going longitudinally.

Spasticity: syndrome associated with a persistent increase in the involuntary reflex activity of a muscle in response to stretch.

Spasticity Grades: spasticity grades (Table 1.2).

Table 1.2

Modified Ashworth Scale

Grade	*Criteria*
0	No increase in muscle tone.
1	Slight increase in muscle tone, manifested by a catch and release or by a minimal resistance at the end of the ROM when the affected part(s) is moved into flexion or extension.
1+	Slight increase in muscle tone, manifested by a catch followed by a minimal resistance throughout the remainder (less than half) of the ROM.
2	More marker increase in muscle tone through most of the ROM but affected part(s) easily moved.
3	Considerable increase in muscle tone, passive movement difficult.
4	Affected part(s) rigid in flexion and/or extension.

Note. Reprinted from "Interrater of a modified Ashworth Scale of muscle spasticity", Bohannon, R.W. & Smith, M.B., 1986, Physical Therapy, 67, p. 206-207.

Stance: part of the gait cycle when the leg is in contact with the ground which includes:

1) after contact
2) midstance
3) before toeoff.

Stride length: distance in centimetres of the swing phase measured from contact to the next contact of the same foot in the forward progressive line.

Swing: part of the gait cycle when the leg is not in contact with the ground which includes (Ounpuu, 1994):

1) after toeoff
2) midswing
3) before contact.

Tone (muscle): amount a muscle resists attempt to stretch; high tone is present in spasticity.

Trunk angle (forward/backward lean): angle of forward flexion and backward extension defined by a absolute positive angle of the horizontal axis and trunk segment. In this study maximum flexion was found during the toeoff phase and maximum extension during contact phase.

CHAPTER 2

Literature Review

2.1 Introduction

The purpose of this literature review was to outline and introduce data from major areas of research that led to the undertaking of the present study. These areas included:

1) basic ideas and protocol of athletic classification focussing on CP-ISRA,
2) studies that existed researching the classification system,
3) alterations suggested to the classification system,
4) definition of cerebral palsy and characteristics of CP gait,
5) kinematic studies of running,
6) biomechanical studies outlining running patterns for populations with a disability, and
7) research comparing treadmill and ground running.

2.2 Athletic Classification

Running is a popular track event in the Olympic and Paralympic Games. Athletes at the Paralympics are assigned to a class, based on their medical and/or functional status. They then compete with other athletes of a similar class. Classification of athletes is dependent on their medical diagnosis and their functional ability. Functional tests are modelled around components such as ROM, flexibility, strength, and coordination. Each of the five international sporting organizations have their separate guidelines and criteria for classification.

For example, CP-ISRA presently recognizes a classifying team that consists of a doctor, sport technician, and rehabilitation professional (an occupational or physical therapist). New athletes competing for the first time are assessed by a certified classification panel and given a label; permanent or review. If the status is permanent, the classification team is confident that the class assigned is correct. If the status is review, the class is ambiguous and needs to be reinvestigated at a later time (L. Holland, personal communication, June 22, 1998).

Although CP-ISRA implemented specific criteria for their athletes, within athletics, a multidisability system was accepted for the IPC World Championships in Athletics, Birmingham, 1998 and XI Paralympic Summer Games, Sydney, 2000. In

Birmingham, wheelchair athletes raced on the track and threw implements in the field simultaneously but awards remained segregated according to disability and classes. Due to the success of this system, the possibility of combining athletes from the ambulatory events is being considered for the 2002 World Championships and 2004 Paralympic Summer Games (L. Holland, personal communication, June 22, 1998). As a result, the four ambulatory CP classes (Class C5 to C8), will most likely compete against different classes and disability groups. The advantages and disadvantages of this proposed system have yet to be determined through research.

2.3 Classification System Studies

To date, performance differences in classes between the current and past classification systems have been investigated. Research has identified the differences between the classes and, in some cases, have helped reduce the overall number of classes. Cooper and Bedi (1992) collected competition results from the top ten finishers in wheelchair road races to examine differences in performance. Performance was based on race time and placement according to the class of the competitor. Cooper and Bedi (1992) used the four wheelchair classes, Class II through V, which represented four paraplegic classifications based on medical assessments. Subsets were created and included: spinal cord injury, spina bifida, polio, amputee, and Les Autres. Results demonstrated no significant difference (p>.05) between classes and disability etiology when compared on time and finishing order. In concert, with these findings, Coutts and Schultz (1988) analysed results of the 1984 International Stoke Mandeville Games and also found no difference in performance time of Class II through V for distance wheelchair races. These findings were reinforced by Higgs, Babstock, Buck, Parsons and Brewer (1990) who investigated athletic performance among wheelchair classes. At the time of the study, seven classes existed for track events and eight for field events. The study used a large sample of 4698 performances (904 athletes) from four separate competitions over five years from eleven athletic events. No significant difference (p >.05) was found between the four classes. Their research helped support a plan to reduce the number of wheelchair classes from seven to three in track and eight to four in throwing. Also, in wheelchair basketball, Brasile (1990), tested 79 males at the National Wheelchair Basketball

Association/ Paralysed Veterans of America Wheelchair Basketball Camp. The classification system for wheelchair basketball included three divisions based on functional ability: Class I, II, and III. Results showed Class II and Class III participants had similar performance times and skills.

Overall, the limited studies that have investigated the classification system played a major role in suggesting changes to reduce or refine the existing system. However, only certain events such as wheelchair sports, in particular wheelchair basketball, racing, and throwing have been investigated. Therefore, expansion in the number of studies and sports within disability sport are two areas that need further research.

2.4 Classifications System Alterations

Alternate systems to replace the current classification system have been suggested. Brookes and Cooper (1987) recommended a four class system for paraplegic racers based on performance; Open, Intermediate A, Intermediate B, and Novice. This system would 1) ensure fair competition between athletes differing in ability, 2) be comprehensive for spectators and media, and 3) increase the popularity of wheelchair sport. This system, although never implemented, highlights certain problems with the classification system.

Another system adopted at the Barcelona Paralympics in 1992, termed functional integrated classification system, grouped athletes of similar physical ability together. This system replaced the old medical system which was based solely on medical criteria. It enabled athletes with different disabilities but similar function to compete against one another.

Although this new class system was sound in theory, it raised many concerns. At the 1992 Paralympics athletes from ISOD and CP-ISRA competed with one another in power lifting. At the time, CP-ISRA had an eight class system based on medical and functional criteria, whereas, ISOD had a nine class system based on the degree of amputation. These classes were modified on a trial basis for the 1992 Paralympics. This integrated system made the assumption that power lifting was an event based on one-time strength and that participants from the two organizations could be evenly matched during the event. However, CP-ISRA obtained only two of the thirty medals awarded for power lifting (Richter, 1993). Based on these results, one could say that CP and amputee competitors were not equally paired for this event. Skill, experience, or fitness levels of the athletes were not investigated or considered.

Endurance events have been a concern for CP athletes. Skrotsky (1983) reported poor performance for athletes with CP could be attributed to the detrimental problems of increased spasticity and increased levels of fatigue in endurance-type activities. Although stretching can reduce the spasticity in resistance and flexibility training (Holland & Steadward, 1990), there is no evidence of such an effect during endurance events.

Since 1992, the classification system has been modified, however, most changes have occurred in wheelchair events. Changes to the existing CP system have been offered, but have yet to be fully accepted by the CP sporting community.

2.5 Definition of CP and Characteristics of CP Gait

Cerebral palsy, a non-progressive disorder, results from a lesion in the brain occurring around time of birth. This brain lesion interferes with normal child development and neurological maturation to alter control of muscles and muscle tone (Ferrara & Laskin, 1997).

People with CP usually experience clonus, spasticity, and contractures which affects movement, speech, and gait. Walking patterns for a person with CP are altered because their muscles do not contract adequately and at appropriate times in the gait cycle. This is attributed to a lack of coordination resulting from co-contraction of the antagonist muscles.

Typically during the gait cycle the heel contacts the ground first. However, in people with CP, the foot often contacts in abnormal ways such as with 1) talipes calcaneus which is a condition where the forefoot is pulled up into extreme dorsiflexion because of spasticity or weakness of the triceps surae, 2) talipes equinus where the foot is fixed in plantarflexion because of spasticity of the plantarflexors, and 3) talipes equinovarus where the foot is curved and body weight is borne on the outer border of the foot (Winters, Gage, & Hicks, 1987).

Medical diagnosis and degree of disability depend on the type of muscle tone and site of injury. Spastic hemiplegic, the most common type of CP within Class C7 and C8, occurs following traumatic brain damage. People with spastic hemiplegia have problems with moving and controlling their limbs and maintaining balance. Winters et al. (1987) have performed extensive studies on spastic hemiplegic gait patterns and have divided the population into four areas of development.

The first area involves a foot-drop during the initial heel contact phase. This area is characterized by: initial contact with the toe; the plantarflexion at the ankle causing increased hip and knee flexion; problem clearing the foot during swing phase due to weakness in anterior tibial muscles; and increased lumbar lordosis due to weak muscles in the abdominal wall or spasticity in the hip flexor muscles which causes the pelvis to tip anteriorly.

The second area of development is typified by static or dynamic contractures of the gastrocnemius muscle, which holds the ankle in plantar flexion throughout the cycle. Plantar flexion causes an external moment that forces the knee into hyperextension.

The third area of development is overactive quadriceps and hamstring muscles, causing a reduction in the knee ROM which decreases flexion in swing phase. Waters, Garland, Perry, Habig and Slabaugh (1979) have attributed this stiff legged gait to an irregular contraction of one or more heads of the quadriceps at the end of stance phase.

According to Winters et al. (1987), the fourth area of development is reduced hip ROM. This is due to spasticity which causes over-activity of the iliopsoas and adductor muscles, which makes the hip unable to extend fully. Consequently anterior pelvic tilt and lumbar lordosis occur at the end of stance phase to preserve stride length.

Despite these areas of development, it is impossible to predict exactly the way in which someone with CP will walk due to the wide range of variance within the disability (Sherrill, Mushett, & Jones, 1988). However, degree of muscle involvement and compensation mechanisms help outline gait parameters. Specific gait parameters for the lower extremities within the sagittal plane associated with CP include the following problems (Whittle, 1991):

1) anterior trunk bending (forward flexion of trunk at time of heel contact to compensate for weak knee extensors; brings centre of gravity forward);

2) posterior trunk bending to compensate for ineffective hip extensors early in contact phase;

3) leg length discrepancy causing increased steppage (exaggerated knee and hip flexion to lift the foot for ground clearance), and vaulting (going up on toes during stance);
4) excessive knee extension (the knee is extended or even hyper extended during stance, due to weak quadriceps; common in spastic individuals due to over-activity of quadriceps);
5) excessive knee flexion (knee fails to extend during heel contact phase due to hip/knee contractures or spasticity of knee flexors); and,
6) poor dorsiflexion which causes a foot slap when foot is coming down on the ground and foot drag because the person is unable to raise the foot during swing phase. This is related to weakness or paralysis of anterior tibial muscles.

Based on the identification of these problems, and the number of studies that have been conducted, researchers are quite familiar with the walking mechanics involved with CP. Running is relatively an unexplored area of research. Therefore, one must rely on nondisability research to understand the primary mechanics of running for people with CP.

2.6 Kinematic Studies of Running from the Nondisabled Population

By definition a person is categorized as running when the double support phase disappears and the person becomes airborne, referred to as double float (Thordarson, 1997). Research has observed that the walking percentages for stance and swing during the gait cycle are reversed when running. Normal percentages for running are 40% stance and 60% swing (Adelaar, 1986). Stance and swing percentages are more variable when running because of a greater difference in velocity (Thordarson, 1997). The double float in the gait cycle occurs at the beginning and end of the swing phase for both limbs and accounts for 30% of the total leg cycle (Adelaar, 1986). A study on running mechanics by Thordarson (1997) reported an increase in cadence by 2/3, a 20% increase in stride length and a decrease in stride time by 1/3 (0.9 to 0.6 seconds) when running velocity increased.

Ounpuu (1994) reported differences in the temporal variables between walking at 117 cm/sec and running at 223 cm/sec (Table 2.1). Stance and swing percentages changed from 59%-43% to 41%-57% respectively, stride length increased 20 cm, from

106 to 126 cm, cadence increased from 134 steps/min to 213 steps/min, and cycle time decreased by 0.3 seconds.

Table 2.1

Comparison Between the Walking and Running Temporal and Stride Variable for the Nondisabled Population

Variable	*Walking*	*Running*
Stance (% gait cycle)	59	43
Swing (% gait cycle)	41	57
Step Length (cm)	53	63
Stride Length (cm)	106	126
Cycle Time (sec)	0.9	0.6
Cadence (steps/min)	134	213
Velocity (cm/sec)	117	223

Note. Reprinted from "The biomechanics of walking and running", Ounpuu, S., 1994, Clinics in Sports Medicine, 14(4), p. 843-863.

In this study, joint movements for the hip, knee, and ankle in the sagittal plane were shown to increase as an individual started to run (Ounpuu, 1994). The hip angle was considered neutral when the hip was perpendicular to the ground, hip flexion was reported when the angle was positive and negative for hip extension. Hip, knee, and ankle kinematics were shown to increase by as much as 20 degrees from walking to running. Ounpuu (1994) reported the ROM in the sagittal plane at the hip was 46 degrees when running and 43 degrees when walking. Similarly, knee motion increased from 60 to 63 degrees and the ankle increased from 30 to 50 degrees. In Table 2.2, the joint variables for walking and running in the sagittal plane are compared. Note that peak knee flexion during swing increased by 20 degrees, ankle dorsiflexion during stance increased by 10 degrees, and plantarflexion stayed the same between walking and running.

Table 2.2

Comparison between the Mean Walking and Running Joint Kinematics for the Nondisabled Population

Variable (degrees)	*Walking*	*Running*
Hip		
Flexion (Contact)	34	47
Flexion (Toeoff)	-5	4
ROM	47	46
Knee		
Flexion (Contact)	8	24
Peak Flexion (Loading Response)	21	47
Peak Flexion (Swing)	65	82
ROM	60	63
Ankle –Negative denotes PF; Positive denotes DF		
Angle (Contact)	-1	2
Peak Dorsiflexion (DF) (Stance)	14	25
Peak Plantarflexion (PF)	-17	-17
ROM	31	42

Note. Reprinted from "The biomechanics of walking and running", Ounpuu, S., 1994, Clinics in Sports Medicine, 14(4), p. 843-863.

2.7 Running Patterns for Special Populations

To date, no published research examining the CP classification system for standing athletic track events has been found. Existing research has compared running patterns of specific disabilities with sprinters without a disability. Mensch and Ellis (1986) and Czerniecki and Gitter (1992) examined biomechanics of running for amputees. It was found that major compensatory patterns were used by below- and above-knee amputee runners. These patterns were: 1) an increase in stance phase, 2) an increase in hip and knee muscle work on the intact limb during swing phase, and 3) an increase in the prosthetic knee flexion during heel-contact.

In another study performed on athletes with visual impairments, Gorton and Gavron (1987) analyzed differences between Class B1 and B2 in the 100m dash. Results showed that head inclination varied a great deal between classes. Also, foot placement at contact was ahead of the centre of gravity almost as if the foot was acting as a probe. The more severely blind class, Class B1, had more distance between their leading foot and centre of gravity.

In one of the few studies examining CP runners Pope, Sherrill, Wilkerson and Pyfer (1993) investigated the biomechanical variables in sprinting in nine male and eight female internationally classified sprinters. Results argued eight variables differed between the sprinters with CP and those without a disability. Stride length for a sprinter without a disability ranged between 3.84 and 5m whereas a CP sprinter ranged between 2.74 and 3.11m. Sprinters with CP displayed a higher step frequency than sprinters without a disability but had lower velocities. Pope et al. (1993) also found decreased stride time, trunk angle, hip extension, increase in stance time, hip flexion, and no change in knee flexion and extension for CP athletes (Table 2.3). Differences in the variables between Class C6, C7, and C8 were reported to be within hip ROM, hip velocity, knee and elbow ROM and trunk angle. The more severe disability class, Class C6, had shorter stride lengths and longer stride times than Class C7 and C8. Class C6 sprinters spent 60%, Class C7 53%, and Class C8 52% of the cycle in stance. It was concluded that as the disability became more severe, the variables tended to move further away from the norms reported in the nondisability literature. Additional analyses found differences between right and left sides of the body, meaning one side was more involved than the other - in hip velocity, angle of contact, and hip, knee, ankle, and shoulder ROM. This study significantly contributed to biomechanical research as it introduces kinematic variable differences between Class C6, C7 and C8 during sprinting. The weaknesses in this study were that it did not address the significance of the differences found between classes, did not use markers to identify joint locations, filmed at a fairly low frequency of 50Hz, analysed only one stride, and omitted Class C5 because, at the time, it was a class which competed using canes.

Table 2.3

Temporal and Angular Variables for Nondisabled Sprinters and Sprinters with CP

Variable	*Male nondisabled*	*Male CP*	*Female nondisabled*	*Female CP*
Stride Time (s)	.436-.444	.436	.537-.556	.475
Stance:Swing ratio	40:60	53:47	44:56	58:42
Trunk Angle (degrees)	80-84	75	80-84	77
Hip Angle (degrees)				
Maximum thigh forward right	27-31	35	29-30	36
Maximum thigh back right	124	119	128	119
Knee Angle (degrees)				
Contact right	145-150	145	145-150	151
Heelrise right	137-140	140	137-140	145
Toeoff right	160-170	160	160-170	165

Note. Reprinted from "Biomechanical variables in sprint running of athletes with cerebral palsy", Pope, C, Sherrill, C., Wilkerson, J. & Pyfer, J., 1993, Adapted Physical Activity Quarterly, 10, p. 226-254.

In another study by Davids, Bagley and Bryan (1998), children (age median 7.7 years) with spastic diplegia and controls were required to walk, run, and sprint at self-selected speeds five separate times. Kinematic and kinetic data was collected using a six-camera system. Five complete gait cycles were averaged for the right side of the body. It was reported that the temporal variables that increased during the running compared to the walking trials were cadence and stride length, and cycle time and stance percentage decreased for both groups. Running variables for the group with CP that were influenced by the age of the sample (Table 2.4) include cadence at 238 steps/minute, stride length at 1.32m, and cycle time at 0.51sec. Other variables such as stance/swing ratio at 44.4:55.6, and double float percentage at 6.9% are valid despite the age of sample. Sagittal plane kinematics showed contact was made with the toe, and knee and hip ROM were significantly less for the CP group compared with the controls (Table 2.5). The ROM of the ankle, knee, and hip for the CP group was reported to be 34, 43, and 50 degrees, respectively.

Table 2.4

Temporal Running Parameters for Children with CP compared to their Walking data and Running data for Control Group

	Running (CP)	*Difference to Walk Trials (CP)*	*Difference to Run Trials (Control)*
Velocity(m/s)	2.59	-1.54	+1.13
Cadence (steps/min)	238	-94	-6
Stride length (m)	1.32	-0.43	+0.62
Cycle time(s)	0.51	+0.69	+0.02
Stance: Swing	44.4:55.6	+18.6:-18.6	-2.7:+2.7
Double Float (%)	6.9	Not applicable	+1.0

Note. Taken from "Kinematic and kinetic analysis of running in children with cerebral palsy". Davids, J.R., Bagley, A.M., & Bryan, M., 1998, Developmental Medicine & Child Neurology, 40, p. 528-535.

Table 2.5

Sagittal Running Variables for Children with CP compared to their Walking data and Running data for Control Group

	Running (CP)	*Difference to Walk Trials (CP)*	*Difference to Run Trials (Control)*
Ankle (degrees)			
ROM	34	-8	+5
Peak PF	-24	-8	-6
Peak DF	11	-1	+9
Knee (degrees)			
ROM	43	+2	+30
Flexion at IC	34	-10	-6
Peak Flexion	66	-15	+24
Peak Extension	23	-16	-5
Hip (degrees)			
ROM	50	-5	+13
Peak Flexion	56	-12	+1
Peak Extension	6	+5	+12

Note: Reprinted from "Kinematic and kinetic analysis of running in children with cerebral palsy". Davids, J.R., Bagley, A.M., & Bryan, M., 1998, Developmental Medicine & Child Neurology, 40, p. 528-535. IC=Contact; ROM=Range of motion; PF=Plantarflexion; DF=Dorsiflexion.

2.8 Treadmill vs. Ground Running

Typically biomechanical research has used two methods to analyze running patterns: a designated level runway, and a treadmill. For the purpose of this study, a pilot study was completed with one subject from Class C7 on a treadmill. Due to the disability and its limitations on the subject, they were unable to successfully run on the treadmill for the time required to film 15 strides. Therefore, it was decided that the study be conducted on level ground instead of on a treadmill. Other studies have shown that running on the ground and running on the treadmill are similar (Boda, Tapp & Findley, 1994). In fact, comparisons between these running surfaces have revealed no significant differences. However, Boda et al.(1994) found that stride rate was faster for ground running, time of support was longer on the treadmill, and vertical velocity of the centre of gravity was less on the treadmill. In contrast, Williams, Snow and Jones (1989) who also compared running on the treadmill versus running on ground surfaces found that runners on the treadmill had a shorter support and longer non-support times and a shorter stride length than runners on the ground. However, results in both these studies suggest that there is little difference between treadmill and ground running.

2.9 Summary

Disability sport is expanding and developing at an increasing rate of popularity. Concurrently, related research has attempted to modify the current classification system. Previous studies have shown little or no significant difference between the examined classes which have challenged the organization to re-consider the current system in two ways: 1) by reducing the number of classes within each disability group, and 2) integrating different disability groups into the same events. As a result, changes to the system have occurred for a small percentage of sports and disabilities. One sport left unchanged is ambulatory running for athletes with CP, a disability characterized by irregular muscle contractions and equilibrium problems, and has eight separate classes which include Class C5, C6, C7, and C8 for ambulatory runners. Athletes with CP vary from person to person which raises much debate about integrated competition. Walking patterns of people with CP are characterized by a drop foot during the swing phase of gait, increased levels of lumbar lordosis, contractures of calf muscles, and decreased ROM around the hip and knee (Winters et al., 1987). It is believed that the quality of sprinting and running patterns decline as severity of the disability increases. Differences between CP classes during sprinting have been identified in terms of biomechanical explanations, however, in-depth research has never been conducted about where the differences lie. Although literature between walking and running of people without a disability, and CP walking and sprinting have illustrated the primary mechanics of CP running, specific research is needed to have a clearer understanding.

CHAPTER 3
Methodology

3.1 Research Hypotheses

Two null-hypotheses were investigated:

1. There would be no significant difference for the selected linear and angular variables between participants.
2. There would be no significant difference for selected linear and angular variables between Class C5, C6, C7, and C8.

It was hypothesized that the quality of running variables would decline as severity of the disability increased and class number decreased. It was expected that C5 and C6 athletes would exhibit more pathological gait components as compared to the more able classes, C7 and C8.

3.2 Sampling

Eight volunteer subjects (age mean 27, range 13-35), two subjects from each CP class, were recruited from the University of Alberta - Rick Hansen Centre, Alberta Cerebral Palsy Sports Association, Cerebral Palsy Association in Alberta, Edmonton Paralympic Sports Association and the Edmonton population (Table 3.1). All subjects were medically diagnosed with CP and classified for the purposes of this study by a classification team, consisting of a physician, physical therapist and a sport technician.

Prospective subjects were initially contacted by the primary researcher. They were given a written description of the testing procedures and required to complete a letter of consent (Appendix A and B). Ethical approval from the Faculty of Physical Education and Recreation was obtained on November 15th, 1998 (Appendix C).

Demographic information from each subject was collected and included age, lower limb length and affected site or side of body. The classification procedures were followed as outlined in the CP-ISRA Classification and Sports Rules Manual (1997) which included gross motor movements, balance, posture, joint motion movements, coordination movements, and running trials. (Appendix D). All tasks were videotaped and distributed to the classification team so that subjects could be designated an appropriate class.

Subjects who had been previously classified were also classified by the study's classification team. The classification team was blinded as to previous assessments to obtain an inter-rater reliability of $r = 0.86$.

Table 3.1

Subject Characteristics

Sub #	*Sex*	*Age*	*Class*	*LL Length (Rt/Lt) (cm)*	*Velocity (m/s)*	*Info*
1	M	14	8	86 / 86.5	2.79	SP/ Grade 1-2
2	F	18	8	94 / 93.5	3.57	SP/ Grade 1-2
3	M	25	7	94 / 95	3.11	SP/ RT/ Grade 2-3
4	F	34	7	100 / 101.5	3.89	SP/ RT/ Grade 2-3
5	F	35	6	101.5 / 99.5	1.19	Ataxia
6	F	30	6	86.4 / 85.2	3.20	Ataxia/ SP Grade 2-3
7	M	35	5	101.5 / 103.6	2.10	SP/ Grade 3
8	F	25	5	83.5 / 82.5	1.29	SP/ Grade 3

Note. Sub # = Subject number; Class = Classification given by study's team; LL = Lower limb; Rt = Right; Lt = Left; Velocity = Average velocity during running trials; Info = Disability specific information (SP = Spasticity, Grade = Modified Ashworth Spasticity Scale, RT = Right).

3.3 Study Design

All subjects (N=8) ran at a predetermined self-selected pace on a 25m track. Each subject ran three to five times on the designated track to allow filming of 15 complete strides for both legs. Video cameras were set up on both sides of the subject to film the sagittal view (Figure 3.1).

Subjects were given the opportunity to become familiar with the track before filming. The primary researcher did not start the testing protocol until each subject felt comfortable and ready to begin.

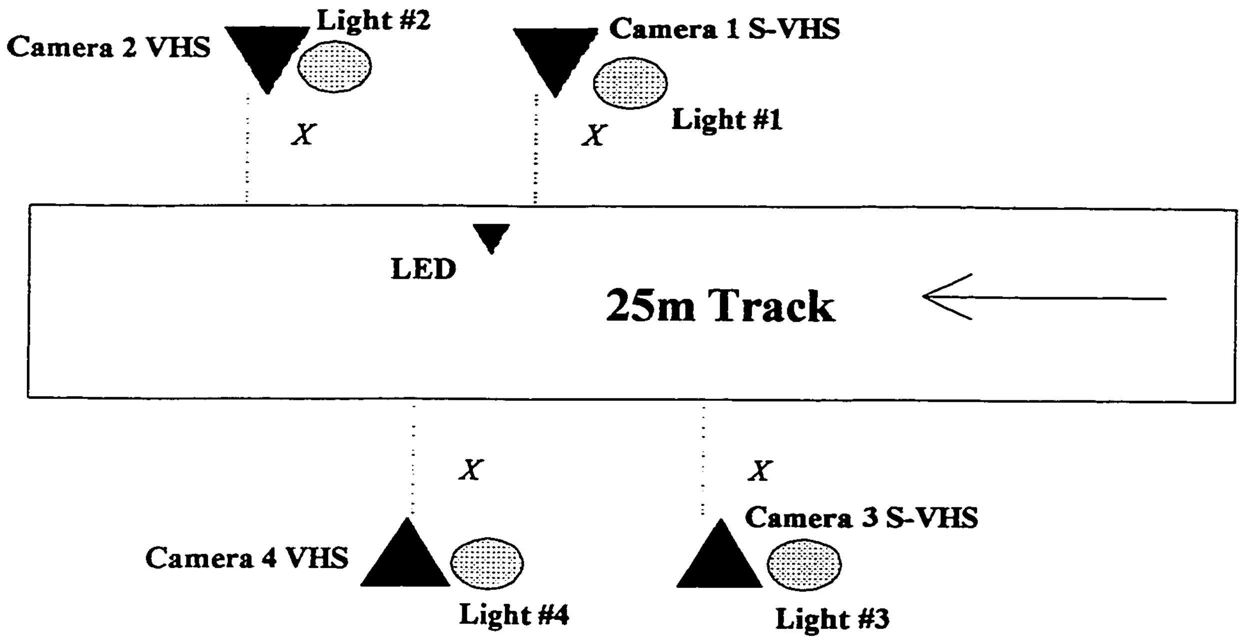


Figure 3.1. Camera Set-up. LED = light emitting diode; VHS = video high-resolution system; S-VHS = super video high-resolution system.

