ABSTRACT

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This was a descriptive study using high speed cinematography and a dynamic pedigraph system to analyze 18 kinematic variables associated with gait in a sample of 15 healthy, elderly women. Two trials of each S (mean age 70.3) were filmed, one at normal (free) and the other at a fast pace. The variables analyzed were velocity, cadence, step length, step width, stride length, foot angle, stride length to body height ratio, cycle duration, stance time, swing time, double support time, swing to stance ratio, patterns of sagittal excursion for the hip, knee and ankle, and mean angular velocity occurring at the hip, knee and ankle throughout the gait cycle. Mean values and standard deviations for the sample at each speed were presented. This study tends to support previous works that reported decreased step and stride lengths, increased temporal variables and decreased velocity of gait with aging. Patterns of lower extremity motion in the sagittal plane were consistent with that of younger samples. At faster walking speeds, many kinematic variables of gait approached those given as representative of normal gait in a younger sample.

A KINEMATIC STUDY OF GAIT PATTERNS IN HEALTHY, ELDERLY WOMEN

A Thesis Presented

to

The Graduate Faculty

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Master of Science Degree

by

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Master of Science - Physical Education

The candidate has completed his oral report.

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This thesis is approved for the College of Health, Physical Education and Recreation.

John C. Mitchem — Nov. 7, 1983
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CHAPTER I

INTRODUCTION

Of the many patterns of human movement available to us, perhaps the most widely used and certainly the most widely studied is that of simple walking. A complete review of the literature dealing with normal and pathological gait would probably have several hundred references. Indeed, Murray (1967) alone cites over 120 sources in her review of normal gait. Beyond the apparent simplicity of the event are a number of inter-related factors that contribute to the overall pattern that is often described only as "a sequential process of falling and recovery" (Contini, Gage & Drillis, 1963, p. 413).

The process by which gait is acquired has been studied in great detail, and there is a generally accepted progression that is followed in the development of gait. For instance, it has been determinded that the basis for this pattern is established at a very young age, often as early as 48 weeks (Illingsworth, 1970), with primitive reflex patterns that mimic walking found even earlier (Barnes, Crutchfield, & Heriza, 1978). Mature gait patterns have been known to exist by age five, with some components of mature gait present at only one and one-half years (Sutherland, Olshen, Cooper & Woo, 1980). As the individual matures and develops, many factors contribute to the characteristics that personalize that individual's walking style. Among these influences are sex, body build, ethnic background, occupation, mental status, personality and age (Contini et al., 1963). Many of the studies that describe normal gait have used young adults for subjects. Although this sample may indeed represent the normal values for that age group, the significance is often interpolated to other age groups as well. Just as Foley, Quanbury and Steinke (1979) point out that it is wrong to assume that the gait patterns children exhibit are simply that of "little adults", it may be equally erroneous to assume that the elderly walk in a pattern that is consistent with that of young