3.4 Procedure

3.4.1 Location of study. Classification procedures and running trials were performed and filmed in the Universiade Pavilion at the Van Vliet Centre, University of Alberta. The classification team reviewed the videotape which included all subjects and returned their assessment to the researcher. Data was analysed in the Sport Biomechanics Lab at the University of Alberta.

3.4.2 Clothing. Subjects were asked to wear tight-fitting dark coloured clothing. This helped identify anatomical landmarks and reflective markers. Subjects wore their own running shoes.

3.4.3 Warm-up. During warm-up, each subject was required to perform up to 5 trials at various speeds. The speed of these trials varied from slow jogging to fast sprinting, to establish a moderate speed that could be repeated during testing. Based on these trials, an average running cadence specific to each individual was calculated. During actual testing, only trials which were run at the average cadence were used for analysis.

3.4.4 Trials. Subjects were instructed to run 25m between the cameras at the predetermined speed. Subjects were required to run the distance until the cameras filmed 15 complete strides for both legs. All subjects were filmed on the same track surface under the same conditions. Two research assistants were recruited for set-up of equipment, videotaping, timing, and spotting during running.

3.4.5 Camera location. Two cameras were set up on each side of the track to film the right and left sides of the participant's body. On each side was one S-VHS and VHS camera. Cameras were staggered and perpendicular to the track on both sides (Figure 3.1). Four lights were placed beside each camera to provide sufficient illumination during filming. Cameras filmed at a speed of 60 Hz and were synchronized by using an externally triggered LED (light emitting diode) visible to all four cameras. By using the light as a starting point, it enabled the researcher to digitize the same trials for both sides of the body. Cameras recorded approximately fifteen strides discontinuously for ten seconds.

3.4.6 Calibration. The researcher calibrated each camera to the centre of the field of view. A calibration tool of a known dimension (100 cm) was filmed before and after filming.

3.5 Data Collection

3.5.1 Reflective markers. Reflective markers, used to aid in the digitizing process, were placed on major segment joints according to Dempster (1955) for the shoulder, hip, knee and ankle. Placement of foot markers were positioned according to Winter (1987). A total of 12 markers, six on each side, were placed on the subject while standing in the anatomical position. Marker position was measured by a measuring tape to ensure proper repositioning in the event they fell off during the trials. Detailed description of points identified through digitizing and angle diagrams are illustrated in Table 3.2, Figure 3.3, and Figure 3.4.

Table 3.2

Anatomical Positions of Marker Location

#	*Anatomical Position*
1	Right - greater tubercle of humerus (most lateral)
2	Right - iliac crest of pelvis (most lateral)
3	Right - lateral epicondyle of femur (most lateral)
4	Right - lateral malleolus of tibia (most lateral)
5	Right - centre of calcaneus (lateral side)
6	Right - distal phalanx of fifth toe (lateral side)
7	Left - greater tubercle of humerus (most lateral)
8	Left - iliac crest of pelvis (most lateral)
9	Left - lateral epicondyle of femur (most lateral)
10	Left - lateral malleolus of tibia (most lateral)
11	Left - centre of calcaneus (lateral side)
12	Left - distal phalanx of fifth toe (lateral side)
13	Fixed point

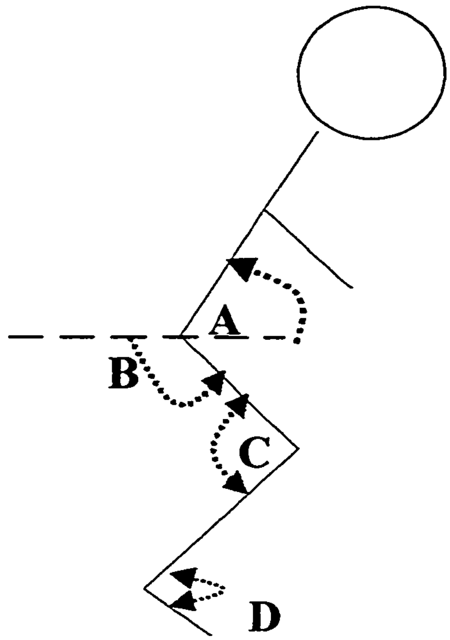


Figure 3.2 Angle definitions on right side of body, A=trunk angle to the horizontal, B=hip angle to the horizontal, C=knee angle, D=ankle angle.

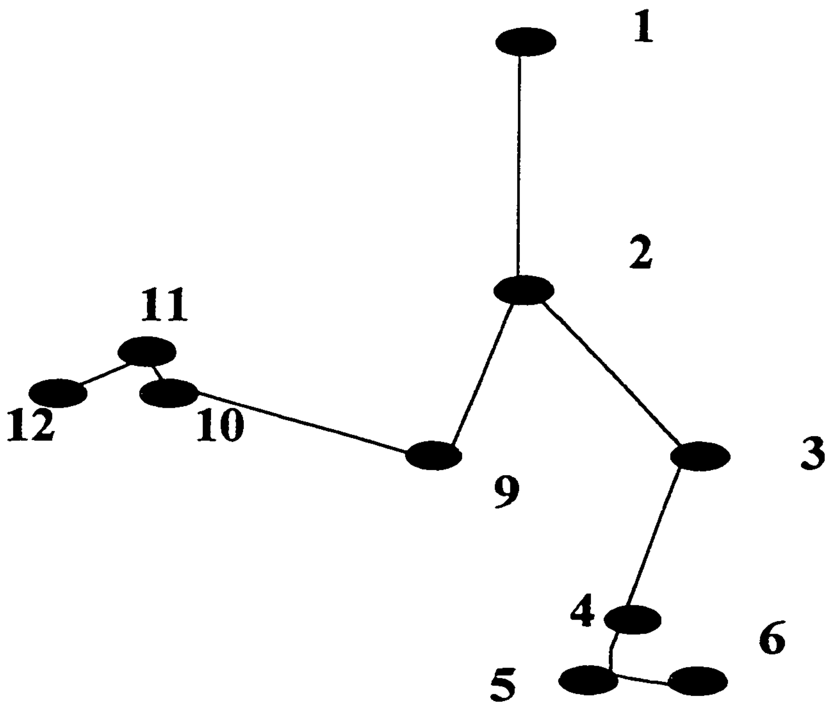


Figure 3.3 Marker positions on right side of body and left leg, 1 to 12 represent marker locations (Table 3.2).

3.5.2 Ariel system. Fifteen strides were videotaped and digitized using the Ariel computer system. The Ariel computer system was found to reduce instrument bias and was considered reliable with excellent reproducibility (Besser, Anton, Denny & Quaile, 1996; Klein & DeHaven, 1995). Besser et al. (1996) found that joint motion intra-class correlation coefficient and testing reliability of individual measurements were greater than .995. Similarly, Klein and DeHaven (1995) reported that the average mean error for three-dimensional linear points was 1.4mm with a standard deviation of 0.30. When testing the accuracy for this study, an object of known dimension was videotaped through the movement plane of all four cameras. Two dimensional co-ordinate data was determined from this video using the same data reduction protocol that was used throughout the study and as described below (Section 3.5.3). The average mean error for all points from camera one and three was 1.05 cm with a standard deviation of 0.48, and camera two and four was 1.12cm with a standard deviation of 0.23.

3.5.3 Digitizing. High speed video analysis (60HZ) was performed using the video recordings interfaced into the Ariel computer system. Using manual and automatic digitizing, the system identified and recorded two-dimensional trajectories. Digitizing re-tests of the smoothed data were randomly completed on all four cameras to determine intra-rater reliability. Reliability was $\underline{r}$ = 0.8035 for the variables in the X plane and $\underline{r}$ = 0.8705 in the Y plane. Fifteen complete strides for the right and left sides of the body were digitized and averaged.

3.5.4 Data smoothing. Once the digitizing process was complete, raw data from this study was smoothed using the step-wise polynomial quintic spline filter, to eliminate amplitude noise. The quintic spline was chosen because of its reported superiority over other filter systems. Wood (1982) stated that the quintic spline was a better system for biomechanical data since higher derivatives remained continuous and smooth without considerable variation affecting the endpoints. However, the quintic spline has been reported to be most beneficial with more than 25 data points.

3.5.5 Selected variables. Kinematic variables for both right and left sides included:

A) Stride time (seconds) and length (centimetres): Measured from contact to the next contact of the same foot in seconds and centimetres, respectively.

B) Cadence (steps/min): Step frequency was determined by analyzing step time.

C) Stance:Swing ratio: Percentage of the cycle where the foot was in contact relative to percentage where foot was not in contact with the ground. Contact time was determined from the calcaneus (Point 5 & 11 in Table 3.2).

D) Double float (percentage): Percentage of the cycle where the foot was not in contact with the ground to the point where the opposite foot contacted the ground. Frames during the gait cycle when neither foot was in contact with ground were identified and time frames were used to calculate the percentage during a complete gait cycle. In cases where there was no double float, double support was calculated using a similar method.

E) Trunk angle (flexion and extension during toeoff and contact phases) (degrees): Measured by an absolute angle along the horizontal axis from point 1 and 2 on the right side, and 7 and 8 on the left side (Angle A in Figure 3.2 and points in Table 3.2).

F) Hip angle (flexion and extension during contact and toeoff phases) (degrees): Measured by an absolute angle along the horizontal axis from point 2 and 3 on the right side, and 8 and 9 on the left side (Angle B in Figure 3.2 and points in Table 3.2).

G) Knee angle (flexion and extension during contact, midstance, toeoff, and midswing phases) (degrees): Measured by a relative angle, defined by the location of the iliac crest (point 2 & 8), lateral epicondyle (point 3 & 9) and malleolus (point 4 & 10), (Angle C in Figure 3.2 and points in Table 3.2).

H) Ankle angle (dorsiflexion and plantarflexion during contact, midstance, toeoff, and midswing phases) (degrees): Measured by a relative angle, defined by the location of the lateral malleolus (point 4 & 10), centre of calcaneus on the most lateral side (point 5 & 11), and distal phalanx of the fifth toe on the most lateral side (point 6 & 12), (Angle D in Figure 3.2 and points in Table 3.2).

3.6 Statistical Analysis

Descriptive statistics were used in this study due to the small sample sizes within each class. Bouffard (1993) states that common methods for analyzing data from special populations such as standard analysis of variance models which incorporates averages may not give a true representation of the data. By collapsing data, essential information on individual relationships can be lost. For this study, inter-individual and interclass comparisons were undertaken. All data was graphed and trends for each variable were reported. Mean and standard deviations for the nine kinematic variables for each class division and each subject were calculated. Nonparametric tests were utilized to test the hypotheses which stated there would be no significant difference for the selected linear and angular variables (stride time and length; cadence; stance and swing ratio; double float; and, trunk, ankle, knee, and hip angles) between the participants of each class, and there would be no significant differences for the selected linear and angular variables between Class C5, C6, C7, and C8. The Kruskal-Wallis test was preferred over standard t-tests since it accounts for a small sample size (Norusis, 1990). Hierarchical clustering was employed using variables expressed in standardized form, Z-scores, following similar methods as Higgs et al. 1990. Dendrograms and squared Euclidean distance from the cluster analysis were used to divide the data into groups.

CHAPTER 4
Results and Discussion

Fifteen running strides from the right and left sides of eight participants were analyzed. Results are presented in graph format with all corresponding tables grouped together at the end of the chapter (Tables 4.2 to 4.12). Smoothed kinematic data for one single subject are contained in the appendix (Appendix E). Variability in the fifteen strides was investigated using angle-angle diagrams of the thigh and knee (Figure 4.22-4.37). These plots showed limited variability between the strides, therefore, means of strides were used throughout the analysis. All results and discussion for the remainder of this chapter, refer to the mean of fifteen strides for each subject and each class. The variables are presented as follows:

1) Stride length, 2) Cadence and stride time, 3) Stance - Swing ratio, 4) Double float percentage, 5) Trunk angle 6) Hip angle 7) Knee angle, and 8) Ankle angle.

Large variance was present between the subjects, supporting the theory that within each class division, athletes have varying levels of disability (Sherrill, Mushett, & Jones, 1988). Therefore, throughout the results and discussion, individual results and class means are presented and discussed.

From visual observation of the video, distinctive running patterns were evident for the four separate classes. Subjects from Class C8, demonstrated little to no running problems (Figures 4.1 A and B). Full ROM about the knee and ankle were evident. A subject from Class C8 positioned their ankle in a pronated position throughout the running cycle, however did not assume a crouch knee stance, commonly referred to as knock knee. Class C7 subjects, the true hemiplegic class, were both affected on the right side (Figures 4.2 C and D). While running, the affected side of the body maintained a neutral ankle position throughout the cycle causing a flat foot contact. It was observed that the right knee had limited flexion during the absorption phase of stance and during midswing. The left side of the body, the unaffected side, had no noticeable limitations, except that one subject seemed to have an exaggerated inwards knee bend (femoral varus) during stance which brought the knee in towards the body. This crouch knee position could have developed to displace the trunk to the left, in order to create more ground clearance on the right side (Novacheck, 1998). Both of the Class C6 runners assumed a crouch knee stance while running on both sides of the body and contacted the ground almost solely with their toes (Figures 4.2 E and F). The ankle positioned in plantarflexion and the knee with limited extension at contact attributed to a shortened stride length. Two subjects from Class C5 displayed a running pattern which was most affected by the limited hip ROM, causing a major shortening of the stride length (Figures 4.2 G and H). Both legs had limited flexion throughout the cycle and a flat foot contact was evident at ground strike.

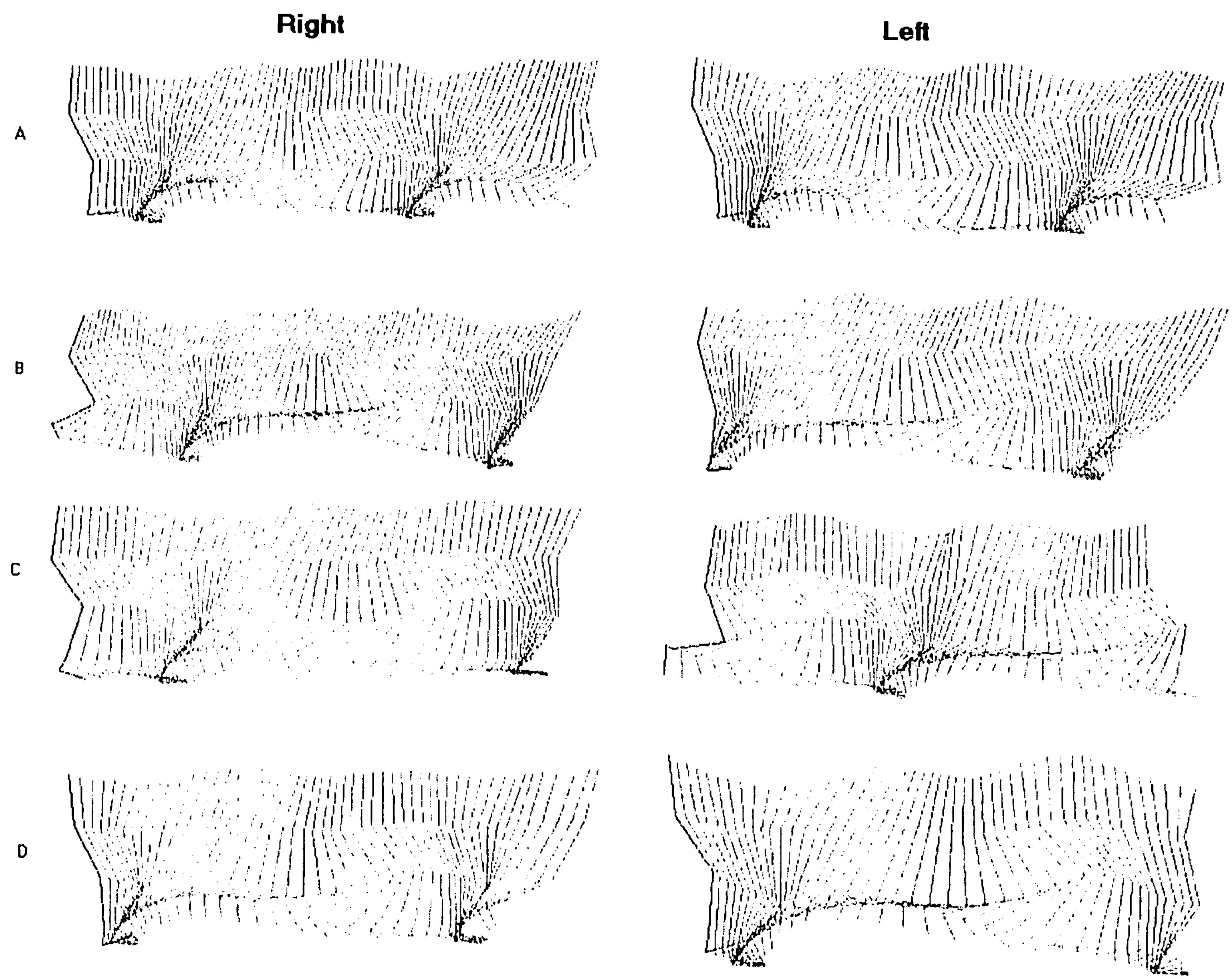


Figure 4.1. Stick diagrams for running cycle for the right and left sides of subjects Class C7 to C8. A = Subject 1/ Class C8; B = Subject 2/ Class C8; C = Subject 3/ Class C7; and D = Subject 4/ Class C7.

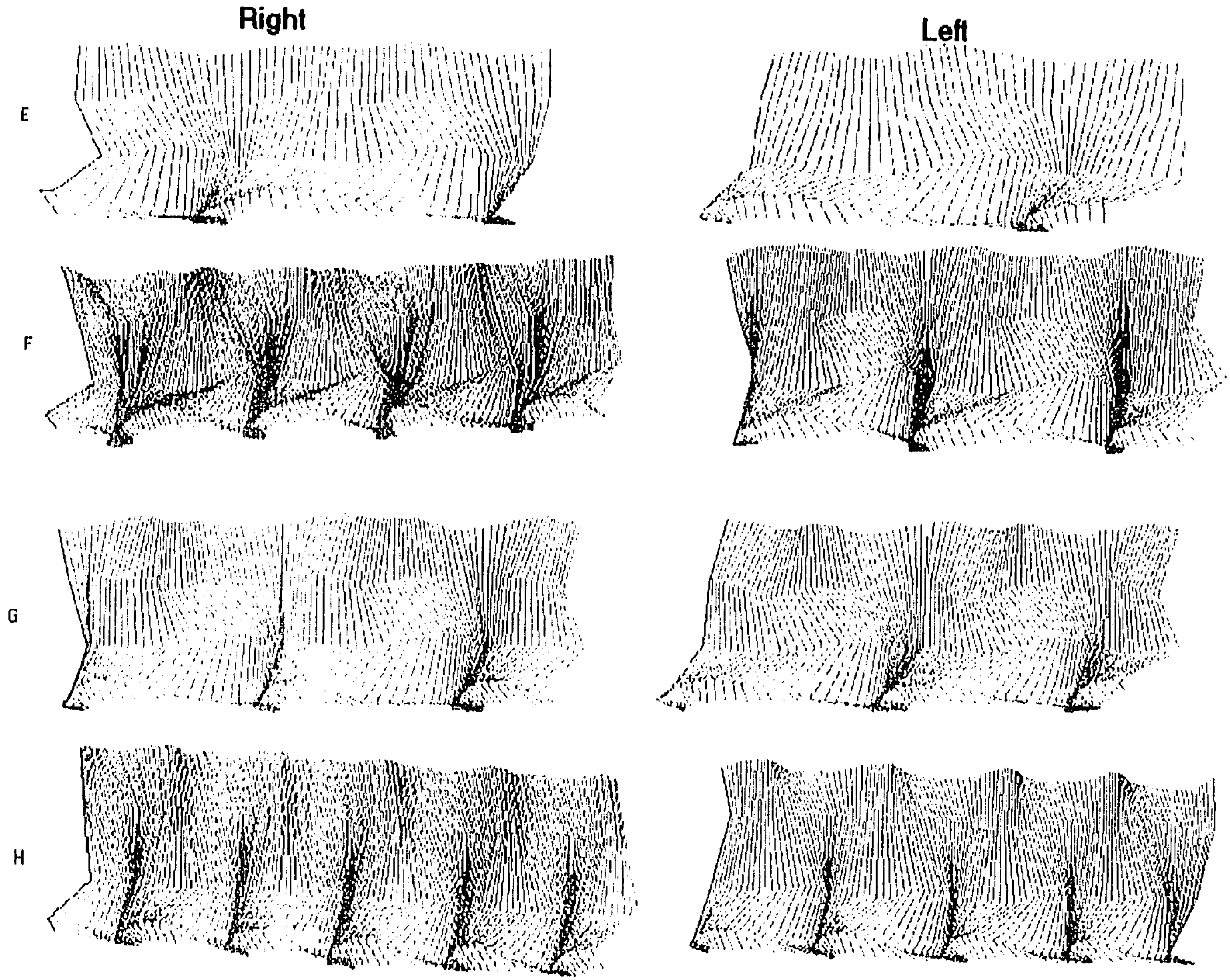


Figure 4.2. Stick diagrams for running cycle for the right and left sides of subjects Class C5 to C6. E = Subject 5/ Class C6; F = Subject 6/ Class C6; G = Subject 7/ Class C5; and H = Subject 8/ Class C5.

4.1 Stride length

A trend is present which suggests that the stride length was longer for the more able classes and tended to shorten as the severity of disability increased (Figure 4.3). The longest stride length was reported to be 287.8cm from the left side of subject 2 - Class C8 and the shortest was 64.7cm from then left side of subject 8 -Class C5. For the two subjects in Class 7, the hemiplegic class, the non-affected side (left) had a longer stride length than the affected side (right). This trend concurred with the visual observations on the videotapes. Class C5 had a shorter stride length because of the limited hip ROM and C6 displayed limited knee extension and the ankle in constant plantarflexion. It is interesting to note that all of the stride lengths for the right and left side were unequal and thus asymmetric. Unequal stride lengths suggest subjects altered their gait pattern in various planes to avoid turning in one direction or swaying to one side. This, for example, could manifest itself in changes in step width.

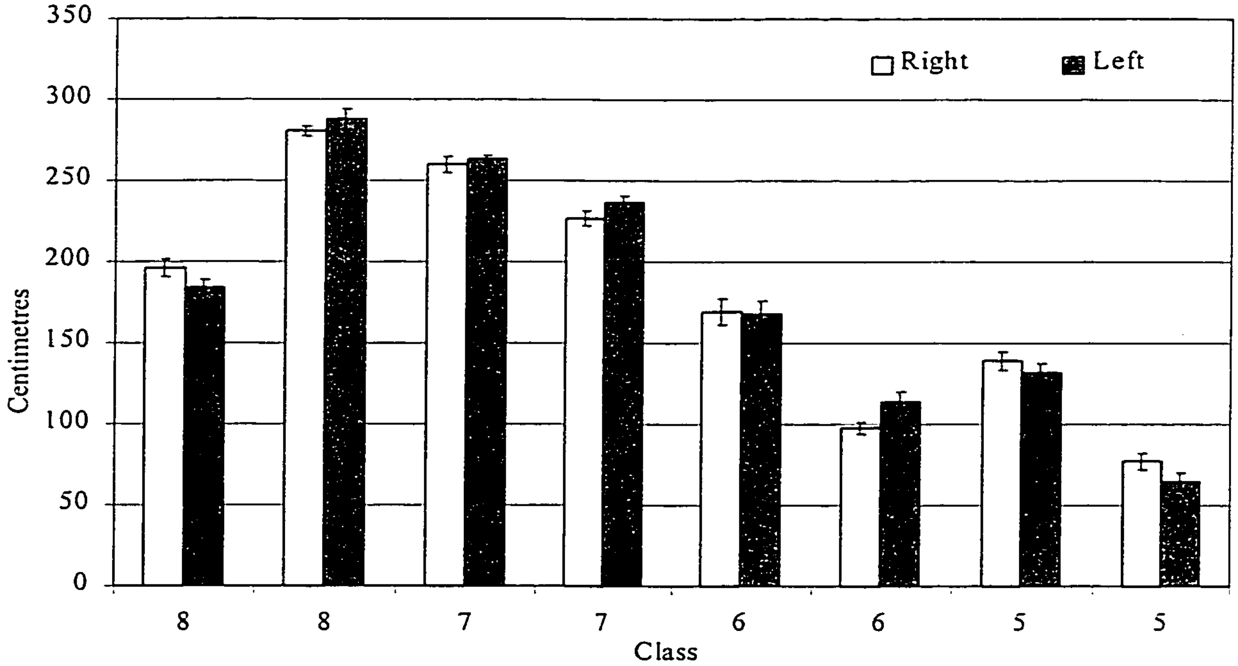


Figure 4.3. Mean stride length in centimetres for all eight subjects Class C5 to C8. Stride length for more able classes tended to be larger than those from the less able classes.

Increased severity of CP could shorten stride length if the individual had weak tibial muscles, contractures of the gastrocnemius, or talipes equines, causing the foot to contact the ground prematurily, shortening the stride (Winters et al., 1987). If the disability caused the individual to have a limited motion about the hip or knee, this also could shorten stride length. Excessive knee extension and leg length discrepancy could shorten stride length. These variables were not investigated in this study.

Pope et al. (1993) found that sprinters without a disability had stride lengths between 384 and 500cm, whereas the CP athletes had stride lengths between 274 and 311cm. Pope et al. (1993) noted that Class C6 athletes had a shorter mean stride length than those from Class C7 and C8 (276, 304 and 303cm, respectively). Literature for people without a disability has shown that the stride length increased as the gait speed increased (Mann & Hagy, 1980). Therefore since gait speed was reduced in CP as the severity of the disability increased, it was not surprizing that stride length decreased as the class number decreased.

Davids et al. (1998) reported a stride length of 132cm in spastic diplegic children (median age of 7.7 years) during running and walking. Class C5 is considered the spastic diplegic class, however, very able person's with spastic diplegia may be classifed as Class C8. Their study criteria was that all subjects were required to demonstrate two periods of double float. This suggests that the participants in the study would have been classified either as a high able Class C5 or a Class C8. Therefore, comparisons between results from the Davids et al. (1998) study and the present study could be accomplished using Class C5 or C8. Results demonstrated that children had an average stride length of 132cm. As body height is positively related to stride length, one would expect that a child's stride length would be shorter due to smaller body segments (Winter, 1987). However, 132cm approximates the mean value for Class C5 found in this study (133.4 and 140.7cm for the right and left sides of the body respectively).

To enable accurate comparisons between subjects, stride lengths were normalized to account for various lower limb lengths. For this study, stride length was divided by leg length, thus making it dimensionless (Hof, 1996). The length of the stride tended to decrease as the class number decreased, not showing dependence on lower limb length (Figure 4.4). Therefore, the smaller stride length seen in Class C5 and C6, are associated to the severity of the disability and not the anatomical height of each subject.

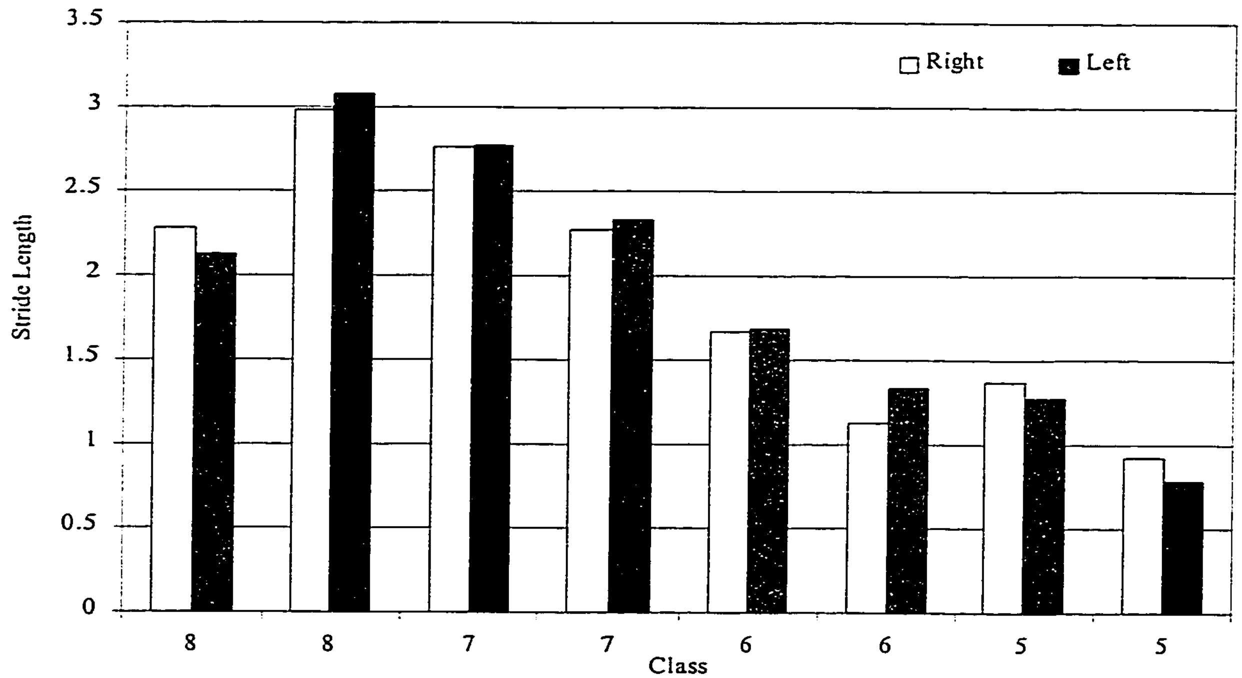


Figure 4.4. Normalized stride length (stride length/ subject lower limb length) for all eight subjects Class C5 to C8. Once normalizing the stride length, it was evident that the more able classes had larger strides than the less able classes.

4.2 Cadence and stride time

4.2.1 Cadence Running speed was predetermined for each subject by finding an average running velocity specific to each individual. After investigating cadence, no difference was apparent between the four classes (Figure 4.5). This suggested that cadence was an individual characteristic and not grouped by class. Subjects had different cadences in relation to others in their class. For example, the greatest cadence reported was 210 steps/minute for the right side of subject 8 - Class C5 and the shortest was the right side of subject 6 - Class C6 at 138 steps/minute. The variance within classes could be attributed to the pre-determined rate each subjects was asked to run, thus interrupting their natural cadence.

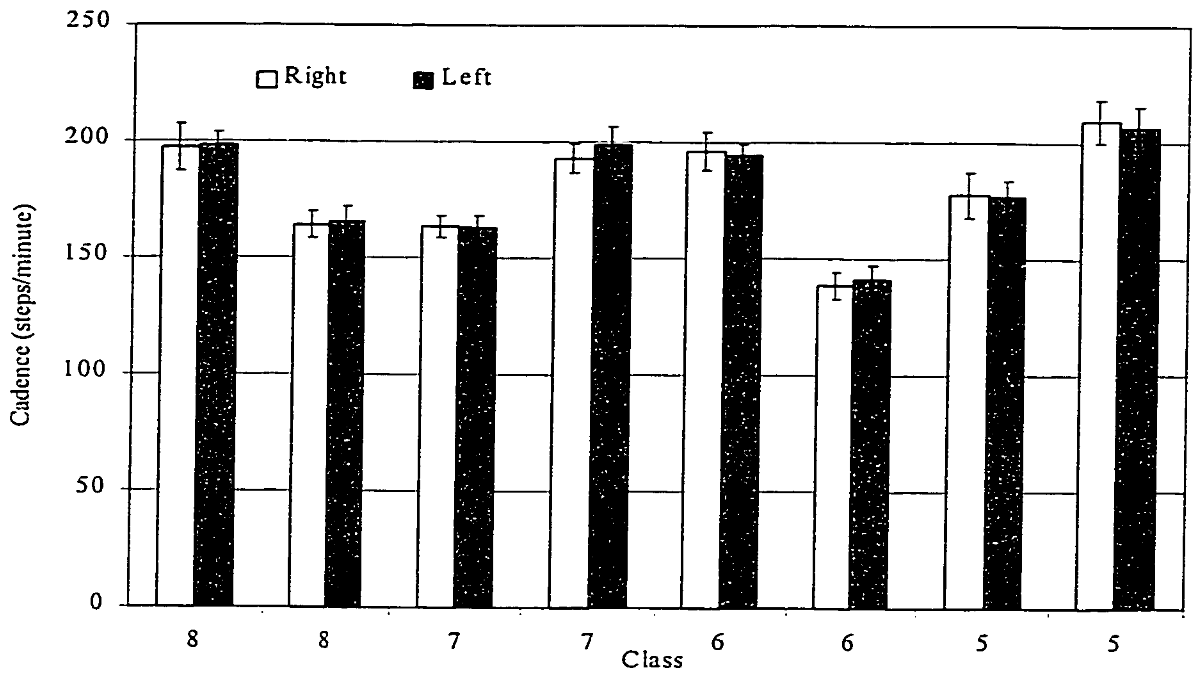


Figure 4.5. Cadence (steps/minute) for all eight subjects Class C5 to C8. When looking at each class division, no trend is apparent.

Cadence in this study (138 - 210 steps/min) was less than reported for the population without a disability (Ounpuu, 1994). In the population with CP, Davids et al. (1998) reported that cadence for children with spastic diplegia was 238 steps/min. As stride length and cadence are interrelated (Winters, 1987), it was evident that cadence in a child with shorter stride lengths due to smaller limb segments, would be higher than that reported for a Class C5 adult (193/191 steps/min for the right and left sides, respectively). However, this co-dependency between stride length and cadence could not explain differences in stride length but no change in cadence.

4.2.2 Stride time. Acknowledging that stride time is directely related to cadence, it was not surprizing that no trend for stride time was also evident. The class means were similar (0.62 / 0.62, 0.75 / 0.73, 0.68 / 0.66, 0.67 / 0.67 seconds) for the right and left sides of Class C5 to C8, respectively. Stride times were similar for both right and left legs.

Pope et al. (1993) reported that stride times were longer for Class C6 compared to Class C7 and C8 (0.23, 0.24, and 0.25sec, respectively). This contradicts the findings of the present study which found no difference in stride time. Even though Class C6 had a stride time longer than Class C7 and C8, it was notably shorter than the stride time recorded for Class C5. Davids et al. (1998) found a stride time of 0.51s, which was comparable to the results of Class C5 from this study, (0.62s) on both the right and left sides.

4.3 Stance - Swing Ratio

Results revealed a trend suggesting that the more able classes had greater swing and shorter stance percentages compared to the less able classes (Figures 4.6 and 4.7). For example, on the right side, Class C7 and C8 had a stance:swing ratio of 37:63 whereas Class C6 was 53:47 and Class C5 was 61:39. The more severely disabled classes spent more time on the ground whereas the more able classes spent more than half the cycle with one of their legs in the swing phase.

Ounpuu (1994) found that the stance-swing ratio for the nondisability population during running was 43:57. Class C7 (37:63 / 37:63 right and left, respectively) and Class C8 (37:63 / 36:64 right and left, respectively) had ratios close to those reported from the nondisability population. Pope et al. (1993) similarly found that stance percentage increased as the class number decreased, Class C6 had a stance - swing ratio of 60:40, Class C7 - 53:47, and Class C8 - 52:48. However, the present study did not find similar stance-swing ratios as stance accounted for a lower percentage of the total in Class C6, C7, and C8. On the other hand, the trend towards a longer swing period was noted. When swing is expressed as a percentage of the gait cycle, a positive relationship with stride length had been reported (Winters, 1987). This was valid for this study, reinforcing the trend apparent for stance - swing ratios.

Davids et al. (1998) discovered a ratio of 44.4:55.6 for children with spastic diplegia. Winters (1987) stated that as an individual's gait pattern matured, swing time is decreased drastically as the velocity increased. The present study displayed a stance-swing ratio of 61:39 / 60:40 for Class C5. Therefore, it is possible to suggest that the results of these studies are comparable.

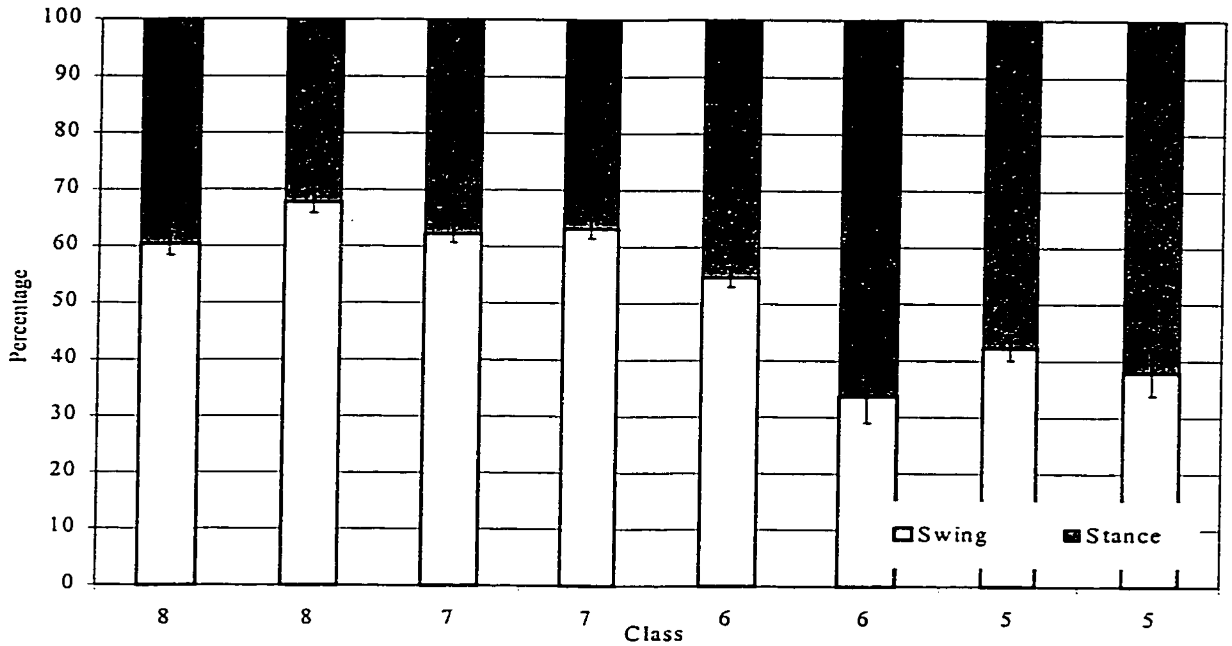


Figure 4.6. Right side - stance:swing ratio (percentage) for all eight subjects Class C5 to C8. The more able classes spent a greater percentage in swing phase, whereas the lower classes spent a greater amount of the cycle on the ground.

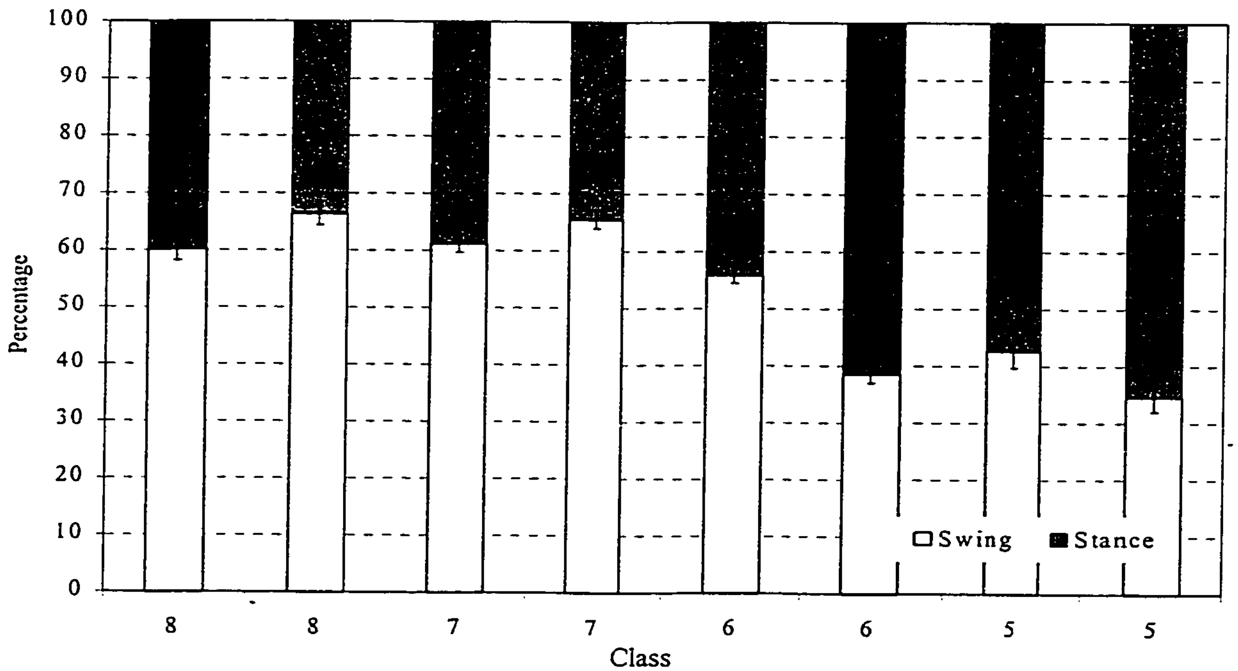


Figure 4.7. Left side - stance: swing ratio (percentage) for all eight subjects Class C5 to C8. Similar to the right side, as the class number increased the percentage of the cycle in swing also increases.

4.4 Double Float Percentage

According to the double float data, there was no common trend identifiable by class distribution (Figure 4.8). The greatest double float was reported to be on the left side of subject 2 - Class C8 at 19.5% of the cycle and the shortest was 2.0% from the right side of subject 5 - Class C6. It is interesting to note the differences between the right and left sides of the body. For example subject 6 - Class C6 had a double float percentage of 15.0% on the right side and 11.4% on the left. Double float results suggest inequality of the two sides of the body, especially in the less able classes, emphasizing the importance of analyzing both sides of the body.

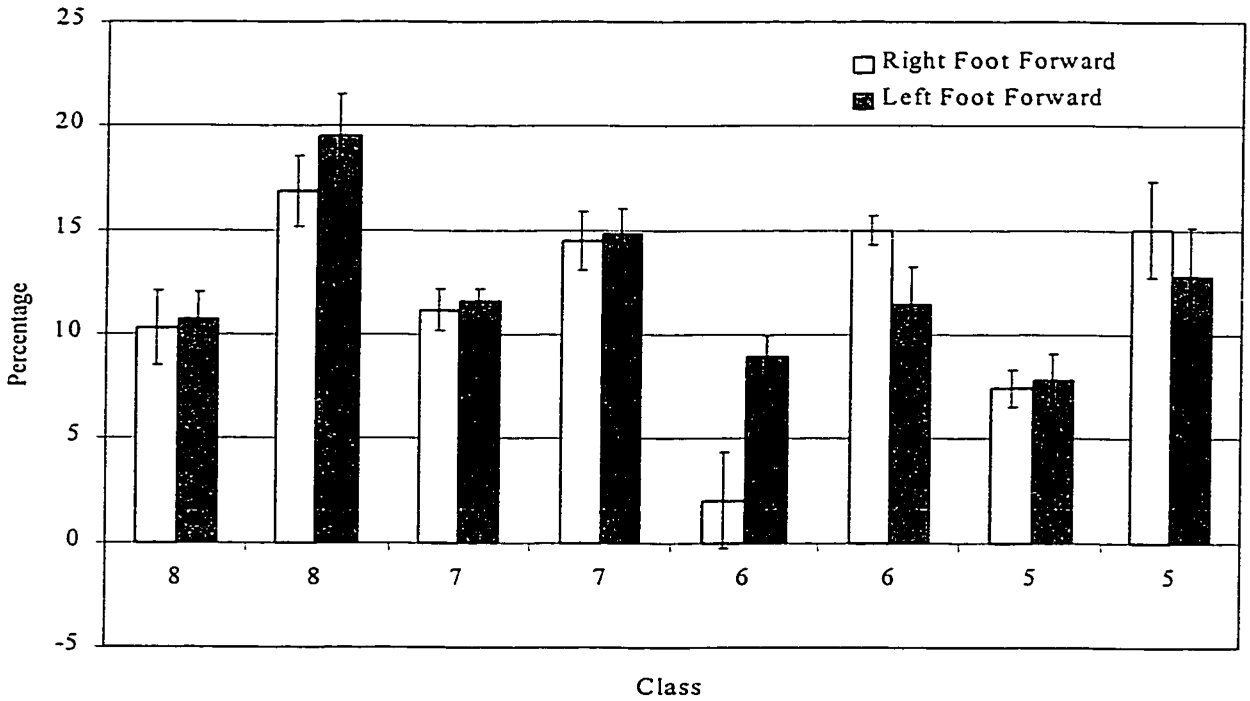


Figure 4.8. Double float period (percentage) for all eight subjects Class C5 to C8 . All classes did display a double float, with the exception of subject 5 - Class C6 with a limited double float on the right side.

In the running cycle for those without a disability, double float has been observed to be 30% of the total cycle, or 15% at the beginning and end of the cycle. (Adelaar, 1986). Davids et al. (1998) accepted only children into the study who displayed two double float periods during the running cycle. Therefore, double float was found to be

6.9% during each period of the gait cycle. In this study, double float was higher than reported by Davids et al., (1998). The spastic diplegic class, C5, had a mean of 11.2 and 10.3% for the right foot forward and left foot forward, respectively. However, double float reported for all subjects, was lower than those reported for the nondisabled population except for subject 2 - Class C8. Double float was calculated by observing the video and advancing it by 0.017s. The low sampling rate of 60Hz made exact time of contact and toeoff difficult. Inaccurate calculation was possible if the frame advanced over the contact or toeoff phases.

4.5 Trunk Angle

Trunk angle was defined so a large angle represented extension. The flexion angle during the toeoff phase decreased as the class decreased (Figure 4.9). The smallest trunk flexion was 96.89 degrees from the right side of subject 8 - Class C5, and the greatest was 54.28 degrees from the right of subject 2 - Class C8. To a lesser degree, trunk extension increased as the class number decreased (Figure 4.10). However, when comparing class means for ROM (Class C8: 25.5 and 25.6 degrees, Class C7: 21.8 and 29.6 degrees, Class C6: 28.6 and 23.5 degrees, and Class C5: 25.6 and 20.4 degrees, for the right and left sides, respectively) no trend was readily apparent.

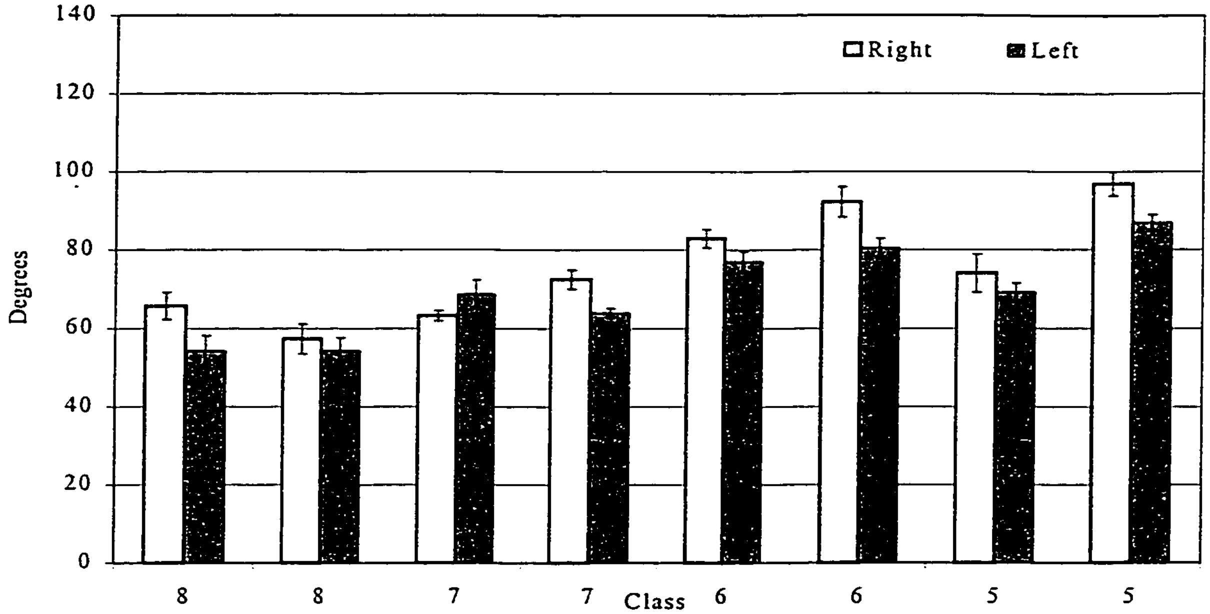


Figure 4.9. Trunk angle – flexion during toeoff phase (degrees) for all eight subjects Class C5 to C8. The angle was defined such that the smaller the angle the greater the trunk flexion. The more able classes had greater trunk flexion than the less able classes.

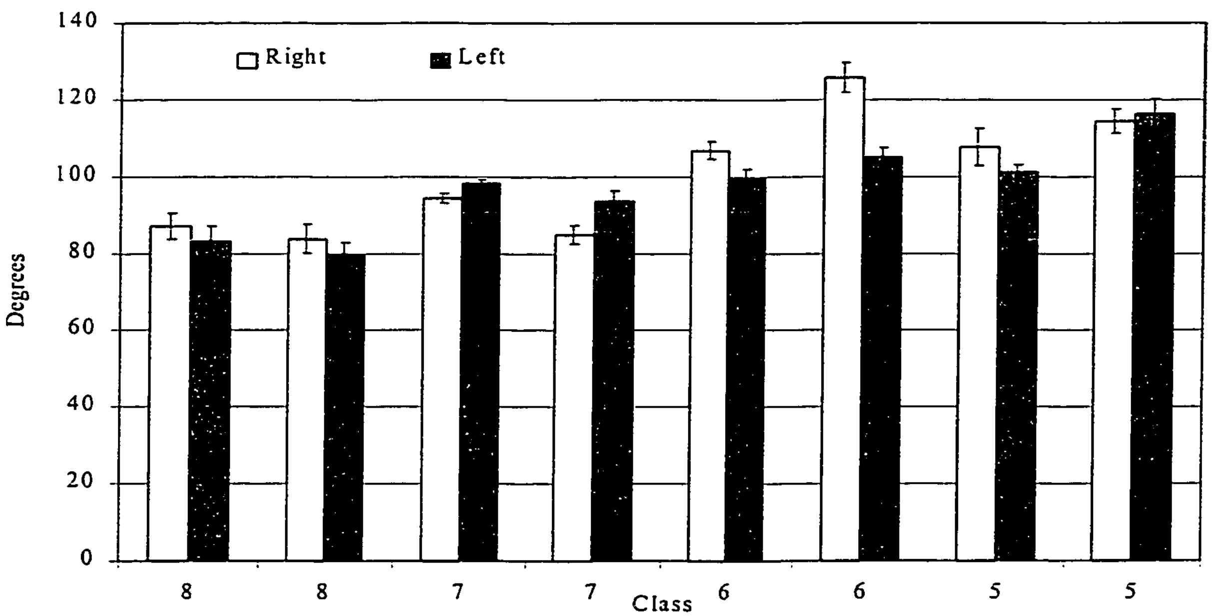


Figure 4.10. Trunk angle – extension during contact phase (degrees) for all eight subjects Class C5 to C8. The greater the angle the more the trunk leaned backwards. The more able classes had lower trunk extension than the less able classes.

Unfortunately, neither Pope et al. (1993) or Davids et al. (1998) considered trunk extension in their analyses. Pope at al. (1993) stated only the extreme flexion of the trunk. However, results from the present study suggested that subjects with more ability had lower trunk extension. It has been reported that increased trunk extension around contact is to compensate for ineffective hip extensors (Whittle, 1991).

Trunk angles and ROM can only be indirectly compared to Pope et al's (1993) research due to the differences between running and sprinting. Trunk angle was measured in a similar manner to the present study, such that the greater the angle the smaller the amount of forward lean. However, when comparing Pope et al's (1993) sprinting results to the running results from the current study under investigation, the amount of trunk flexion in sprinting was less than that found for running. For example, Pope et al. (1993) reported that Class C7 demonstrated the least amount of flexion at 78 degrees, Class C6 at 73 degrees, and Class C8 at 76 degrees. Results from the present study indicated that Class C5 had a trunk flexion of 85.4 and 76.1 degrees; Class C6 – 87.6 and 78.8 degrees; Class C7 – 67.8 and 66.3 degrees; and, Class C8 – 60.0 and 55.8 degrees, for the right and left sides, respectively.

4.6 Hip Angle

Hip angle was measured using an absolute angle from the horizontal axis, which meant that the smaller the angle, the closer the thigh was to the rear of the body. Results illustrated decreased hip extension as the class decreased (Figure 4.11). However, no obvious trend with hip flexion was present (Figure 4.12). ROM was reported as 63.5 and 60.9 degrees, 62.3 and 70.3 degrees, 49.2 and 47.3 degrees, and 38.3 and 33.4 degrees for the right and left sides, respectively, for Class C8 through C5. The angle - angle diagrams demonstrate ROM at the hip on the y-axis (Figures 4.22 to 4.37). ROM during the running cycle decreased as the severity of the disability decreased. Class C8 (60.9 degrees) and Class C5 (47.3 degrees) illustrated the differences in hip ROM as the class number decreased (Figures 4.23 and 4.37). Visual examination of the running style in Class C5 showed limited hip ROM, which is in agreement with the calculated data and the angle-angle diagrams (Figure 4.22 to 4.37). When discussing the trend in stride length, it was stated that if the disability caused limited motion about the hip, it would also shorten stride length (Winters et al., 1987). In this study ROM about the hip decreased as the class decreased which is similar to the trend observed in stride length. Davids et al. (1998) reported on hip ROM and found similar to the present study, a ROM of 50 degrees (st dev 10). This is comparable to the ROM recorded for the class means of the present study (33 - 70 degrees).

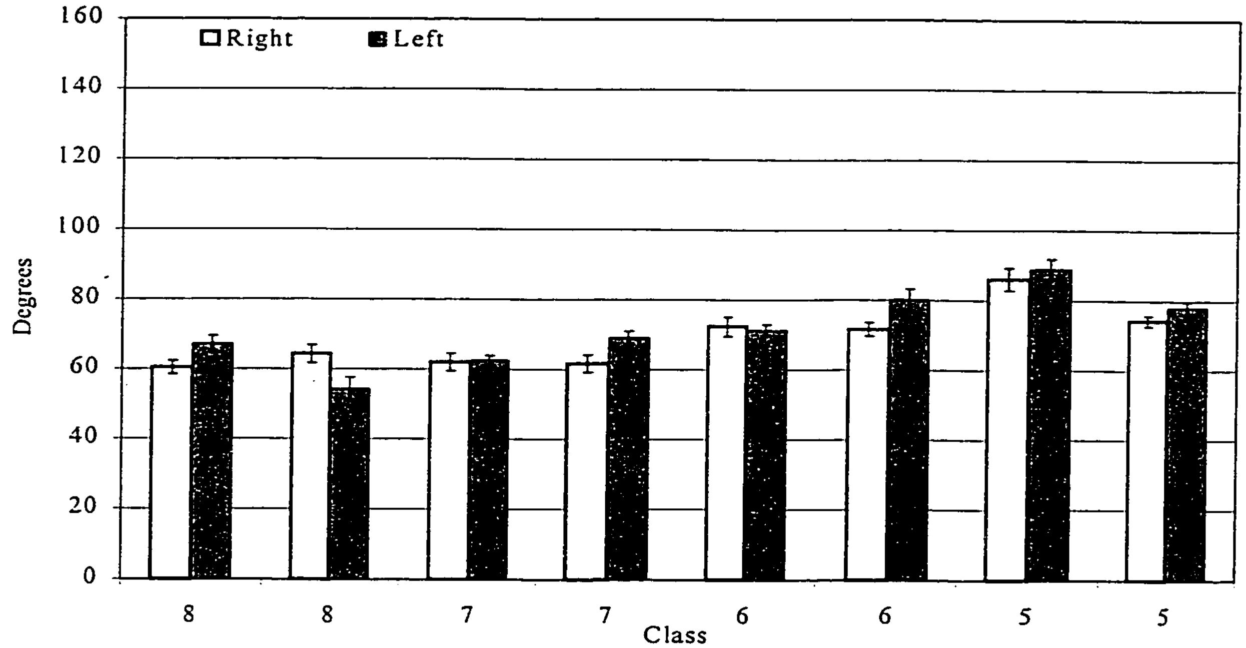


Figure 4.11. Hip angle - extension during toeoff phase (degrees) for all eight subjects Class C5 to C8. The angle was defined such that the smaller the angle the greater the hip extension. The more able classes had greater hip extension than the less able classes.

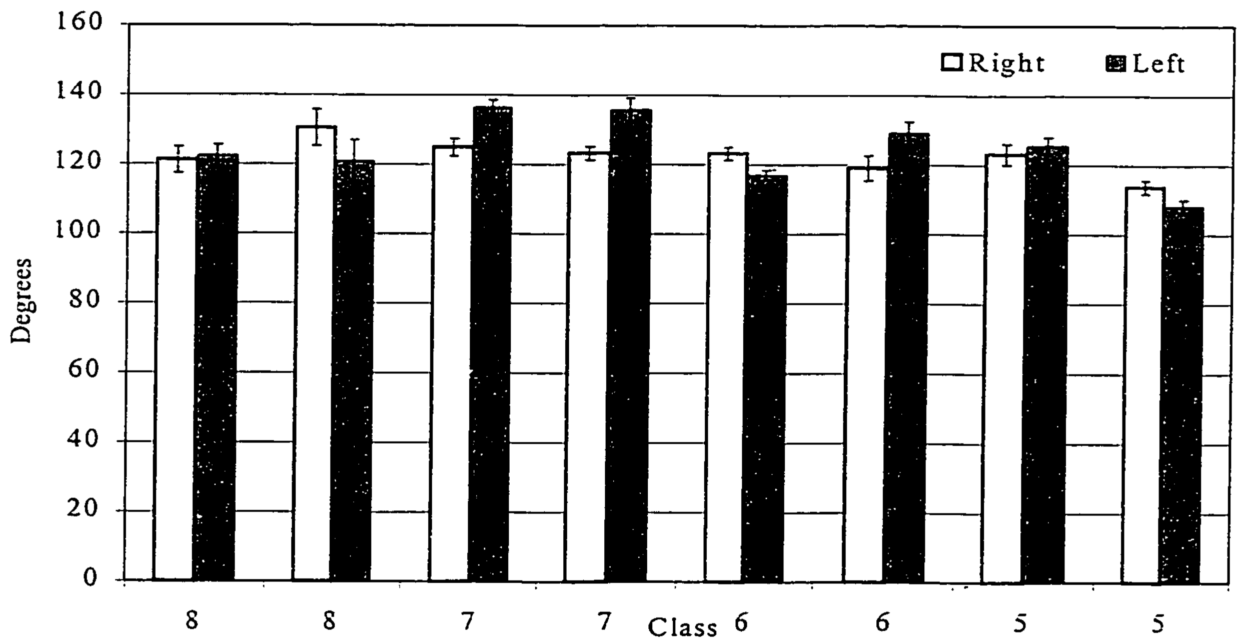


Figure 4.12. Hip angle - flexion during contact phase (degrees) for all eight subjects Class C5 to C8. As the angle increased, the greater the hip flexion. No trend in regards to class is apparent.

Pope et al. (1993) also reported differences between classes reporting that Class C7 and C8 had similar hip extension but Class C6 had a much smaller extension angle. In the present study Class C7 had a hip mean extension of 62 / 66 degrees and Class C8 - 62 / 60 degrees for the right and left sides respectively. Based on these figures hip extension for Class C7 and C8 were similar.

Hip flexion as reported in Pope et al. (1993) and the present study, was greatest for C8, less for Class C7 and C6, and even less for C5 (in the present study). A smaller hip ROM in the less able classes was attributed to greater hip contractures, immobile hip joints, more overactive iliopsoas and adductor muscles, thus limiting hip ROM (Winters et al., 1987).

4.7 Knee Angle

Knee angles for flexion and extension were graphed by combining Class C7 & C8 and C5 & C6. Separate graphs and tables represent the right and left sides (Figures 4.13 to 4.16). The knee angle was determined from an angle between the thigh and shank segments of each leg. As the degree of the angle increased, the knee moved into extension.

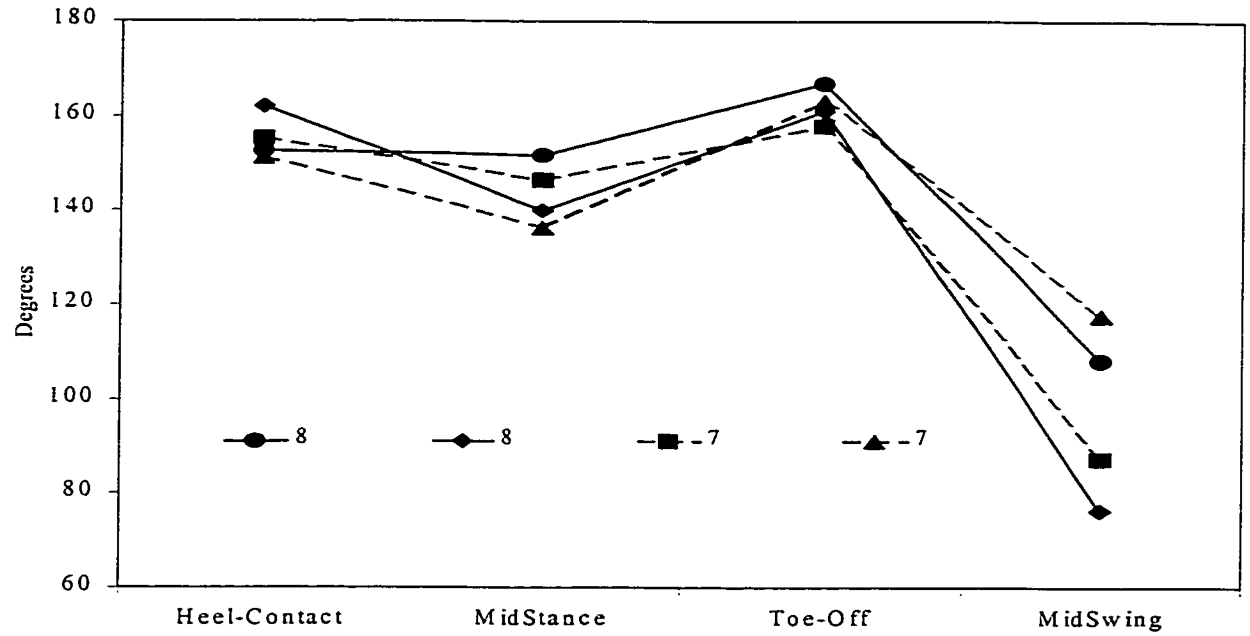


Figure 4.13. Knee angle right - for subjects Class C7 & C8 with two periods of flexion during midstance and midswing phases and extension during contact and toeoff phases. Limited knee flexion during stance is apparent for Class C7 subjects.

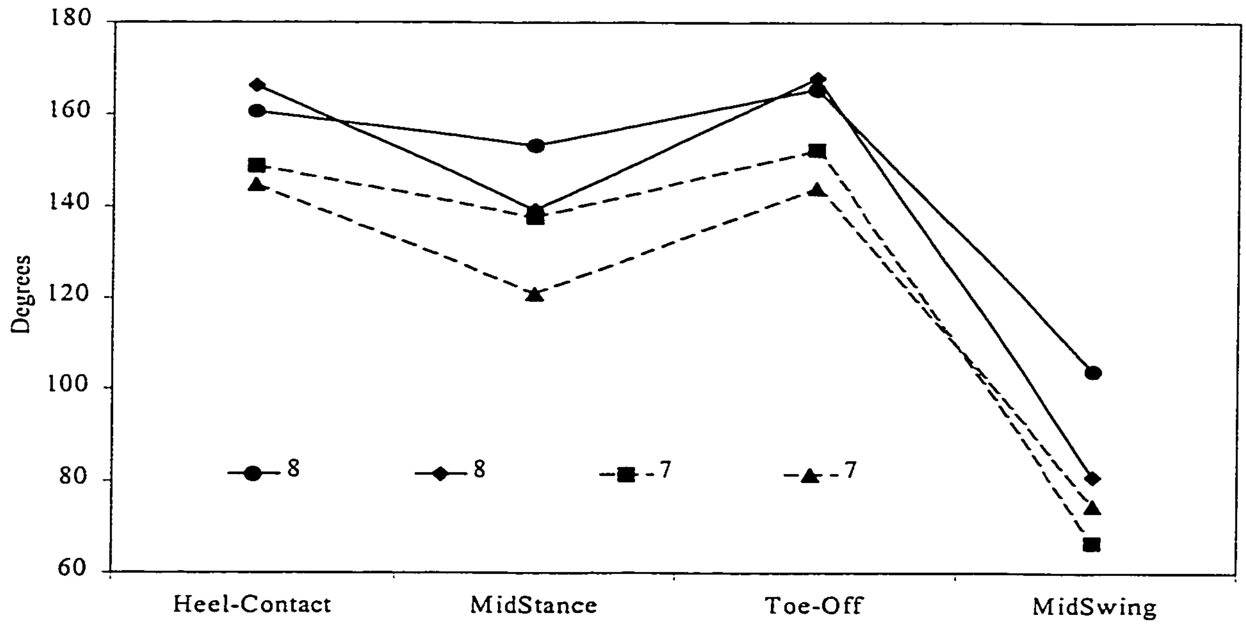


Figure 4.14. Knee angle left - for subjects Class C7 & C8, with a much greater ROM for Class C7 on the left (unaffected) side.

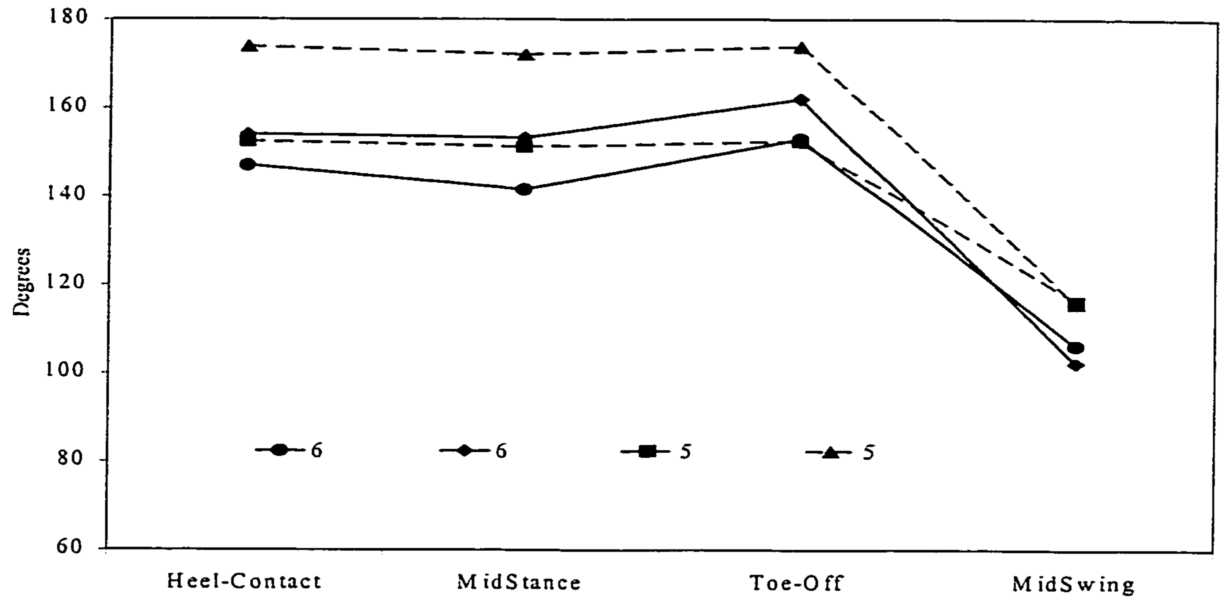


Figure 4.15. Knee angle right - for subjects Class C5 & C6, where flexion at both phases during the cycle is limited.

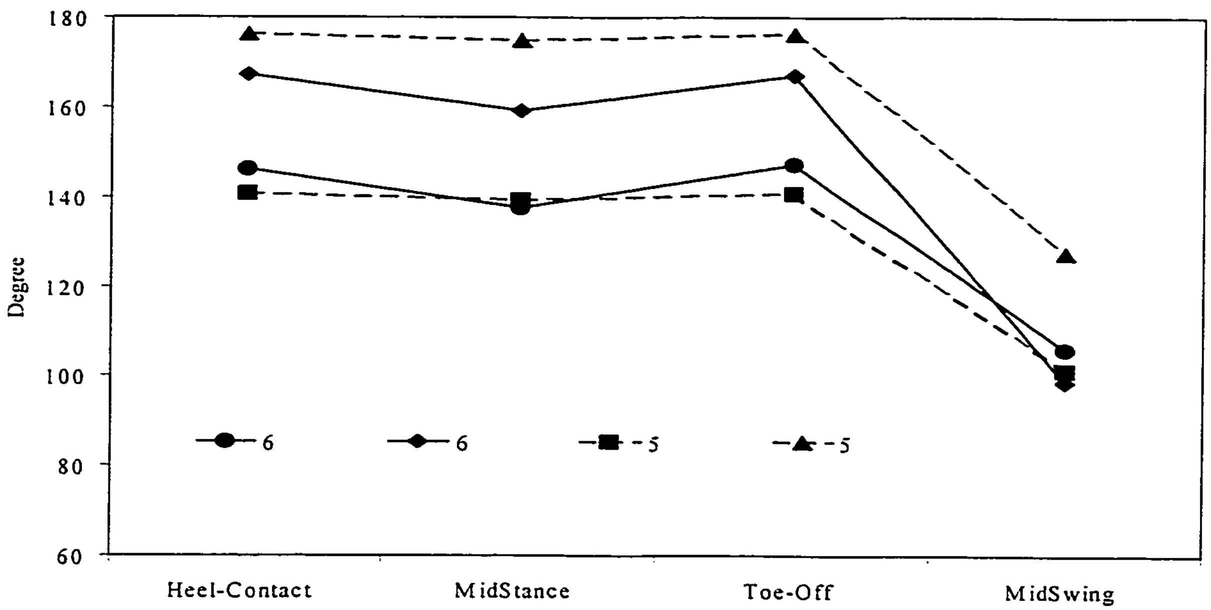


Figure 4.16. Knee angle left - for subjects Class C5 & C6, similar to the right side, where flexion at both phases during the cycle is limited, reducing knee ROM.

Right and left sides of Class C7 and C8 compared with Class C5 and C6, illustrated that the less able classes had limited flexion during stance. Milliron and Cavanagh (1990) stated within the nondisabled population that knee flexion was 15% into the cycle before midstance, referred to as the cushioning phase of 10 to 20 degrees. However, Class C5 only had 1-2 degrees of flexion following contact. Davids et al. (1998) identified 24 degrees of knee flexion after contact for children with spastic diplegia. The present study did not find similar results within Class C5. The more able classes, C7 and C8, however, displayed a cushioning angle of flexion of 141.2 / 129.2 and 145.7 / 146.1 degrees for the right and left sides, respectively. This cushioning angle of 17 and 12 degrees for the right and left sides respectively, for both classes, is comparable to nondisability literature (Milliron & Cavanagh, 1990). Pope et al. (1993) reported that the flexion found after contact for Class C6, C7, and C8 were 149 / 154, 147 / 146, and, 148 / 149 degrees for the right and left sides, respectively. Since degree of knee flexion after contact is related to speed and sprinting is faster than running, it can be suggested that these results were comparable to the data found in the present study which were 145.7/146.1; 141.2/129.2; 147.2/148.3; 162.3/157.8 for the right and left sides of Class C8 to C5, respectively.

Knee flexion during the midswing phase for Class C8 to C5 was reported to be 92.3 / 92.4, 102.5 / 70.6, 104.3 / 102.3, and 116.1 / 114.4 degrees for the right and left sides, respectively. The more able classes had a greater maximum flexion angle. Interestingly, the affected side of C7, displayed a much lower flexion angle than the unaffected knee. This may be due to contractures and spastic muscles about the knee, limiting the ability of the knee to flex. This is in accordance with what was reported from the observational data, which concluded that the affected limb had decreased flexion during midswing.

Knee flexion during swing has been reported to be greater for the nondisabled class compared to runners with CP. Davids et al. (1998) emphasized that as the severity of the disability increased, knee flexion decreased.

Extension which occurred around the toeoff and contact phases, did not seem to be a distinguishing variable for the four classes. The greatest extension was 166.7 from Class C8 and 147.6 on the nonaffected sides of Class C7. Pope et al. (1993) recorded extension angles around toeoff for Class C6, C7, and C8 as 160 / 163, 162 / 162, 165 / 156 degrees for the right and left sides, respectively. In the sprinting data and the present running research, no trend seemed to be apparent for extension. Pope et al. (1993) also stated that Class C7 had no difference between the right and left sides. The present study demonstrated that knee extension was greater for the affected side than the unaffected side. Davids et al. (1998) found knee extension to be 157 degrees which was similar to the extension angles found in the present running study.

Ounpuu (1994) stated that knee ROM for the nondisabled population during running was 63 degrees. However, studies investigating CP running found significantly lower knee ROM for the CP group compared to controls (Davids et al., 1998). ROM in children was 43 degrees (std dev. 8). The present running study recorded knee ROM for Class C8 to C5 as 72.2 / 74.3, 57.9 / 77.5, 53.2 / 54.8, and 47.1 / 44.2 degrees for the right and left sides, respectively. This knee ROM can clearly be seen in the hip/knee angle-angle diagrams (Figure 4.22 to 4.37). The most drastic differences between the right and left sides of the body were present in Class C7 which demonstrated that ROM at the knee was considerably less for the affected right leg compared to the unaffected left limb (Figures 4.28 and 4.29). The limitations in knee ROM for the less able classes, Class C5 and C6 were demonstrated (Figures 4.34, 4.36, and 4.37).

Knee flexion and extension was reduced for the less able classes. This was attributed to overactive quadriceps and hamstring muscles, increased knee contractures, and increased spasticity of the flexors which caused reduced ROM at the knee, thus decreasing knee extension and flexion (Winters et al., 1987).

4.8 Ankle Angle

During the running cycle the ankle experiences two periods of plantarflexion during the contact and toeoff phases, and two periods of dorsiflexion during the midstance and midswing phases. Ankle angles were graphed by combining Class C7 & C8 and C5 & C6. The ankle angle was determined from an angle, between the foot and shank segments of each leg. As the angle increased, the ankle moved into plantarflexion (Tables 4.17 to 4.20).

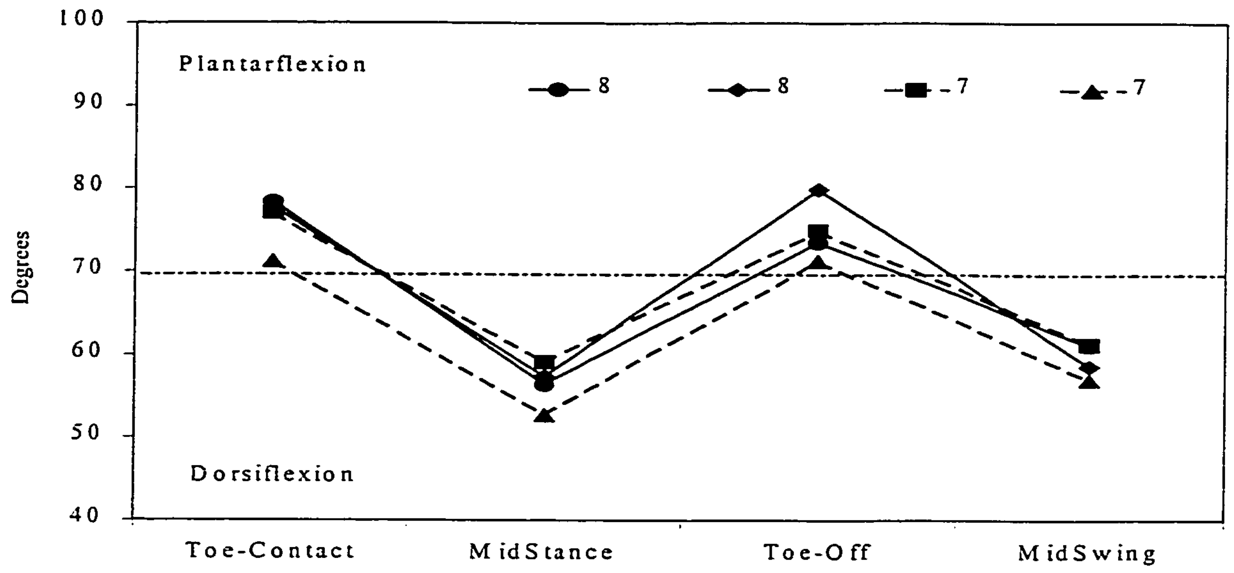


Figure 4.17. Ankle angle right - for subjects Class C7 & C8 with two periods of plantarflexion during contact and toeoff phases and dorsiflexion during midstance and midswing phases, where angles are similar for both classes.

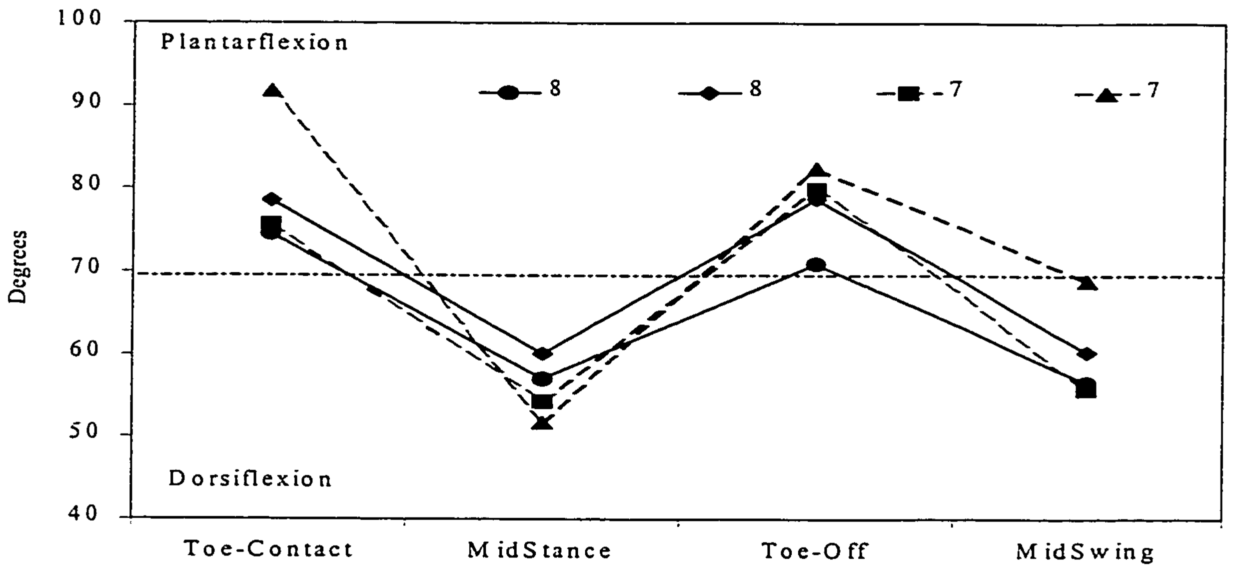


Figure 4.18. Ankle angle left - for subjects Class C7 & C8.

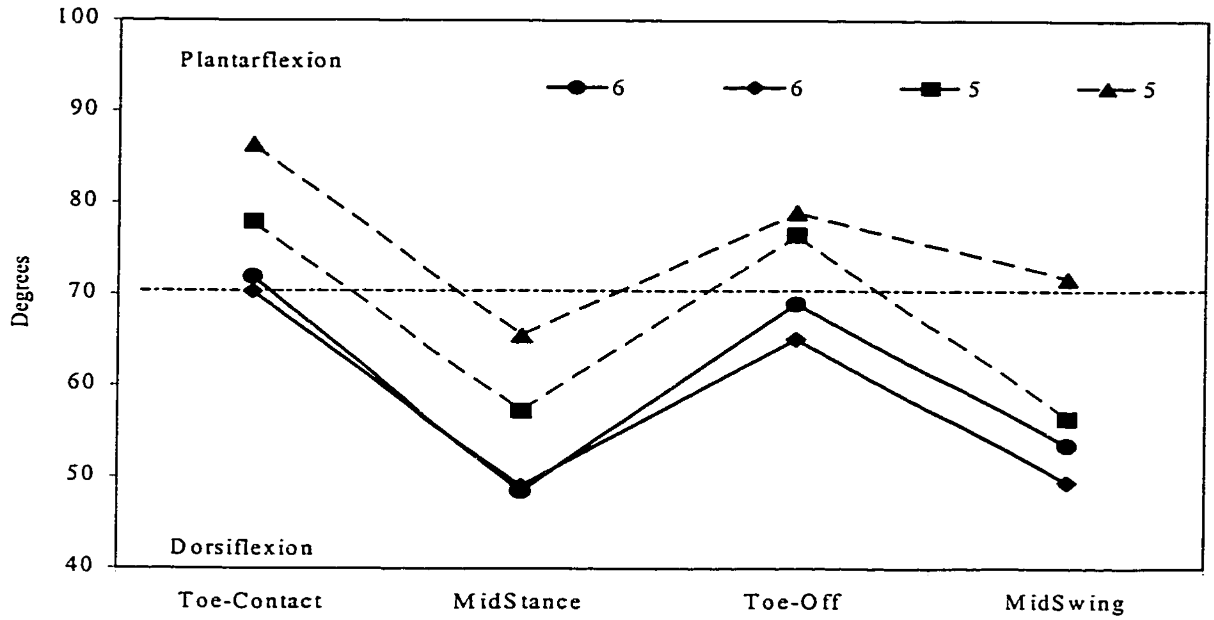


Figure 4.19. Ankle angle right - for subjects Class C5 & C6, where limited plantarflexion for Class C5 and limited dorsiflexion for Class C6 is evident.

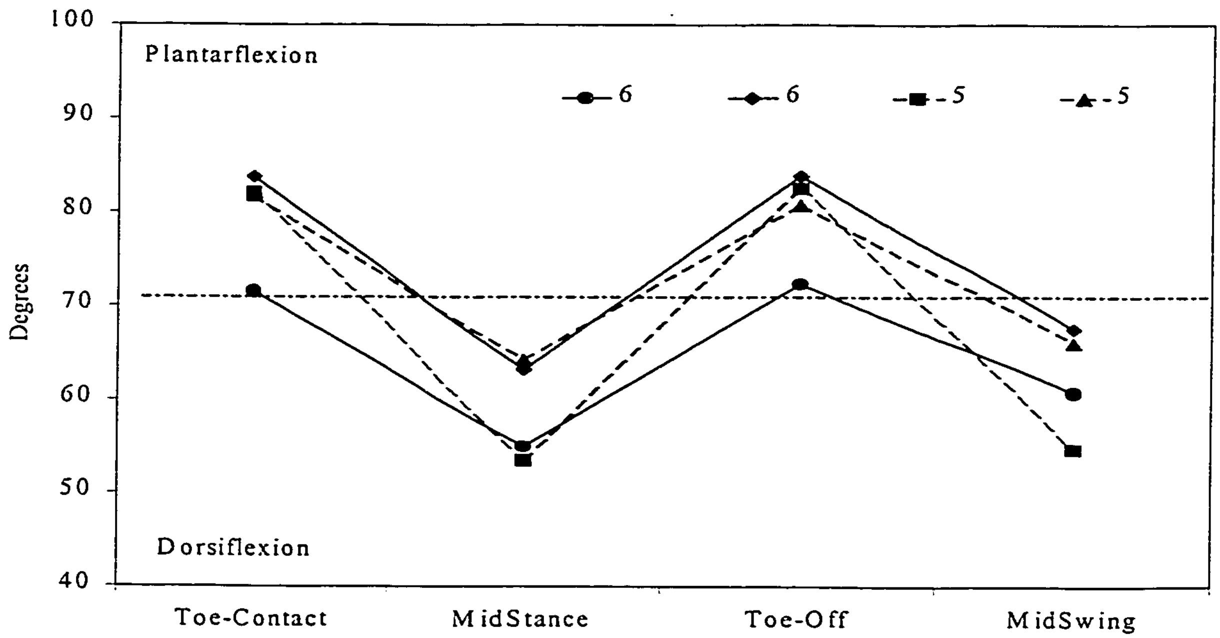


Figure 4.20. Ankle angle left - for subjects Class C5 & C6 where angles are similar for both classes.

All classes demonstrated two periods of plantar and dorsiflexion (Figures 4.23, 4.24, 4.25, and 4.26). ROM which ranged from 40.0 degrees from subject 3 - Class C7 on the left side and 16.63 degrees from subject 5 - Class C6 on the left side, revealed no apparent trend between classes. Davids et al. (1998) also found a ROM of 34 degrees (std dev 13) which compliments the present study's findings. In the visual observation Class C7 maintained the affected ankle in a neutral position, Class C6 had the ankle in plantarflexion, and Class C5 had the ankle in dorsiflexion throughout the cycle. The reported data was not evident during the visual observation, due to the size and speed of the ankle movements.

Milliron and Cavanagh (1990) stated that individuals with a smaller ROM tended to have tighter gastrocnemius muscles and less ankle flexibility. With this consideration, nonaffected side of Class C7 reported the greatest ankle ROM at 30.7 degrees, and Class C8 had one of the smallest ROM at 21.1 and 17.9 degrees for the right and left side, respectively. It was speculated that as the ankle went through the cycle, movement was not completely within the sagittal plane, therefore the true ROM was not recorded due to only one plane being examined. Other anatomical movements such as hip hiking and increased hip circumduction, not examined in this study, could also have attributed to the low ankle ROM for Class C8.

Due to the nature of sprinting, Pope et al. (1993), reported angles which ranged between 92 - 101 degrees during contact and 104 - 120 degrees during toeoff. It was reported that maximum plantarflexion was at toeoff. In the present running study, plantarflexion during contact was between 91.7 and 71.2 degrees for all four classes and plantarflexion during toeoff was 83.8 and 65.1 degrees. Milliron and Cavanagh (1990) reported that for the nondisabled population during running, the ankle was approximately 90 degrees during contact and 110 degrees during toeoff (maximum plantarflexion). The present running study illustrated every subject from each class did not reach maximum plantarflexion during toe-off as reported in the sprinting literature for both nondisabled and CP (Milliron & Cavanagh, 1990; Pope et al., 1993).

Dorsiflexion was reported at 79 degrees in children with CP while running (Davids et al., 1998). The present study showed greater dorsiflexion during both the midstance and midswing phases of the cycle for all four classes. Despite no apparent trend, Class C8 reported 20 degrees of dorsiflexion at the ankle which is comparable to the nondisability literature (Milliron & Cavanagh, 1990; Ounpuu, 1994).

4.9 Statistical Analysis

After examining apparent trends in the data, a connection between Class C7 & C8 and Class C5 & C6 emerged. The data was grouped not by individual classes but by two classes together after performing a hierarchical cluster analysis using standardized z-scores. The dendrogram of the cluster clearly illustrated that Class C7 & C8 and Class C5 & C6 combined together. Case 1-4, representing subjects one through four from Class C7 and C8 were grouped together and Case 5-8, representing subjects 5 through 8 from Class C5 and C6 were grouped together (Figure 4.21).

```
C A S E      0         5        10        15        20        25
Label     Num  +---------+---------+---------+---------+---------+

Case 3     3    -+---+
Case 4     4    -+   +---+
Case 1     1    -----+   +---------------------------------------+
Case 2     2    ---------+
Case 5     5    -----+-------------+
Case 7     7    -----+             +-------------------------------+
Case 6     6    -------------+-----+
Case 8     8    -------------+
```

Figure 4.21. Dendrogram using hierarchical cluster analysis (case representing subject) where the most alike cluster was grouped from subjects 3 and 4, both of Class C7, the next most alike clusters were made from a combination of subjects from Class C5 and C6. The nearest to the origin the greatest the similarity between the linked cases.

The Kruskal Wallis test which ranks data and accounts for smaller sample sizes, was implemented twice: once for significance of variables for all classes treated separately and another for significance in the combination of Class C7 & C8, and Class C5 & C6 together. With a liberal alpha level set at .05, none of the variables were significant by individual class. However, when Class C7 & C8 and C5 & C6 were grouped, fifteen variables were significant and two variables approach significance (Table 4.1). The significant variables were stance time, stride length, stance and swing ratio, hip and trunk ankle at maximum extension, and trunk angle at maximum flexion for both the right and left sides of the body, and swing time for the left side only. The variables which approached significance were knee angle at maximum flexion and hip angle at maximum flexion for the right side only. Grouping classes together demonstrated that Class C5 & C6 and C7 & C8 were more similar than the classes by themselves. The six significant variables which presented trends within the data were stride length, swing percentage, trunk extension and flexion, and hip extension and flexion. It is not surprising that stride length and swing percentage were significant, as they require full range of motion from all the lower limb joints, which is a limitation of CP. The less able classes have greater limitations in their lower limb joints than those in the higher, more able classes. The most involved joints seem to be the trunk and hip segments, as they were significant between Class C7 & C8 and Class C5 & C6. These data would suggest that these classes could be combined for competition however, caution must be exercised due to the limited number of subjects and indicated intra and interclass trends.

Table 4.1

Nonparametric Tests - Kruskal Wallis Test - Grouping Variable by Class C5 & C6 and C7 & C8 (n=8)

Variable	*Right*		*Left*	
	x^2	p	x^2	p
Swingtime	6.05	.20	6.00	.01**
Stancetime	1.83	.04**	1.83	.03**
DoubleFloat%	.96	.56	.96	.15
Stridetime	.75	.66	.24	1.00
Cadence	.54	.77	.24	1.00
Stridelength	6.00	.02**	6.00	.02**
Swing %	3.84	.02**	2.94	.02**
Stance %	3.84	.02**	2.94	.02**
Ankle- PF (1)	.06	1.00	.06	.77
Ankle- DF (1)	.54	.56	.96	.39
Ankle- PF (2)	.96	.56	.54	.25
Ankle- DF (2)	.96	.25	.24	.77
Knee- Extension (1)	2.00	.35	.12	.64
Knee-Peak Flexion	.96	.56	.96	.39
Knee- Extension (2)	.96	.56	.24	1.00
Knee-Max Flexion	.24	.08*	3.84	.56
Hip- Extension	6.00	.02**	6.00	.02**
Hip- Flexion	.96	.08*	.96	.25
Trunk- Extension	6.00	.02**	3.84	.02**
Trunk- Flexion	6.00	.02**	6.00	.02**

Note. % = Percentage of cycle; PF = Plantarflexion; DF = Dorsiflexion; Max = Maximum; (1) = First time during the cycle; (2) = Second time during the cycle; ** = Significant (at 0.05 level); * = Approaching significance; p = significance; x^2 = Chi Square value.

Table 4.2
Stride Time in Seconds for all Subjects with Class Means and Standard Deviations (Std Dev)

Subject	*Right*	*Std Dev*	*Left*	*Std Dev*
1 - C8	0.61	0.03	0.61	0.03
2 - C8	0.73	0.03	0.73	0.03
Class 8 Mean	0.67	0.03	0.67	0.03
3 - C7	0.73	0.02	0.73	0.03
4 - C7	0.63	0.02	0.60	0.03
Class 7 Mean	0.68	0.02	0.665	0.03
5 - C6	0.61	0.03	0.62	0.01
6 - C6	0.90	0.13	0.85	0.04
Class 6 Mean	0.755	0.08	0.735	0.03
7 - C5	0.67	0.03	0.67	0.03
8 - C5	0.57	0.03	0.58	0.03
Class 5 Mean	0.62	0.03	0.625	0.03

Table 4.3
<u>Stride Length in Centimetres for all Subjects with Class Means and Std Deviations (Std Dev)</u>

Subject	*Right*	*Std Dev.*	*Left*	*Std Dev.*
1 - C8	195.93	5.14	183.79	4.70
2 - C8	280.42	2.95	287.85	6.40
Class 8 Mean	238.17	4.04	235.82	5.55
3 - C7	259.72	4.78	263.42	1.79
4 - C7	226.91	4.70	236.59	3.87
Class 7 Mean	243.31	4.74	250.00	2.83
5 - C6	169.18	7.99	167.74	7.99
6 - C6	97.70	3.48	113.69	6.25
Class 6 Mean	133.44	5.73	140.71	7.12
7 - C5	139.12	5.49	131.95	5.10
8 - C5	77.27	4.96	64.69	5.41
Class 5 Mean	108.19	5.22	98.32	5.25

Table 4.4

Cadence (steps/minute) for all Subjects with Class Means and Std Deviations (Std Dev)

Subject	*Right*	*Std Dev*	*Left*	*Std Dev*
1-C8	197.30	10.33	198.36	5.61
2- C8	164.10	5.86	165.70	6.64
Class 8 Mean	180.7	8.09	182.03	6.12
3-C7	163.52	4.67	163.14	5.19
4-C7	192.93	6.27	198.86	7.84
Class 7 Mean	178.22	5.47	181	6.51
5-C6	196.03	8.16	194.39	4.76
6-C6	138.42	5.87	141.22	5.88
Class 6 Mean	167.22	7.01	167.80	5.32
7-C5	177.53	9.85	176.74	7.08
8-C5	209.50	9.21	206.41	9.38
Class 5 Mean	193.51	9.53	191.57	8.23

Table 4.5
<u>Stance - Swing Ratio (Percentage) for all Subjects with Class Means and Std Deviations (Std Dev)</u>

Subject	*Right*			*Left*		
	Stance %	Swing %	Std Dev	Stance%	Swing %	Std Dev
1-C8	39.83	60.17	2.04	39.62	60.38	2.07
2-C8	33.60	66.40	1.93	32.22	67.78	1.81
Class 8 Mean	36.71	63.28	1.98	35.92	64.08	1.94
3-C7	38.81	61.19	1.61	37.76	62.24	1.52
4-C7	34.52	65.48	1.73	36.84	63.16	1.66
Class7 Mean	36.66	63.33	1.67	37.3	62.7	1.59
5-C6	44.15	55.85	1.73	45.33	54.67	1.40
6-C6	61.40	38.60	4.71	66.30	33.70	1.65
Class6 Mean	52.77	47.22	3.22	55.81	44.18	1.52
7-C5	57.33	42.67	2.22	57.75	42.25	3.08
8-C5	65.40	34.60	4.18	62.08	37.92	2.65
Class 5 Mean	61.36	38.63	3.20	59.91	40.08	2.86

Table 4.6
Double Float Period (Percentage) for all Subjects with Class Means and Std Deviations (Std Dev)

Subject	*Right Foot Forward*	*Std Dev*	*Left Foot Forward*	*Std Dev*
1-C8	10.28	.065	10.74	.065
2- C8	16.87	.125	19.53	.14
Class 8 Mean	13.57	0.095	15.13	.102
3-C7	11.18	.08	11.16	.085
4-C7	14.49	.09	14.83	.09
Class 7 Mean	12.83	.085	12.99	.087
5-C6	2.03	.015	8.94	.055
6-C6	14.99	.135	11.45	.10
Class 6 Mean	8.51	.075	10.19	.077
7-C5	7.42	.05	7.80	.05
8-C5	15.05	.085	12.83	.075
Class 5 Mean	11.23	.067	10.31	.062

Table 4.7

Trunk Angle - Absolute (Max) Flexion and Extension (Ext) (Degrees) for all Subjects and Range of Motion (ROM) with Class Means and Std Deviations (Std Dev)

	Right					*Left*				
Subject	*Max Flexion*	*Std Dev*	*Max Ext*	*Std Dev*	*ROM*	*Max Flexion*	*Std Dev*	*Max Ext*	*Std Dev*	*ROM*
1-C8	87.18	2.60	65.73	3.45	21.45	83.34	3.93	57.30	3.90	26.04
2- C8	83.87	3.34	54.28	3.79	29.59	79.55	5.38	54.31	3.31	25.24
Class 8 Mean	85.52	2.97	60.00	3.62	25.52	81.44	4.65	55.80	3.60	25.64
3-C7	84.90	1.70	63.20	1.30	21.70	93.69	2.00	68.71	1.14	24.98
4-C7	94.40	2.84	72.47	2.44	21.93	98.18	3.42	63.91	2.54	34.27
Class 7 Mean	89.65	2.27	67.83	1.87	21.81	95.93	2.71	66.31	1.84	29.62
5-C6	106.70	3.96	82.92	2.37	23.78	99.40	3.12	77.03	2.46	22.37
6-C6	125.71	5.05	92.26	3.87	33.45	105.08	3.37	80.52	2.30	24.56
Class 6 Mean	116.20	4.50	87.59	3.12	28.61	102.24	3.24	78.77	2.38	23.46
7-C5	107.61	3.30	74.01	4.85	33.60	101.16	3.84	69.16	2.01	32.00
8-C5	114.44	2.22	96.89	3.09	17.55	116.31	2.14	86.98	3.86	29.33
Class 5 Mean	111.02	2.76	85.45	3.97	25.57	108.73	2.99	76.07	2.93	20.44

Table 4.8

Hip Angle - Absolute (Max) Flexion and Extension (Ext) (Degrees) for all Subjects and Range of Motion (ROM) with Class Means and Std Deviations (Std Dev)

	Right					Left				
Subject	*Max Flexion*	*Std Dev*	*Max Ext*	*Std Dev*	*ROM*	*Max Flexion*	*Std Dev*	*Max Ext*	*Std Dev*	*ROM*
1-C8	121.27	3.88	60.40	1.90	60.87	122.28	3.21	67.19	2.31	55.2
2- C8	130.52	5.29	64.29	2.69	66.23	120.95	6.18	54.31	3.29	66.6
Class 8 Mean	125.89	4.58	62.34	2.29	63.55	121.61	4.69	60.75	2.80	60.9
3-C7	123.34	2.55	61.71	2.59	62.94	135.79	2.28	69.14	1.35	73.9
4-C7	124.93	1.94	61.99	2.57	61.62	136.43	3.45	62.53	1.93	66.6
Class 7 Mean	124.13	2.24	61.85	2.58	62.28	136.11	2.86	65.83	1.64	70.3
5-C6	123.24	1.83	72.34	2.87	50.89	116.95	1.56	71.33	1.62	45.6
6-C6	119.08	3.64	71.60	1.91	47.48	129.09	3.36	80.14	3.18	48.9
Class 6 Mean	121.16	2.73	71.97	2.39	49.18	123.02	2.46	75.73	2.40	47.3
7-C5	123.12	3.01	86.06	3.26	37.06	125.59	2.48	88.96	2.99	36.6
8-C5	113.82	1.98	74.27	1.54	39.55	108.23	1.90	78.05	1.84	30.2
Class 5 Mean	118.47	2.49	80.16	2.40	38.30	116.91	2.19	83.50	2.41	33.4

Table 4.9

Knee Angle Left - Relative (Peak) and Absolute (Max) Maximums and Minimums (Degrees) for all Subjects with Range of Motion (ROM), Class Means and Std Deviations (Std Dev)

	Left								
Subject	*Max Flexion*	*Std Dev*	*Peak Extension*	*Std Dev*	*Peak Flexion*	*Std Dev*	*Peak Extension*	*Std Dev*	*ROM*
1-C8	103.93	5.93	160.44	3.62	153.14	4.97	165.57	3.81	61.65
2- C8	80.90	6.60	166.17	4.68	139.16	4.62	167.83	4.32	86.94
Class 8 Mean	92.41	6.26	163.30	4.15	146.15	4.79	166.70	4.06	74.29
3-C7	66.56	5.35	148.68	2.91	137.52	2.26	152.34	1.25	85.78
4-C7	74.72	2.81	144.75	4.89	120.89	2.24	142.92	3.50	69.21
Class 7 Mean	70.64	4.08	146.71	3.90	129.20	2.25	147.63	2.37	77.49
5-C6	105.95	3.26	146.28	1.37	137.49	2.49	147.20	1.68	41.25
6-C6	98.61	3.89	167.18	4.07	159.15	1.22	166.99	1.94	68.38
Class 6 Mean	102.28	3.57	156.73	2.72	148.32	1.85	157.09	1.81	54.81
7-C5	54.72	3.82	--	--	101.31	2.42	140.76	5.11	39.45
8-C5	66.11	4.51	--	--	127.48	4.48	176.35	3.30	48.87
Class 5 Mean	60.41	4.16	--	--	114.39	3.45	158.55	4.44	44.16

Table 4.10

Knee Angle Right - Relative (Peak) and Absolute (Max) Maximums and Minimums (Degrees) for all Subjects with Range of Motion (ROM), Class Means and Std Deviations (Std Dev)

	Right								
Subject	*Max Flexion*	*Std Dev*	*Peak Extension*	*Std Dev*	*Peak Flexion*	*Std Dev*	*Peak Extension*	*Std Dev*	*ROM*
1-C8	108.27	7.47	152.64	4.45	151.61	4.17	166.93	3.96	58.66
2- C8	76.33	2.85	162.10	3.27	139.84	3.14	161.03	2.05	85.77
Class 8 Mean	92.30	5.16	157.37	3.85	145.72	3.65	163.98	3.00	72.21
3-C7	87.28	4.21	155.14	2.26	146.24	5.56	157.80	2.10	70.52
4-C7	117.81	1.83	151.20	2.85	136.23	2.12	163.19	2.18	45.38
Class 7 Mean	102.54	3.02	153.17	2.55	141.23	3.84	160.49	2.14	57.95
5-C6	106.29	4.09	146.92	2.88	141.49	4.34	152.97	2.82	46.68
6-C6	102.37	5.60	153.93	5.98	153.08	5.53	162.01	5.40	59.64
Class 6 Mean	104.33	4.84	150.42	4.43	147.28	4.93	157.49	4.11	53.16
7-C5	56.39	3.06	--	--	116.26	3.22	152.40	3.00	96.01
8-C5	71.76	2.56	--	--	115.89	2.88	173.85	1.68	102.09
Class 5 Mean	64.07	2.81	--	--	116.07	3.05	163.12	2.34	99.05

Table 4.11

Ankle Left - Relative (Peak) and Absolute (Max) Maximums and Minimums for Plantarflexion (PF) and Dorsiflexion (DF) (Degrees) for all Subjects with Range of Motion (ROM), Class Means and Std Deviations (Std Dev)

	Left								
Subject	*Max PF*	*Std Dev*	*Max DF*	*Std Dev*	*Peak PF*	*Std Dev*	*Peak DF*	*Std Dev*	*ROM*
1-C8	74.53	4.27	57.08	6.24	70.94	2.81	56.58	2.17	17.45
2- C8	78.51	3.95	60.04	4.19	78.69	5.74	60.22	4.07	18.46
Class 8 Mean	76.52	4.11	58.56	5.22	74.82	4.27	58.40	3.12	17.95
3-C7	75.61	3.95	54.21	1.87	79.98	1.83	55.77	2.86	21.41
4-C7	91.74	2.93	51.69	1.22	82.45	4.02	68.94	3.15	40.05
Class 7 Mean	83.68	3.44	52.95	1.54	81.22	2.93	62.35	3.01	30.73
5-C6	71.62	4.07	54.99	3.98	72.33	4.27	60.78	2.23	16.63
6-C6	83.73	5.03	63.21	2.80	83.81	4.58	67.51	4.45	20.52
Class 6 Mean	77.68	4.55	59.10	3.39	78.07	4.43	64.15	3.34	18.57
7-C5	82.04	5.85	53.51	3.80	82.52	5.46	54.72	3.82	28.53
8-C5	81.79	3.74	64.20	4.01	80.76	2.78	66.11	4.51	17.59
Class 5 Mean	81.92	4.80	58.86	3.91	81.64	4.12	60.42	4.17	23.06

Table 4.12

Ankle Right - Relative (Peak) and Absolute (Max) Maximums and Minimums for Plantarflexion (PF) and Dorsiflexion (DF) (Degrees) for all Subjects with Range of Motion (ROM), Class Means and Std Deviations (Std Dev)

				Left					
Subject	*Max PF*	*Std Dev*	*Max DF*	*Std Dev*	*Peak PF*	*Std Dev*	*Peak DF*	*Std Dev*	*ROM*
1-C8	78.36	3.65	56.42	3.13	73.48	3.87	61.07	4.23	21.94
2- C8	77.72	2.81	57.40	3.67	79.92	3.62	58.60	2.20	20.33
Class 8 Mean	78.04	3.23	56.91	3.40	76.70	3.74	59.83	3.22	21.14
3-C7	77.04	2.75	59.05	3.12	74.93	2.49	61.23	2.01	17.99
4-C7	71.19	3.50	52.75	2.23	71.28	3.44	57.00	2.63	18.44
Class 7 Mean	74.11	3.12	55.90	2.68	73.11	2.96	59.11	2.32	18.22
5-C6	71.93	5.53	48.47	3.26	68.97	6.74	53.47	2.05	23.46
6-C6	70.33	6.20	49.01	3.35	65.06	3.89	49.39	4.60	21.32
Class 6 Mean	71.13	5.86	48.74	3.31	67.01	5.32	51.43	3.33	22.39
7-C5	77.94	4.14	57.24	3.32	76.53	4.73	56.39	3.06	20.70
8-C5	86.36	3.03	65.53	2.32	79.03	2.76	71.76	2.56	20.83
Class 5 Mean	82.15	3.59	61.38	2.82	77.78	3.74	64.08	2.81	20.76

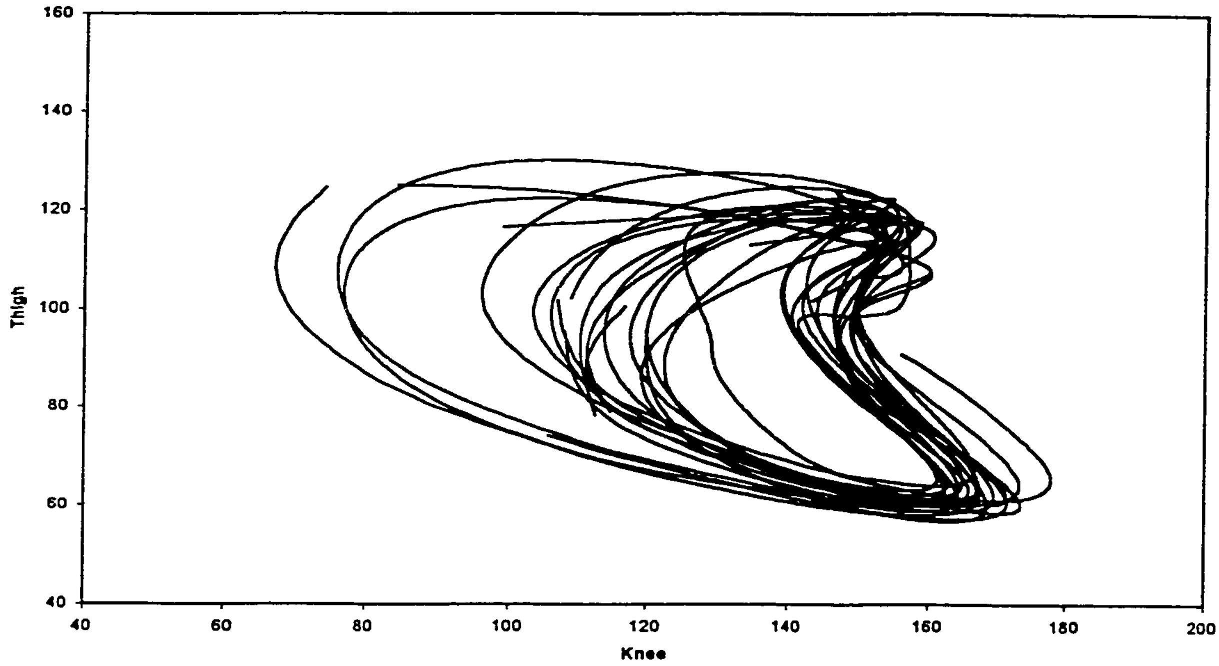


Figure 4.22. Subject 1/Class C8- right side: knee/thigh angle diagram

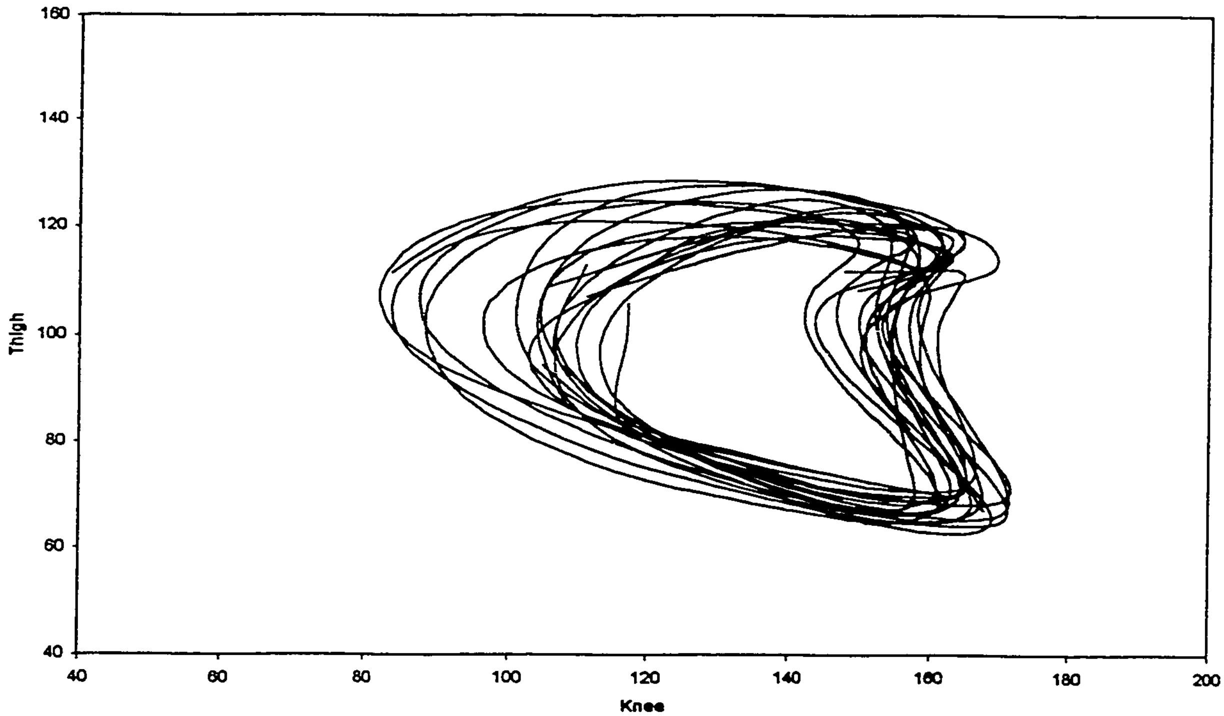


Figure 4.23. Subject 1/Class C8- left side: knee/thigh angle diagram

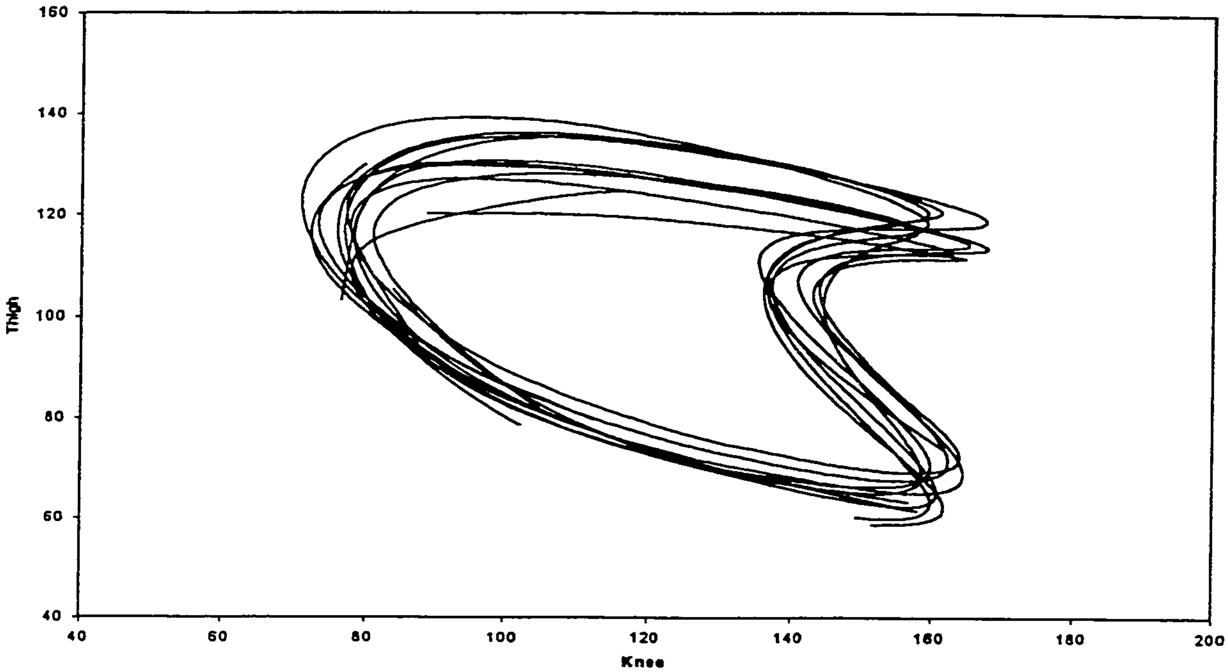


Figure 4.24. Subject 2/Class C8- right side: knee/thigh angle diagram

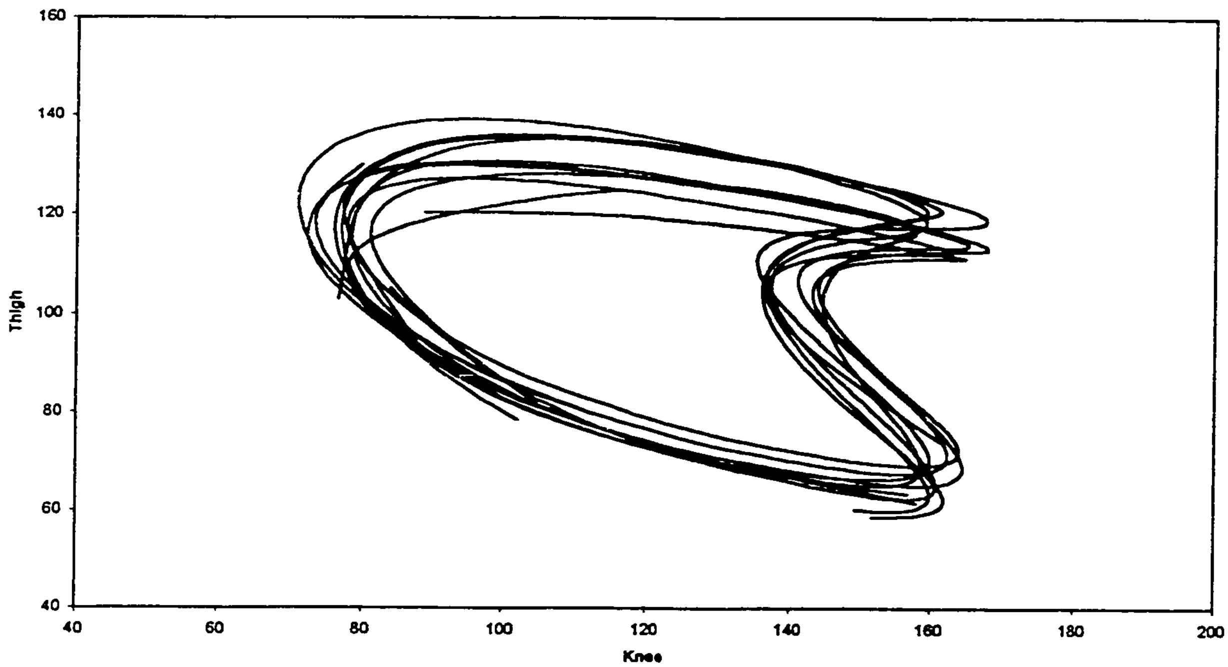


Figure 4.25. Subject 2/Class C8- left side: knee/thigh angle diagram. Similar patterns and ROM as the right side throughout the strides.

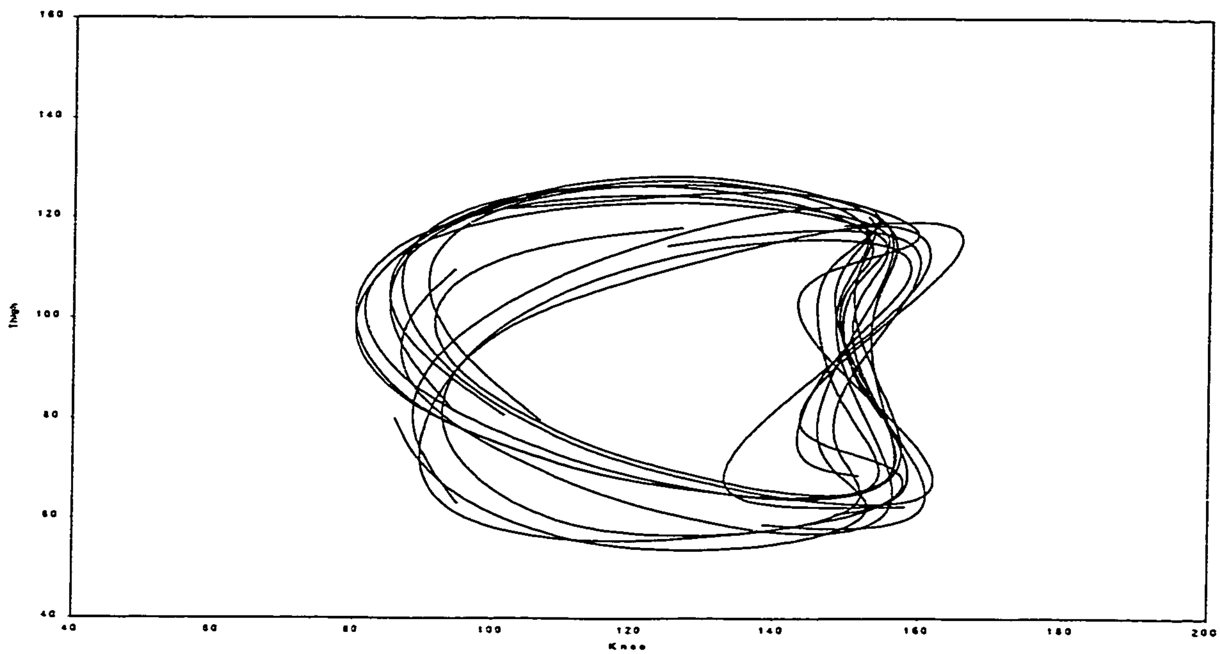


Figure 4.26. Subject 3/Class C7- right side: knee/thigh angle diagram

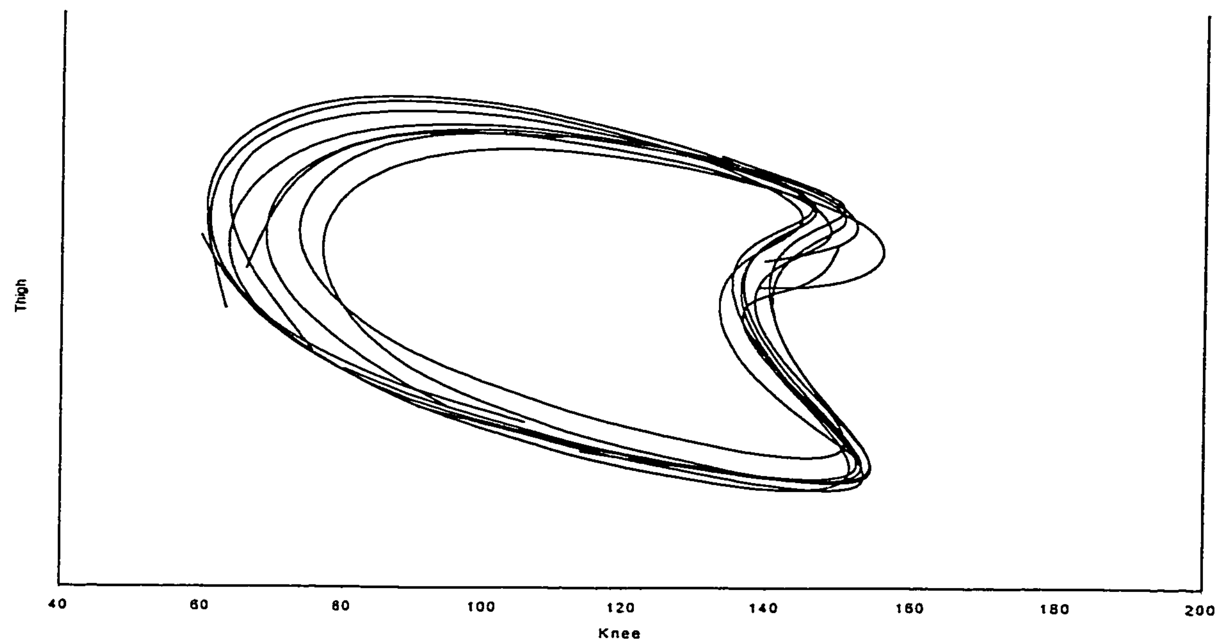


Figure 4.27. Subject 3/Class C7- left side: knee/thigh angle diagram. Comparing to Figure 4.26, it is clear that the two sides of the body are not symmetrical. The non affected side (left) has less variability between the strides, and a greater ROM about the knee.

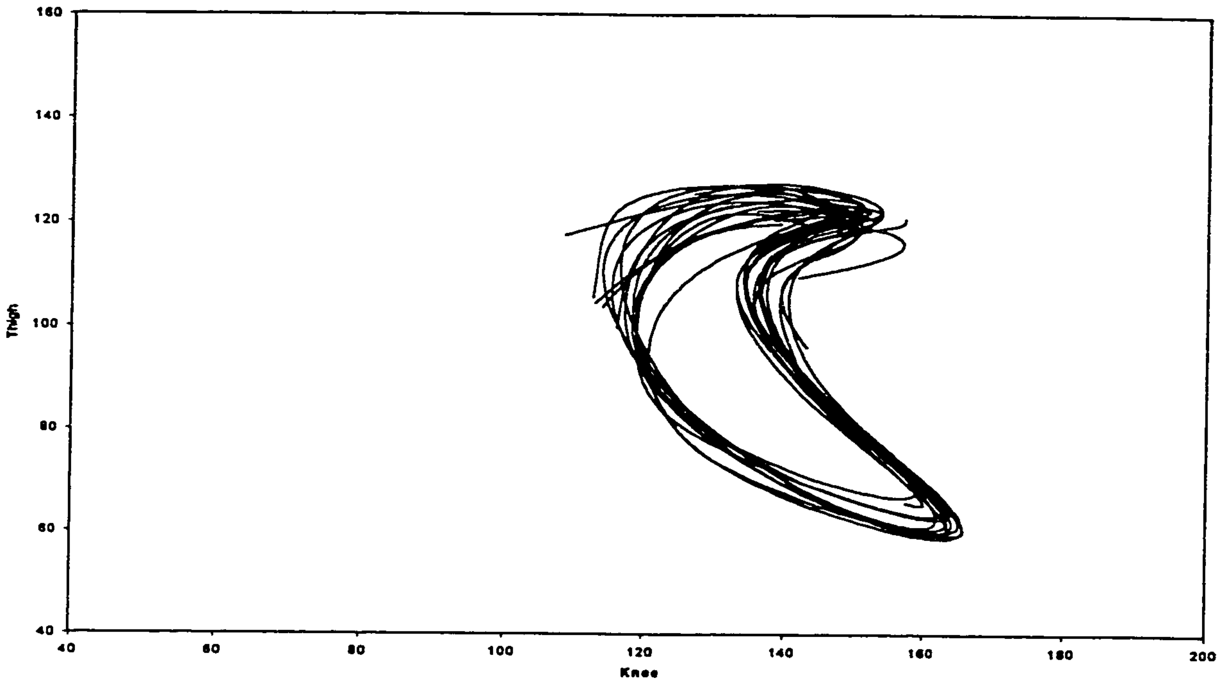


Figure 4.28. Subject 4/Class C7- right side: knee/thigh angle diagram

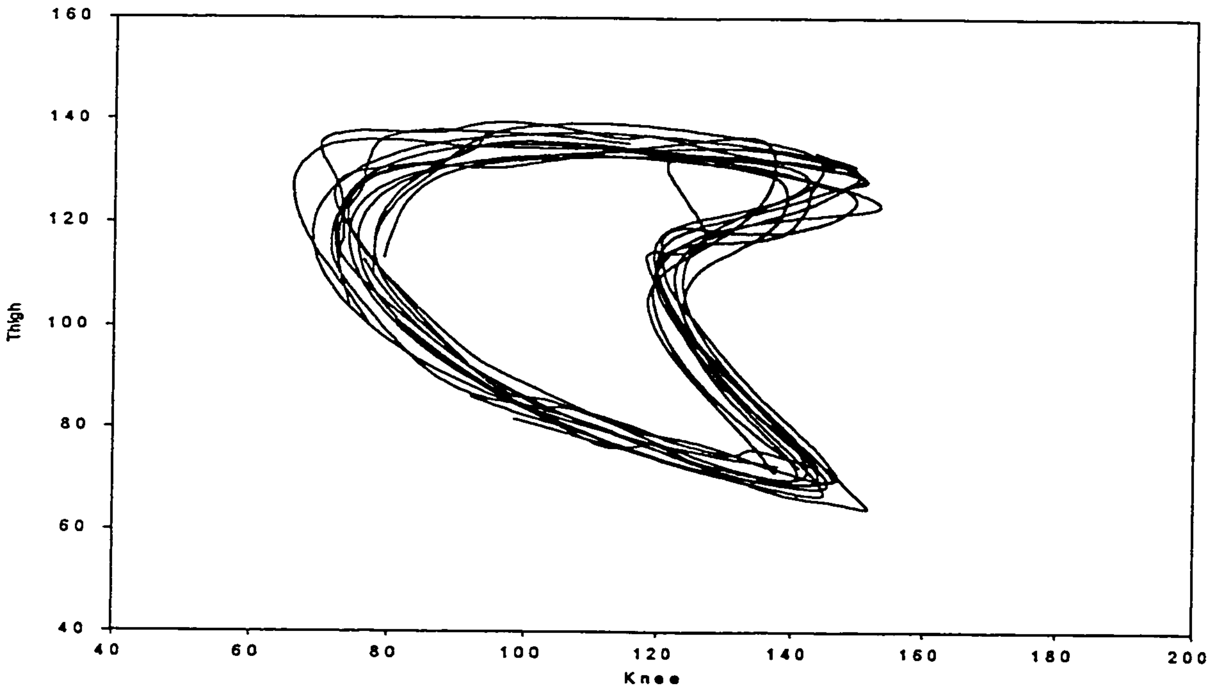


Figure 4.29. Subject 4/Class C7- left side: knee/thigh angle diagram. The knee ROM is clearly the distinguishing factor between the affected and non affected side.

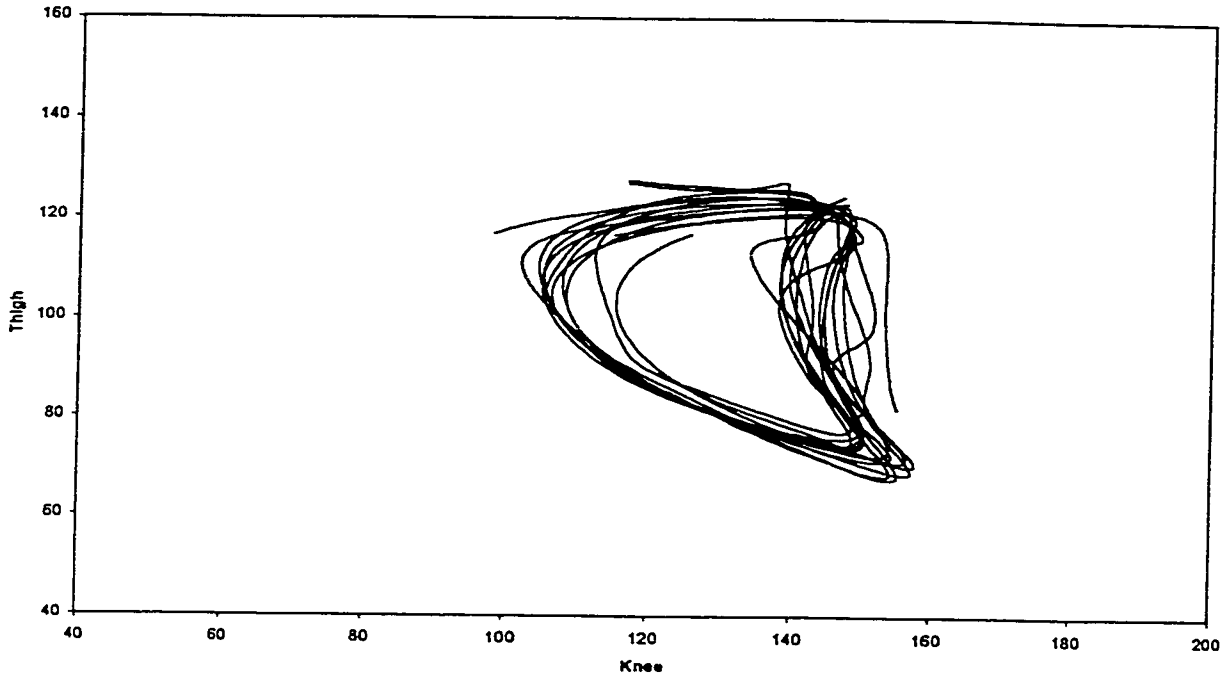


Figure 4.30. Subject 5/Class C6- right side: knee/thigh angle diagram

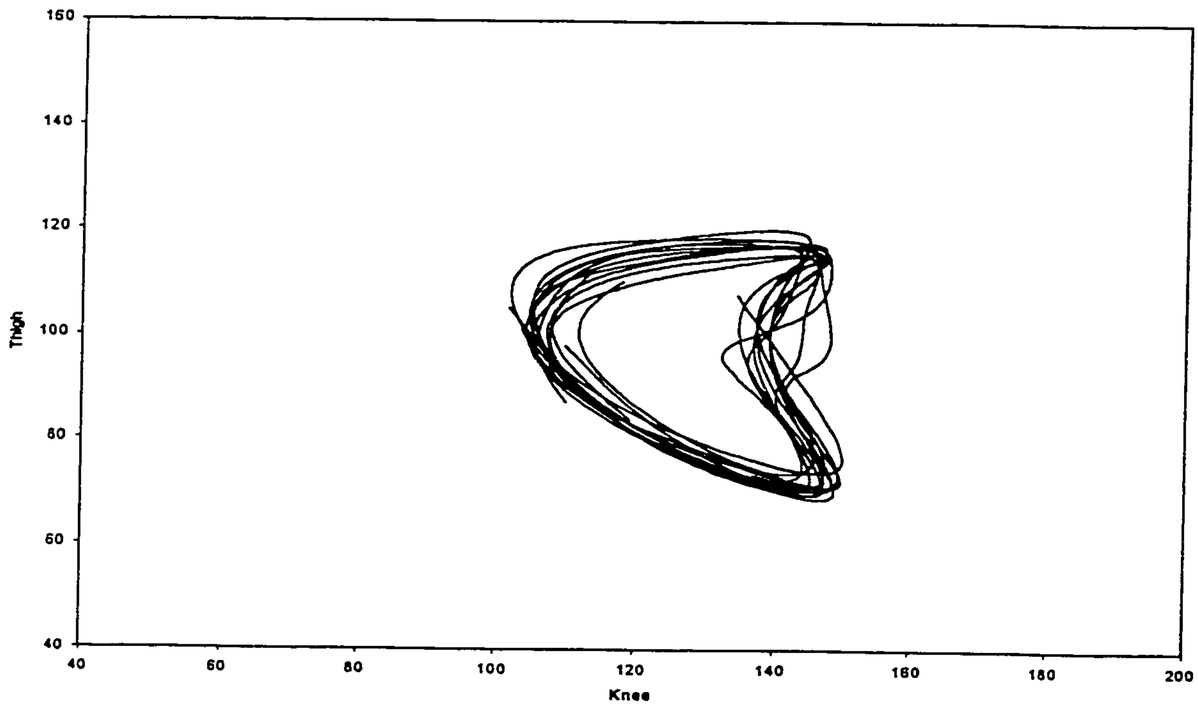


Figure 4.31. Subject 5/Class C6- left side: knee/thigh angle diagram

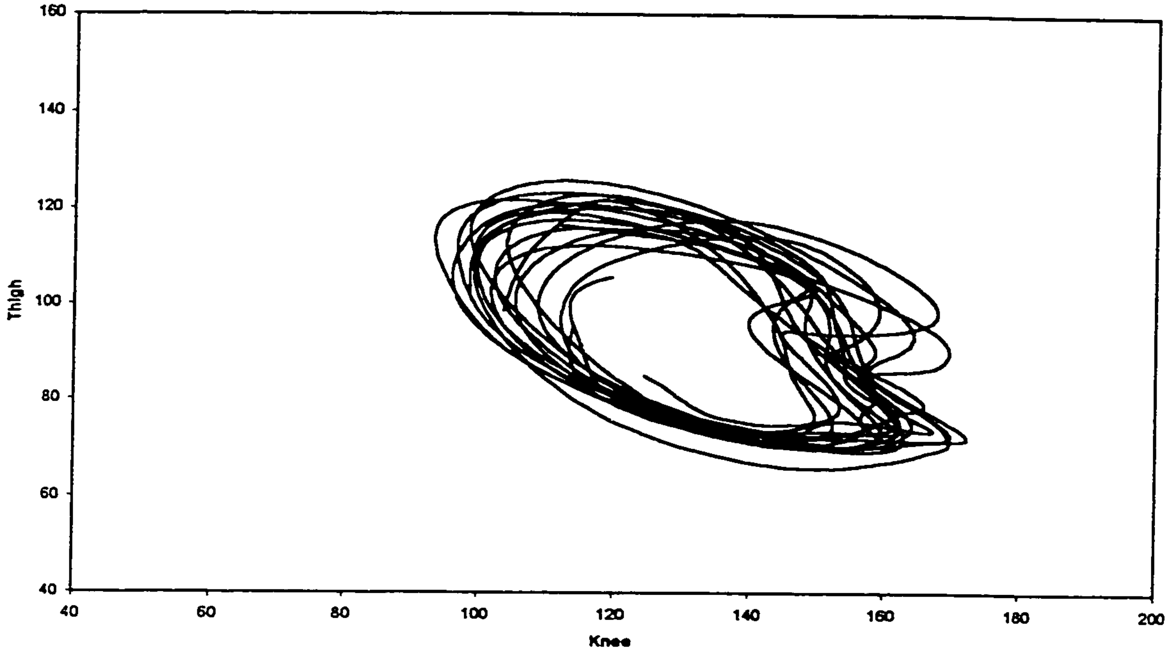


Figure 4.32. Subject 6/Class C6- right side: knee/thigh angle diagram

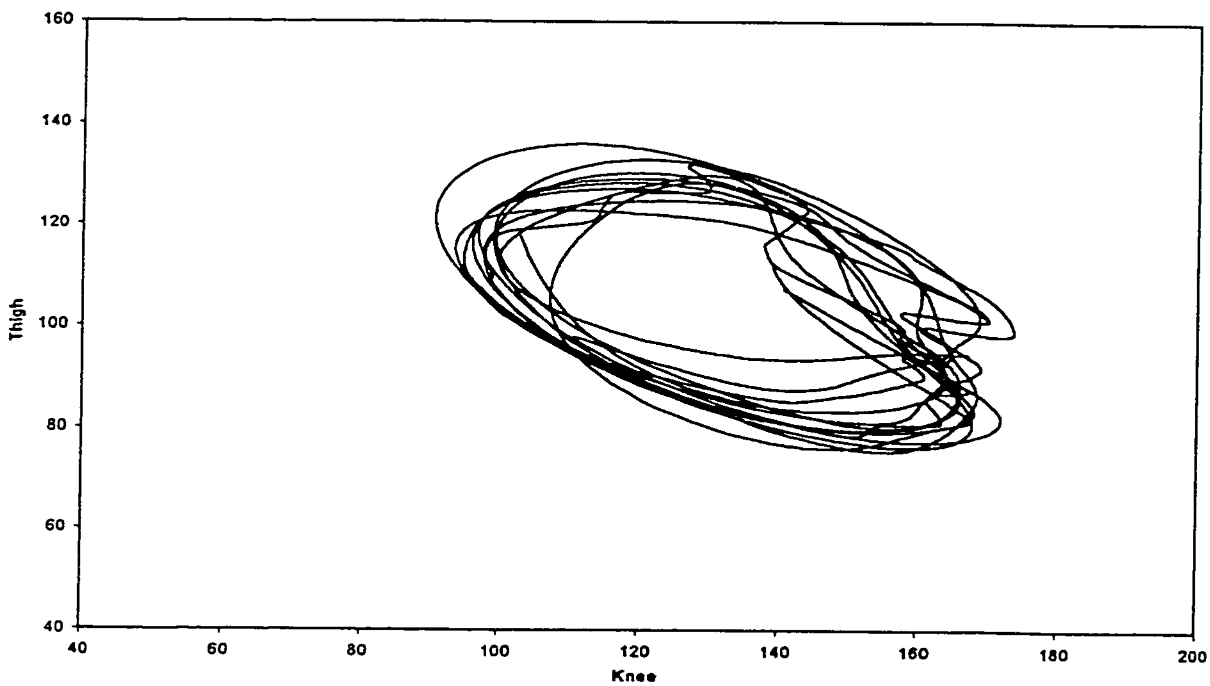
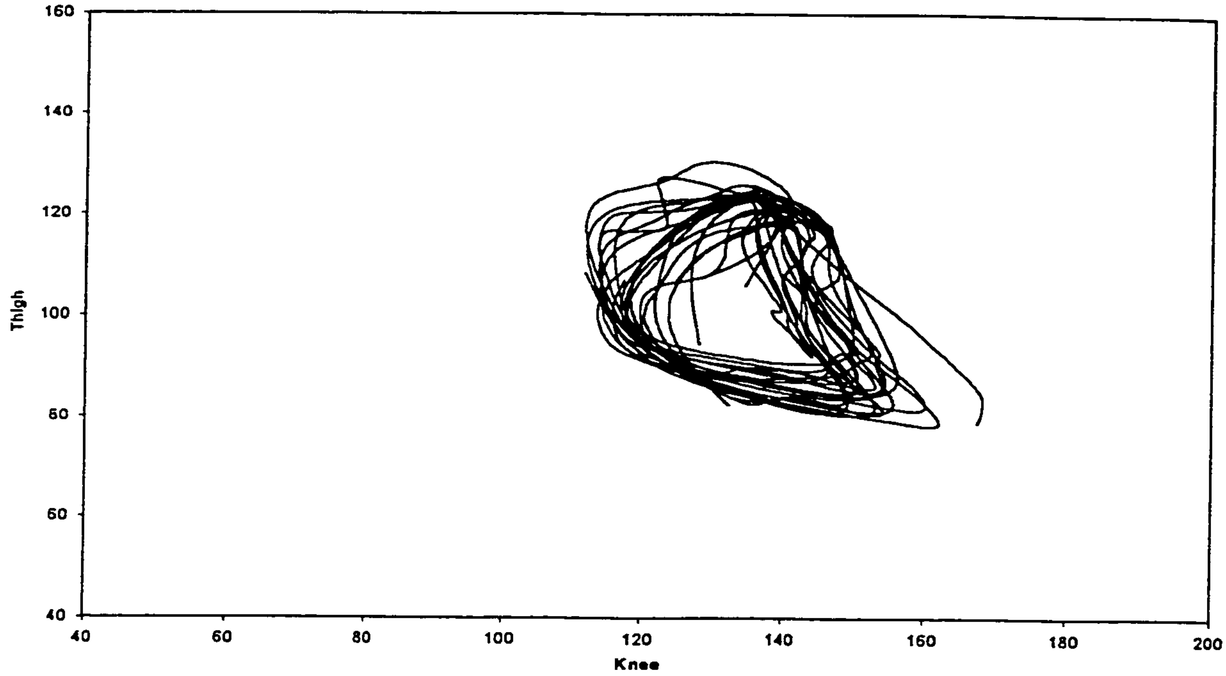
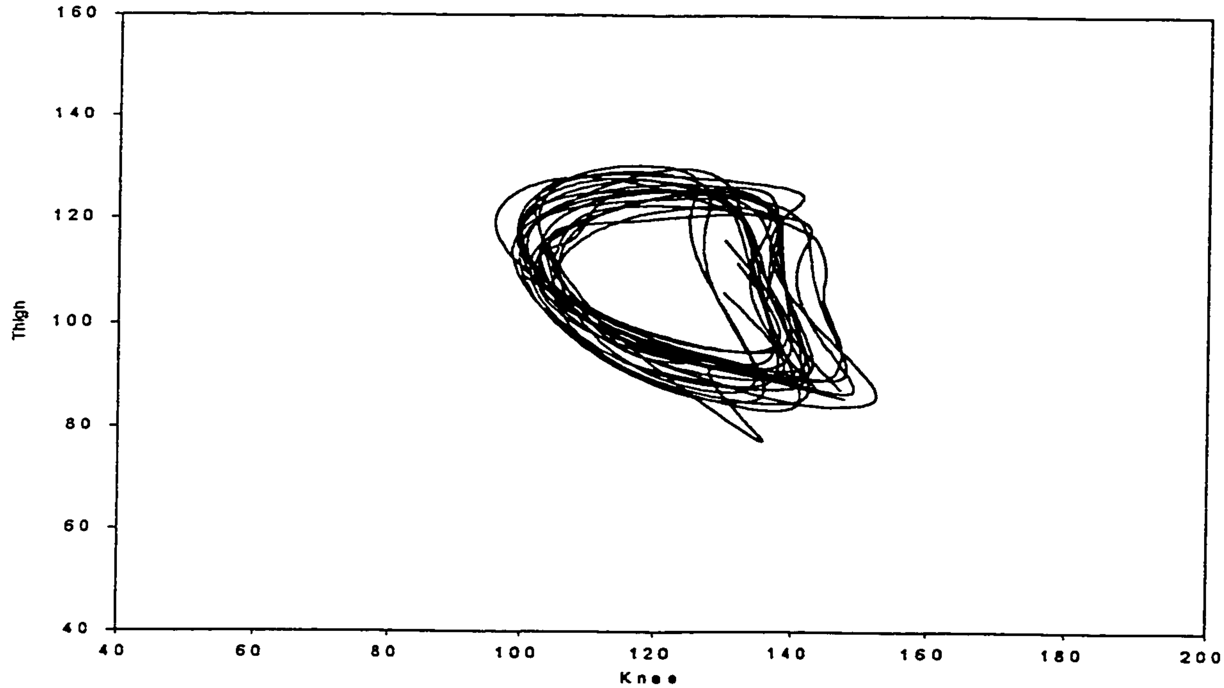


Figure 4.33. Subject 6/Class C6- left side: knee/thigh angle diagram



<u>Figure 4.34.</u> Subject 7/Class C5- right side: knee/thigh angle diagram



<u>Figure 4.35.</u> Subject 7/Class C5- left side: knee/thigh angle diagram

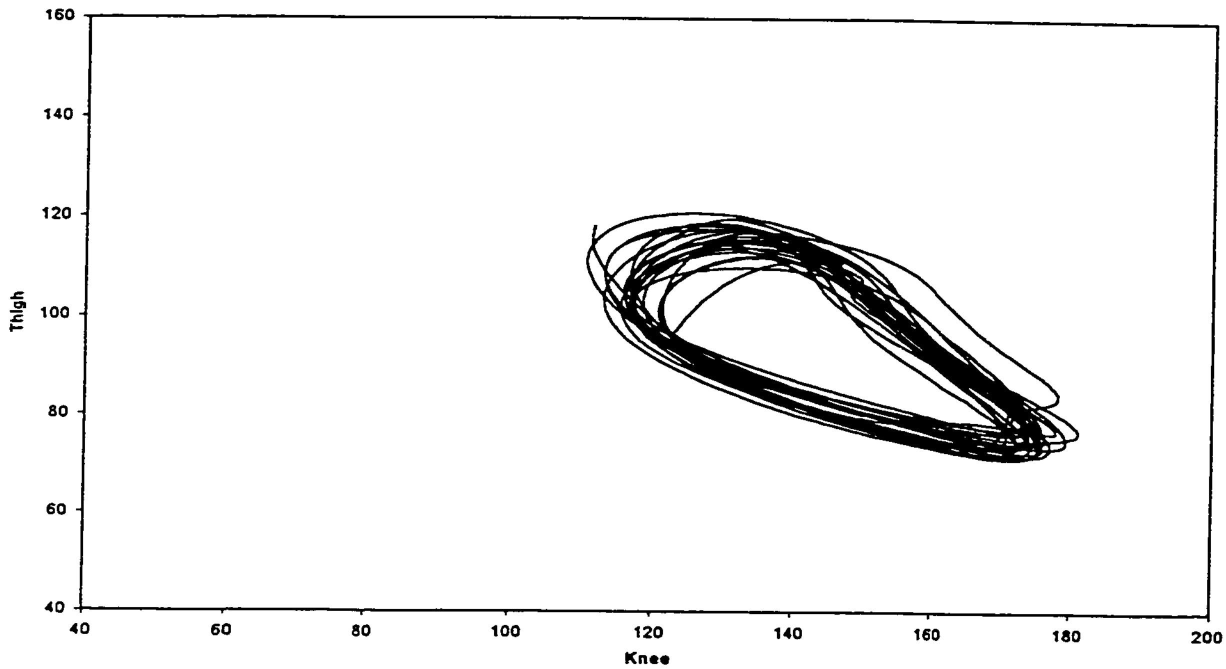


Figure 4.36. Subject 8/Class C5- right side: knee/thigh angle diagram

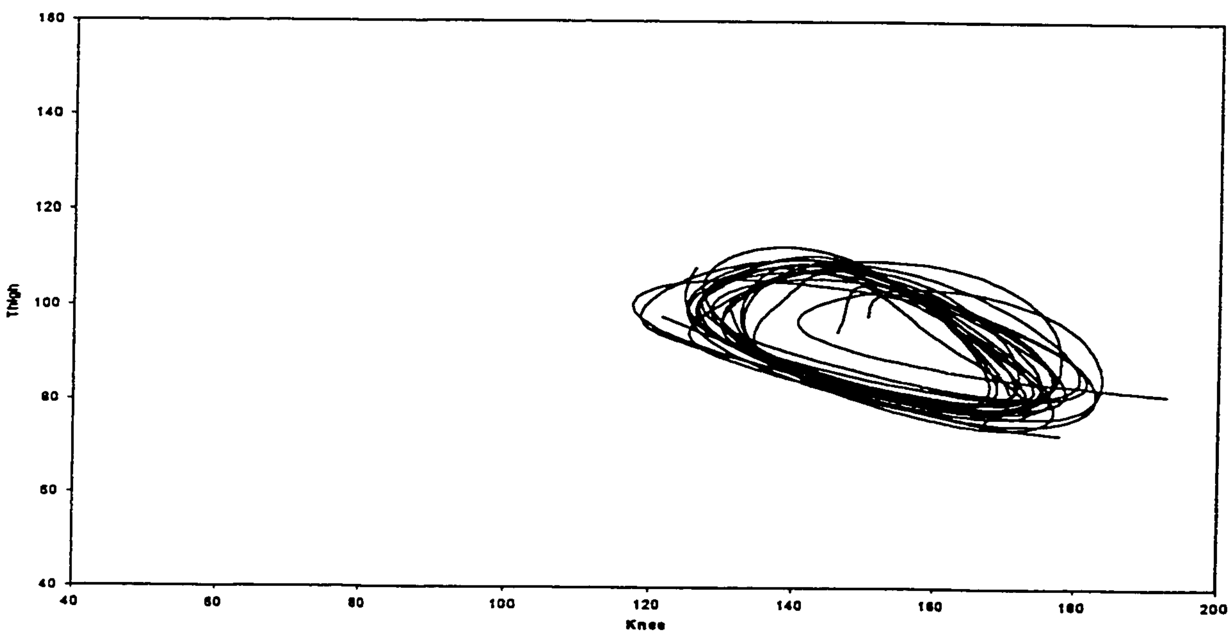


Figure 4.37. Subject 8/Class C5- left side: knee/thigh angle diagram

CHAPTER 5
Summary and Conclusions

5.1 Summary

This study was undertaken in an attempt to gain a greater understanding of the running mechanics for people with CP. The purpose of the study was to analyze and compare the temporal and kinematic variables of the trunk and lower limb segments throughout the running cycle of four different classes of athletes with CP. Eight subjects were filmed while running at a predetermined pace. Four cameras were used during filming, two on each side of the track. Simultaneous movement from the right and left side of the runner were analyzed to compute the temporal and lower limb angular information of specific lower body segments during the running cycle. Fifteen complete strides from both sides of the body were recorded and the average of these fifteen strides were used in the analysis.

There were no significant findings between classes. However, evidence from a hierarchical cluster analysis suggested that Classes C5 & C6 and C7 & C8 could be grouped together. Subsequent analyses which examined differences between these grouped classes found fifteen variables to significantly differ between the groups while two variables approached significance. The fifteen significant variables were stance time, stride length, stance and swing ratio, hip ankle at maximum extension, trunk angle at maximum flexion, and trunk angle at maximum extension, for both the right and left sides of the body, and swing time for the left side only. Two variables, knee angle at maximum flexion and right hip angle at maximum flexion, approached but did not attain significance.

When trends within the data were investigated, it became evident that: stride length increased as the class number increased, swing percentage was longer for the more able classes, trunk flexion decreased as the class number decreased, trunk extension increased as the class number decreased, hip extension and flexion decreased as the class number decreased, knee flexion during stance and swing decreased with the less able classes, and the ROM of the hip and knee decreased with the less able classes.

5.2 Conclusions

Based on the results of this study, it is possible to conclude that:

1. No variables attained statistical significance between the four CP classes.
2. Statistically, fifteen variables were significant when Class C7 & C8, and C5 & C6 were grouped together ($p<.05$).
3. The more able the class, the more temporal and kinematic variables increased and represented values found in the nondisability literature.
4. Inter-class variability existed between subjects. Therefore, for descriptive purposes individual subject averages were calculated in addition to class means.

Based on these conclusions, the first null-hypothesis which tested the differences between participants in the same class on the dependent variables was rejected. Results illustrated variability between subjects in the individual classes was high. The second null-hypothesis which stated that the variables would not be significant between the four class divisions was retained as no variables reached significance. However, when grouping Class C5 & C6, and C7 & C8, fifteen variables were significantly different.

5.3 Recommendations for future research

It is important to recognize that this study was unique. No other study, to my knowledge, has investigated the biomechanics involved in running for athletes with CP. Therefore, there remains plenty of research opportunities in this area. A strong recommendation to continue this avenue of study, is given towards any researcher who sees the potential this type of research could have on sporting organizations and their athletes. Findings in this area have the potential to increase knowledge within the academic field and help develop a class system which can only benefit athletes with CP and aspiring athletes with CP in competition.

Although temporal and kinematic movement of the trunk and lower limb segments within the sagittal plane were investigated, there is no research to date on the involvement of the upper body, the movement through other planes, and kinetic information. This study revealed trends within the data for particular variables, however many questions were raised throughout the discussion. It is important to further study the association between stride length and cadence. Stride length demonstrated a trend towards longer strides as the class number increased whereas cadence did not. Further research is necessary to examine the stride length - cadence relationship. Similarly, further research could also investigate the velocity - cadence relationship.

To improve generalizability, and validity of findings, future investigations will want to increase the sample size. To increase power and effect size, each class would need a minimum of seventeen subjects per class. A more conservative alpha level could be used with a larger sample size, adding strength to the results. Different genders and skill levels should be investigated.

Based on this study which employed two different analyses of movement, it has been apparent that more sophisticated equipment may have aided in gathering more information throughout the cycle. Also, additional cameras would allow multiplanar and three dimensional information to be collected.

Future research may also want to investigate sprinting, periods of acceleration, and endurance running. Examining different kinds of running could add to the research by investigating the spasticity - fatigue relationship, and effect it has on running patterns.

The use of other disability groups such as people with mental/cognitive disabilities, amputees, and people with ambulatory spinal cord injury/head trauma would expand knowledge in terms of classification by identifing if these groups could be integrated for participation in disability sport.

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APPENDICES

Appendix A –
Subject Information Letter

EXPLANATION OF STUDY
Sports Biomechanics Laboratory
Rick Hansen Centre
Faculty of Physical Education & Recreation
University of Alberta

Title: Kinematics for ambulatory CP runners.

Investigators:
Researcher: Karen E. Natho BSc BPHE MSc candidate
. Office #(403) 492-9389, Rick Hansen Centre W1-67 Van Vliet Complex

Advisors: Robert Steadward, PhD
Office #(403) 492-7298,
W1-67 Van Vliet Complex

Pierre Gervais, PhD
Office #(403) 492-1039,
W2-60 Van Vliet Complex

Dear Prospective Participant:

I am a student in Physical Education and Recreation, at the University of Alberta in Edmonton, Canada, working on my Masters of Science. My research interests are in adapted physical activity concentrating on sport advancement in biomechanics.

Purpose:
Your participation is being sought in this study to help determine differences during running between people in the four CP ambulatory classes, Class C5, C6, C7 and C8. It is hoped that we can identify what are the technical differences between the four classes. All subjects will be informed of their results.

Background:
The Paralympic International Committee is continuously researching into the current classification system. This is done to help athletes, coaches and classifiers better understand the system.

Procedures:
Participation in this study will require you to run on 25m track for a time interval that will allow filming of 15 complete strides for both legs. These strides will be video taped. You will run the 25m track approximately three to five times, with as much rest as you feel you need in between each run. This will be approximately 5 minutes of running. Before the filming date, you will be given a chance to try out running on the track and practice until you feel completely comfortable.
You will be classified by a trained classification team, consisting of a physical therapist, doctor and sport technician, for the purposes of this study only. You will also be asked to do simple tasks, which are walking, jumping, running, standing, sitting and lifting your legs off the ground. These tasks will be videotaped and shown to the classification team. You will also be asked questions on your age and which limbs are most affected.

Once you feel comfortable on the track a date for the actual filming can be arranged between you and the researcher. At the beginning of the filming date, you will be asked to warm-up. The warm-up will be similar to the actual filming period. During this time a fast running pace that you feel comfortable with will be determined. This warm-up will not be videotaped. After the warm-up, you will start to run on the track. You will be asked to run several times past the cameras so that 15 complete strides can be videotaped. Throughout the filming period, reflective markers will be attached to your body using two sided adhesive stickers, which will tell us about how your body is moving.
Total amount of time to complete the study's requirement will not exceed three hours. All video taping, classification tasks and running training will be done at the University Pavilion.

Benefits/Risks:
Every person who runs can experience muscle tightness or soreness. However, the physical stresses or risks of the exercise done in this study can be regarded as small. They are no greater than would normally be experienced during a normal training bout of similar duration and intensity. There will be a medical professional available on site if needed. There will always be two spotters close to you as you run. Video taping is harmless and non-invasive and will not pose any physical risk to you.
None of the subjects will receive money but your personal results and a summary from the results will be provided to you. You can contact me at the Rick Hansen Centre in Edmonton and I look forward to delivering to you a summary of the results.

Confidentiality:
To ensure confidentiality, data will be coded and stored in a locked office to which only the investigator will have access. All data will remain completely confidential and all video recording and data will be used for educational purposes only. Videotapes and all data extracted from them will be used exclusively for this project and will be stored safely by the researcher for seven years after filming. After the seven years, the tapes will be returned to you on request or destroyed.

Freedom to withdraw:
You can choose not to participate or to withdraw from the study anytime without any negative consequences. You can also choose not to have your data used for the study at any time. This can be done by simply telling any of the researchers that you wish to do so.

Additional Contact:
If you would like to talk to someone else about this study you may call the Dean of the Faculty of Physical Education and Recreation, Dr. H.A. Quinney at: (403) 492-3364.
If you have any questions or concerns, before, during or after the study, please do not hesitate to contact me. I would be pleased to answer or discuss anything with you. I can be reached at (403) 492-9389.

Thank-you,

Karen Erika Nattrass

Appendix B –
Informed Consent Form

Consent Form
Sports Biomechanics Laboratory -Rick Hansen Centre
Faculty of Physical Education & Recreation, University of Alberta
Title: Kinematics for ambulatory CP runners

In conjunction with the Explanation of Study form.
(To be completed by participant or parent/guardian if under the age of majority)

Do you understand that you have been asked to be in a research study? Yes No

Have you read and received a copy of the attached information sheet? Yes No

Do you understand the benefits and risks of in taking part in this research study? Yes No

Have you had an opportunity to ask questions and discuss this study Yes No

Do you understand that you are free to refuse to participate or leave the study at any time? You do not have to give a reason and in no way will it affect you. Yes No

Has the issue of confidentiality been explained to you? Do you understand who will have access to your records, data and video recordings? Yes No

Do you understand you will be videotaped doing simple tasks and while running? Yes No

Do you understand that the class given to you is for purposes of this study only? Yes No

Do you want the investigator(s) to inform your coach or organization that you are taking part in this research study? If so, please provide the appropriate name and contact number:................................

This study was explained to me by:...I agree to take part in this study.

....
(Signature of participant) (Parent/guardian for particiapnts under the age of majority)

---------------------------------1999
(Date:day/month/year)

....
(Printed name)

....
(Witness:printed name)
I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

....
(Signature of investigator or designee) (Date)
THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH SUBJECT

Appendix C –
Ethical Approval

Faculty of Physical Education and Recreation
University of Alberta

Proposal No.98-1009-01

Ethics Review Approval

The Ethics Committee of the Faculty of Physical Education and Recreation (University of Alberta):

Name	Position
Dr. Jane Watkinson	Professor and Associate Dean
Dr. Romeo Chua	Assistant Professor (Primary Reviewer)
Dr. Dick Jones	Professor (Pulmonary Medicine) (Primary Reviewer)
Dr. Stu Petersen	Associate Professor
Dr. Marcel Bouffard	Professor
Dr. Wendy Rodgers	Associate Professor
Dr. Paul Zehr	Assistant Professor

have reviewed the proposal entitled:
Kinematics for ambulatory runners with CP - REVISION DATED JANUARY 15TH, 1999

submitted by **Karen Natho, Bob Steadward, and Pierre Gervais**

__X__ **finds it within acceptable standards for human experimentation**

_____ **finds it within acceptable standards subject to the following revisions:**

_____ **finds it unacceptable in its present form**

Jane Watkinson

Dr. Jane Watkinson, Chair, Ethics Committee
Faculty of Physical Education and Recreation

Date: February 2, 1999

Appendix D –
Subject Classification Protocol Sheet

Subject Information Sheet:

Name: ______________________________________

Gender: M F

Age: ____________

Disability Information:
Right leg: ________________________

Left leg: _________________________

Right arm: _______________________

Left arm: ________________________

Class if appropriate: ___________

Consent form & information letter given and signed? Yes No

Classification Tests:

☐ Gross motor movements
1. front walking
2. back walking
3. right and left foot hopping
4. jumping

☐ Balance and posture
1. Standing upright
2. Touching toes
3. Balance on one foot (right and left) leaning to all four sides
4. Balance on one foot with leg extended to front (right and left)
5. Balance on one foot with leg extended backwards (right and left)

☐ Joint motion movements (4, 5, 6 holding on to rail if necessary)
1. Rotate wrists (right and left)
2. Flex and extend elbows (right and left)
3. Rotate and shrug shoulders (right and left)
4. Rotate ankles (right and left)
5. Flex and extend knees (right and left)

6. Flex, extend, adduct, abduct hip (right and left)

☐ Coordination movements

1. Touching lines, back and forth 5 times
2. Standing to sitting to lying down to sitting to standing

☐ Actual Event

1. Running

Tested Speeds (distance/time) (25m)

1. Slow running: _________m / ___________s
2. Sprinting (as fast as you can go) : ________m / __________s
3. Middle distance running practice trial #1: __________m / __________s
4. Middle distance running practice trial #2: __________m / __________s
5. Middle distance running practice trial #3 (if necessary): __________m / __________s

Marker Measurement (Cm)

Right Side

1. Hip to Knee : ________________
2. Knee to Ankle :________________
3. Ankle to Heel: ________________
4. Heel to Toe: ________________

Left Side

1. Hip to Knee : ________________
2. Knee to Ankle :________________
3. Ankle to Heel: ________________
4. Heel to Toe: ________________

Running Trial Speeds:

#1 _________m / __________s
#2 _________m / __________s
#3 _________m / __________s
#4 _________m / __________s
#5 _________m / __________s
#6 _________m / __________s

Problems/ Notes/ Concerns:

Appendix E –
Smoothed Kinematic Data for One Subject

Subject 4 Class7 Left

ltheel D	ltheel D	lttoe DX	lttoe DY	lt heel-	lt thigh	lt thigh	lt trunk DZ
Time	Time	Time	Time	Time	Time	Time	Time
Sec	Sec	Sec	Sec	Sec	Sec	Sec	Sec
Cm	Cm	Cm	Cm	Deg	Deg	Deg	Deg
1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
-78.36	-61.44	-63.23	-56.36	60.99	217.77	124.21	96.89
-72.85	-62.97	-58.90	-58.36	72.63	214.54	120.38	99.41
-68.14	-64.39	-54.92	-60.42	82.15	212.25	117.06	101.28
-64.79	-65.62	-51.59	-62.53	87.38	211.35	114.36	102.22
-62.95	-66.60	-49.07	-64.57	87.02	211.96	112.21	102.22
-62.42	-67.32	-47.38	-66.33	80.75	213.84	110.38	101.22
-62.73	-67.77	-46.44	-67.62	71.24	216.40	108.55	98.81
-63.40	-67.98	-46.11	-68.37	62.56	218.94	106.37	94.30
-64.06	-67.98	-46.23	-68.68	56.78	220.87	103.58	87.25
-64.47	-67.74	-46.68	-68.70	54.03	221.71	100.01	78.65
-64.55	-67.23	-47.33	-68.65	53.90	221.17	95.56	70.93
-64.29	-66.39	-48.06	-68.67	56.06	219.20	90.24	65.98
-63.71	-65.12	-48.76	-68.82	60.25	216.01	84.29	63.88
-62.76	-63.36	-49.35	-69.02	66.12	212.20	78.13	63.54
-61.38	-61.05	-49.73	-69.07	72.66	208.63	72.35	63.55
-59.47	-58.18	-49.77	-68.68	78.01	206.23	67.51	62.96
-56.95	-54.80	-49.28	-67.57	80.46	205.78	64.03	62.03
-53.69	-51.02	-48.08	-65.52	80.05	207.77	62.11	62.12
-49.53	-46.98	-45.96	-62.55	78.38	212.36	61.77	64.04
-44.29	-42.88	-42.78	-58.86	77.07	219.31	62.91	66.75
-37.81	-38.97	-38.38	-54.82	76.85	228.07	65.24	69.26
-30.07	-35.49	-32.68	-50.86	77.57	237.82	68.49	71.69
-21.21	-32.67	-25.62	-47.39	78.52	247.72	72.40	74.55
-11.57	-30.69	-17.21	-44.84	79.03	257.04	76.86	78.12
-1.54	-29.66	-7.52	-43.53	79.01	265.30	81.85	82.04
8.52	-29.64	3.39	-43.63	78.85	272.19	87.46	85.80
18.48	-30.61	15.39	-45.09	78.30	277.57	93.78	88.96
28.41	-32.46	28.35	-47.60	76.54	281.33	100.79	91.30
38.52	-35.06	42.09	-50.62	73.51	283.18	108.19	92.98
49.00	-38.20	56.42	-53.52	69.76	282.71	115.35	94.40
59.99	-41.67	71.09	-55.75	65.52	279.72	121.61	95.60
71.55	-45.28	85.85	-57.02	60.82	274.38	126.49	96.32
83.68	-48.82	100.45	-57.34	56.21	267.10	129.70	96.23
96.27	-52.18	114.60	-56.93	52.97	258.36	131.11	95.44
109.03	-55.27	127.99	-56.14	52.74	248.69	130.79	94.11
121.41	-58.04	140.29	-55.36	56.37	238.70	129.07	92.74
132.72	-60.50	151.12	-55.01	62.16	229.15	126.47	92.54
142.36	-62.67	160.24	-55.39	67.01	220.72	123.49	94.14
150.06	-64.56	167.50	-56.62	69.72	213.76	120.25	96.04
155.83	-66.17	172.96	-58.61	70.66	208.50	116.79	97.06
159.80	-67.46	176.80	-61.10	70.37	205.22	113.21	97.80
162.23	-68.44	179.31	-63.73	69.22	204.16	109.70	98.92
163.44	-69.09	180.84	-66.12	67.35	205.41	106.52	99.64
163.78	-69.44	181.68	-67.96	64.93	208.91	104.02	98.38
163.58	-69.52	182.11	-69.15	62.27	214.40	102.65	94.18
163.10	-69.41	182.31	-69.77	59.58	221.29	102.52	86.94
-100.52	-28.63	-103.57	-41.66	66.72	265.11	77.67	75.53
-91.05	-28.32	-95.03	-41.80	72.10	273.24	84.25	78.54

-81.62	-28.33	-85.86	-42.24	75.58	280.56	91.11	81.43
-72.20	-28.92	-75.65	-43.19	76.68	286.26	98.20	84.07
-62.75	-30.24	-64.25	-44.71	75.47	289.88	105.45	86.34
-53.16	-32.32	-51.80	-46.72	72.53	291.22	112.73	88.13
-43.25	-35.09	-38.54	-48.98	69.09	290.21	119.66	89.45
-32.87	-38.41	-24.76	-51.22	66.40	286.89	125.77	90.33
-21.94	-42.12	-10.76	-53.17	64.87	281.36	130.56	90.87
-10.48	-46.00	3.22	-54.68	64.18	273.90	133.69	91.18
1.34	-49.89	16.91	-55.71	63.97	264.91	135.07	91.35
13.20	-53.63	30.01	-56.37	64.17	254.91	134.84	91.46
24.65	-57.08	42.13	-56.85	64.77	244.57	133.26	91.59
35.19	-60.18	52.88	-57.43	65.58	234.64	130.70	91.75
44.34	-62.88	61.90	-58.32	66.19	225.93	127.58	91.92
51.77	-65.17	68.99	-59.67	66.32	219.20	124.35	92.04
57.36	-67.05	74.17	-61.48	65.96	214.96	121.34	91.98
61.19	-68.55	77.62	-63.62	65.30	213.42	118.72	91.59
63.54	-69.68	79.68	-65.86	64.59	214.31	116.42	90.70
64.75	-70.47	80.72	-67.92	64.00	216.88	114.14	89.17
65.18	-70.96	81.10	-69.58	63.47	219.96	111.43	86.83
65.14	-71.16	81.11	-70.75	62.75	222.41	107.90	83.52
64.85	-71.09	80.94	-71.46	61.64	223.57	103.49	79.24
64.46	-70.74	80.74	-71.83	60.12	223.28	98.33	74.46
64.11	-70.06	80.53	-71.98	58.53	221.62	92.56	69.97
63.89	-68.98	80.27	-72.01	57.34	218.81	86.36	66.50
63.92	-67.43	79.89	-71.93	57.00	215.24	80.02	64.27
64.36	-65.30	79.41	-71.64	57.87	211.48	73.87	63.13
65.39	-62.55	78.95	-70.97	60.04	208.33	68.38	62.78
67.25	-59.16	78.74	-69.72	63.24	206.73	64.03	62.91
70.18	-55.21	79.14	-67.71	66.78	207.51	61.27	63.33
74.39	-50.84	80.54	-64.90	69.87	211.12	60.25	64.06
79.99	-46.27	83.26	-61.37	71.99	217.49	60.84	65.23
87.02	-41.72	87.55	-57.37	73.28	226.13	62.77	66.98
95.44	-37.41	93.54	-53.14	74.26	236.31	65.74	69.40
105.13	-33.52	101.26	-48.95	75.56	247.21	69.38	72.63
115.90	-30.12	110.51	-44.94	77.63	258.25	73.39	76.69
127.43	-27.15	120.93	-41.16	80.69	269.31	77.65	81.33

-99.58	-28.36	-102.20	-42.85	79.99	293.97	106.06	88.72
-91.12	-30.83	-90.21	-45.03	75.51	291.86	113.19	89.77
-82.34	-33.50	-78.04	-47.23	69.97	289.38	120.11	90.72
-73.00	-36.51	-65.58	-49.43	65.46	285.82	126.10	91.56
-62.95	-39.91	-52.83	-51.49	62.84	280.65	130.67	92.30
-52.18	-43.64	-39.82	-53.22	61.87	273.71	133.53	92.96
-40.86	-47.57	-26.66	-54.47	61.99	265.15	134.60	93.54
-29.32	-51.48	-13.61	-55.21	62.98	255.40	134.02	94.03
-18.02	-55.17	-1.12	-55.58	64.90	245.12	132.10	94.41
-7.49	-58.46	10.17	-55.84	67.38	235.15	129.31	94.65
1.75	-61.25	19.68	-56.36	69.66	226.40	126.20	94.68
9.30	-63.50	26.99	-57.42	71.09	219.62	123.19	94.45
14.98	-65.24	32.04	-59.14	71.33	215.30	120.57	93.87
18.82	-66.54	35.15	-61.34	70.31	213.58	118.40	92.85
21.03	-67.46	36.82	-63.71	68.12	214.21	116.53	91.34
22.00	-68.10	37.55	-65.85	64.99	216.48	114.60	89.24
22.12	-68.51	37.79	-67.49	61.36	219.35	112.24	86.44
21.77	-68.73	37.80	-68.53	57.86	221.79	109.09	82.89
21.25	-68.77	37.71	-69.10	55.16	223.10	104.98	78.70
20.79	-68.60	37.56	-69.43	53.78	222.98	99.90	74.31
20.54	-68.14	37.35	-69.68	53.90	221.47	94.08	70.32

27.18	-74.07	46.10	-74.94	52.91	218.57	94.16	75.62
27.09	-73.33	46.19	-75.02	53.31	216.68	88.32	71.06
27.37	-72.20	46.19	-75.10	54.77	213.90	82.36	67.83
28.17	-70.49	46.04	-75.07	57.37	210.71	76.55	65.84
29.61	-67.93	45.75	-74.69	61.05	207.79	71.26	64.80
31.83	-64.33	45.52	-73.65	65.49	206.01	66.87	64.42
34.97	-59.62	45.70	-71.63	69.79	206.21	63.76	64.52
39.25	-53.93	46.73	-68.44	72.87	209.01	62.17	65.05
44.95	-47.58	49.14	-64.04	74.59	214.70	62.12	66.06
52.27	-40.92	53.34	-58.59	75.72	223.14	63.38	67.69
61.27	-34.34	59.48	-52.34	77.01	233.88	65.60	70.05
71.68	-28.06	67.31	-45.60	78.68	246.15	68.42	73.12
-139.64	-38.81	-144.58	-53.97	82.31	254.26	74.35	76.62
-127.85	-34.71	-134.43	-48.50	83.95	264.83	79.00	80.80
-116.13	-31.21	-123.94	-44.08	85.56	274.77	83.81	84.78
-104.57	-28.76	-112.81	-41.44	86.28	283.48	89.22	88.41
-93.29	-27.65	-100.85	-40.87	85.98	290.55	95.62	91.47
-82.33	-27.99	-87.98	-42.18	84.90	295.71	103.16	93.73
-71.61	-29.70	-74.16	-44.87	82.66	298.60	111.58	95.11
-60.85	-32.59	-59.44	-48.32	78.73	298.88	120.19	95.72
-49.71	-36.39	-43.96	-51.90	73.59	296.42	128.11	95.81
-37.87	-40.80	-27.92	-55.05	68.35	291.42	134.52	95.60
-25.17	-45.51	-11.62	-57.42	63.86	284.35	138.85	95.34
-11.70	-50.26	4.54	-58.91	60.79	275.65	140.91	95.22
2.23	-54.81	20.12	-59.62	59.67	265.76	140.83	95.37
16.05	-58.96	34.66	-59.78	60.63	255.13	138.91	95.84
29.09	-62.59	47.74	-59.77	63.05	244.34	135.59	96.66
40.64	-65.62	59.01	-60.05	65.85	234.15	131.37	97.75
50.11	-68.04	68.20	-61.08	68.27	225.49	126.84	98.96
57.24	-69.88	75.20	-63.03	70.07	219.20	122.53	100.03
62.04	-71.23	80.06	-65.67	70.92	215.87	118.82	100.62
64.82	-72.14	83.03	-68.42	70.15	215.51	115.75	100.35
66.04	-72.68	84.45	-70.62	67.40	217.50	113.06	98.88
66.22	-72.92	84.78	-71.93	63.22	220.67	110.34	95.86
65.84	-72.87	84.45	-72.43	58.75	223.79	107.18	90.96
65.28	-72.54	83.87	-72.52	55.21	225.96	103.33	84.33
64.84	-71.91	83.33	-72.58	53.27	226.79	98.77	76.98
64.74	-70.89	83.04	-72.74	52.95	226.10	93.55	70.66
65.17	-69.41	83.09	-73.00	53.91	223.79	87.73	66.53
66.25	-67.45	83.49	-73.22	55.78	219.83	81.38	64.56
68.04	-65.03	84.15	-73.19	58.06	214.37	74.56	64.10
70.47	-62.25	84.98	-72.77	60.40	207.82	67.47	64.50
-138.93	-29.13	-147.11	-43.73	83.99	296.79	97.94	90.36
-130.05	-30.24	-134.89	-45.46	80.38	298.34	106.70	91.77
-120.93	-31.93	-122.22	-47.46	75.86	299.47	115.49	92.98
-111.32	-34.58	-108.77	-49.85	71.35	299.06	123.70	93.94
-100.99	-38.25	-94.51	-52.47	67.31	296.44	130.84	94.66
-89.73	-42.75	-79.60	-55.05	63.93	291.46	136.47	95.19
-77.50	-47.70	-64.32	-57.31	61.35	284.35	140.25	95.60
-64.45	-52.70	-49.02	-59.06	59.78	275.51	141.98	95.99
-50.91	-57.42	-34.08	-60.30	59.66	265.35	141.67	96.45
-37.42	-61.64	-19.88	-61.14	61.39	254.38	139.56	97.00
-24.61	-65.27	-6.86	-61.85	64.74	243.27	136.13	97.63
-13.14	-68.28	4.53	-62.74	68.62	232.90	132.02	98.25
-3.59	-70.74	13.91	-64.08	71.65	224.19	127.84	98.73
3.72	-72.69	21.05	-65.97	72.86	217.93	124.06	98.89

-104.11	-71.41	-88.71	-65.22	69.17	220.72	126.83	99.12
-95.21	-72.82	-80.55	-65.48	75.74	215.55	124.10	100.71
-88.19	-74.14	-73.65	-66.59	79.08	211.78	121.69	102.02
-83.39	-75.29	-68.34	-68.55	79.34	209.81	119.62	102.89
-80.67	-76.22	-64.68	-71.05	76.13	209.74	117.83	103.11
-79.57	-76.90	-62.50	-73.56	69.75	211.30	116.14	102.48
-79.46	-77.30	-61.48	-75.57	62.56	213.89	114.23	100.81
-79.79	-77.45	-61.24	-76.79	56.79	216.62	111.74	97.90
-80.17	-77.37	-61.44	-77.21	52.84	218.69	108.37	93.68
-80.44	-77.05	-61.84	-77.11	50.51	219.67	104.08	88.35
-80.59	-76.48	-62.29	-76.88	49.71	219.53	99.05	82.54
-80.60	-75.61	-62.73	-76.87	50.54	218.41	93.60	77.17
-80.41	-74.36	-63.12	-77.21	53.11	216.51	88.02	72.98
-79.86	-72.61	-63.44	-77.83	57.25	214.09	82.55	70.22
-78.79	-70.29	-63.61	-78.40	62.23	211.60	77.43	68.72
-77.03	-67.33	-63.51	-78.47	66.76	209.75	72.99	68.21
-74.46	-63.73	-62.93	-77.58	69.60	209.33	69.59	68.41
-70.97	-59.57	-61.61	-75.39	70.53	211.01	67.56	69.17
-66.43	-54.98	-59.30	-71.87	70.48	215.14	67.04	70.38
-60.63	-50.18	-55.74	-67.29	70.71	221.65	68.01	72.02
-53.43	-45.45	-50.77	-62.20	72.00	230.10	70.27	74.10
-44.83	-41.09	-44.26	-57.22	74.34	239.84	73.60	76.63
-35.01	-37.36	-36.19	-52.89	77.02	250.05	77.79	79.59
-24.23	-34.49	-26.61	-49.56	79.20	259.98	82.71	82.88
-12.84	-32.63	-15.64	-47.50	80.32	268.97	88.24	86.34
-1.20	-31.85	-3.46	-46.85	80.34	276.49	94.34	89.73
10.43	-32.12	9.71	-47.47	79.39	282.14	100.92	92.84
21.94	-33.35	23.66	-48.99	77.37	285.56	107.87	95.46
33.42	-35.41	38.18	-50.90	74.02	286.53	114.89	97.54
45.05	-38.09	53.07	-52.71	69.43	284.96	121.52	99.05
57.05	-41.18	68.19	-54.11	64.13	281.05	127.20	100.05
69.58	-44.49	83.38	-54.99	58.90	275.21	131.41	100.57
82.72	-47.89	98.59	-55.42	54.81	267.77	133.82	100.66
96.45	-51.29	113.79	-55.50	53.06	258.93	134.45	100.40
110.61	-54.66	128.97	-55.38	54.63	248.92	133.63	99.88

-141.08	-29.36	-150.09	-42.96	84.98	284.59	89.26	88.53
-130.96	-29.16	-138.18	-44.43	77.99	289.32	98.08	90.41
-120.88	-29.76	-125.79	-46.12	73.92	293.54	107.12	91.99
-110.75	-31.57	-112.60	-48.15	72.38	296.01	115.82	93.20
-100.36	-34.56	-98.47	-50.49	71.20	295.94	123.67	94.02
-89.42	-38.42	-83.45	-52.95	68.39	293.07	130.18	94.55
-77.67	-42.77	-67.69	-55.31	64.11	287.57	135.01	94.89
-65.01	-47.32	-51.43	-57.33	60.12	279.91	137.98	95.18
-51.56	-51.88	-35.08	-58.89	58.10	270.66	139.07	95.51
-37.66	-56.26	-19.21	-59.99	58.92	260.27	138.38	95.98
-23.84	-60.31	-4.43	-60.75	62.44	249.20	136.13	96.61
-10.75	-63.91	8.70	-61.39	67.26	238.07	132.71	97.39
0.93	-67.04	19.75	-62.14	71.20	227.73	128.67	98.23
10.67	-69.76	28.56	-63.23	72.53	219.14	124.63	98.98
18.13	-72.11	35.16	-64.78	71.15	213.07	121.05	99.48
23.30	-73.95	39.78	-66.76	68.28	209.91	118.15	99.51
26.45	-75.12	42.74	-68.97	65.35	209.53	115.82	98.88
28.01	-75.56	44.46	-71.08	62.86	211.29	113.71	97.42
28.50	-75.49	45.35	-72.79	60.32	214.11	111.33	94.99
28.37	-75.23	45.76	-73.95	57.56	216.87	108.29	91.40
27.97	-74.93	45.93	-74.58	55.14	218.73	104.38	86.64
27.52	-74.57	46.01	-74.84	53.54	219.30	99.60	81.10

20.59	-67.33	37.11	-69.95	55.44	218.82	87.84	67.21
21.01	-66.07	36.91	-70.19	58.06	215.37	81.51	65.14
21.86	-64.25	36.75	-70.27	61.35	211.68	75.48	63.99
23.26	-61.76	36.65	-69.99	65.02	208.58	70.15	63.55
25.35	-58.53	36.67	-69.10	68.95	207.00	65.91	63.68
28.31	-54.54	37.02	-67.31	72.95	207.87	63.13	64.28
32.38	-49.85	38.08	-64.40	76.59	211.86	62.05	65.29
37.74	-44.63	40.35	-60.29	79.35	219.12	62.68	66.71
44.53	-39.15	44.26	-55.17	80.86	229.16	64.76	68.57
52.77	-33.76	50.11	-49.49	80.91	240.96	67.94	70.92
62.31	-28.85	57.92	-43.86	79.44	253.27	71.93	73.72
72.82	-24.76	67.44	-38.88	76.73	264.98	76.60	76.84
83.89	-21.77	78.22	-35.08	73.29	275.37	81.96	80.09
95.08	-20.02	89.82	-32.82	69.75	284.10	88.18	83.19
106.02	-19.55	101.88	-32.22	66.74	291.09	95.43	85.95
116.52	-20.25	114.16	-33.21	64.73	296.43	103.79	88.31
126.57	-21.86	126.55	-35.43	63.83	300.37	113.09	90.33

-82.80	-67.00	-66.94	-67.94	67.08	210.16	111.35	98.56
-82.29	-67.29	-67.57	-68.17	69.58	212.01	106.27	96.38
-81.97	-67.53	-68.13	-68.22	69.84	215.34	102.94	91.02
-81.98	-67.66	-68.59	-68.10	67.08	219.50	101.07	82.00
-82.26	-67.59	-68.93	-67.97	62.69	222.58	98.91	72.26
-82.56	-67.21	-69.15	-67.99	59.04	223.26	95.23	64.89
-82.58	-66.38	-69.26	-68.26	57.93	221.41	89.85	60.67
-82.10	-65.00	-69.26	-68.76	60.25	217.78	83.30	58.87
-80.96	-62.93	-69.14	-69.31	65.70	213.56	76.45	58.59
-79.07	-60.14	-68.81	-69.54	72.36	210.11	70.15	59.15
-76.39	-56.59	-68.14	-68.92	77.09	208.59	65.10	60.14
-72.90	-52.35	-66.93	-66.91	77.91	209.86	61.77	61.33
-68.49	-47.54	-64.91	-63.30	75.60	214.28	60.34	62.65
-62.94	-42.43	-61.79	-58.46	72.75	221.67	60.74	64.20
-56.00	-37.36	-57.32	-53.11	71.52	231.43	62.71	66.16
-47.56	-32.73	-51.33	-47.96	72.35	242.71	66.01	68.60
-37.77	-28.89	-43.78	-43.48	74.52	254.68	70.53	71.37
-26.96	-26.10	-34.74	-40.07	77.01	266.51	76.26	74.18
-15.64	-24.50	-24.37	-38.07	79.03	277.35	83.06	76.87
-4.32	-24.13	-12.84	-37.68	80.32	286.23	90.53	79.59
6.63	-24.97	-0.30	-38.88	80.54	292.44	98.24	82.48
17.10	-26.92	13.13	-41.44	78.88	295.77	106.03	85.28
27.30	-29.86	27.34	-44.89	74.94	296.33	113.67	87.76
37.62	-33.59	42.21	-48.63	70.02	294.39	120.79	89.83
48.51	-37.85	57.59	-52.05	66.04	290.32	127.01	91.38
60.29	-42.39	73.27	-54.69	63.60	284.32	131.88	92.42
73.06	-46.92	88.97	-56.38	62.41	276.30	135.02	93.11
86.60	-51.19	104.31	-57.14	62.15	266.25	136.20	93.61
100.41	-55.00	118.81	-57.12	62.65	254.68	135.54	93.93
113.70	-58.23	131.98	-56.54	63.38	242.62	133.43	93.98
125.67	-60.88	143.43	-55.79	63.83	231.27	130.34	93.76
135.66	-62.99	152.91	-55.54	64.31	221.55	126.63	93.46
143.30	-64.68	160.32	-56.49	65.48	214.07	122.56	93.34
148.60	-66.03	165.70	-58.75	67.20	209.32	118.45	93.37
151.84	-67.08	169.19	-61.75	68.55	207.77	114.73	93.20
153.44	-67.84	171.05	-64.74	68.57	209.57	111.76	92.42
153.90	-68.34	171.60	-67.04	66.67	214.22	109.59	90.85
153.70	-68.63	171.23	-68.33	62.80	220.42	107.94	88.63

-114.11	-69.95	-97.57	-65.49	60.65	226.66	129.77	97.42

8.75	-74.19	25.97	-68.34	71.80	214.55	120.90	98.61
11.74	-75.28	28.93	-70.92	68.51	214.05	118.33	97.74
13.13	-76.04	30.36	-73.34	63.91	215.90	116.11	96.11
13.44	-76.52	30.81	-75.27	59.53	219.07	113.83	93.52
13.18	-76.76	30.77	-76.54	56.32	222.26	110.99	89.83
12.73	-76.79	30.62	-77.21	54.40	224.41	107.18	85.17
12.35	-76.60	30.53	-77.47	53.61	224.94	102.27	80.09
12.19	-76.14	30.53	-77.52	53.72	223.73	96.43	75.37
12.32	-75.33	30.54	-77.53	54.63	221.03	90.05	71.62
12.83	-74.06	30.50	-77.56	56.32	217.33	83.53	69.04
13.81	-72.19	30.45	-77.55	58.91	213.32	77.31	67.51
15.40	-69.57	30.51	-77.24	62.35	209.86	71.78	66.76
17.77	-66.07	30.88	-76.24	66.06	207.82	67.31	66.60
21.08	-61.59	31.78	-74.12	69.15	208.03	64.22	66.90
25.48	-56.14	33.46	-70.66	71.04	211.10	62.70	67.62
31.14	-49.94	36.21	-65.93	71.97	217.18	62.76	68.80
38.22	-43.36	40.39	-60.30	72.54	225.93	64.25	70.49
46.84	-36.93	46.32	-54.30	73.23	236.49	66.91	72.76
57.00	-31.23	54.17	-48.51	74.35	247.81	70.48	75.60
68.56	-26.67	63.94	-43.42	76.05	259.02	74.80	78.96
81.26	-23.35	75.38	-39.31	78.05	269.75	79.83	82.73
94.75	-21.01	88.08	-36.15	79.87	280.07	85.50	86.73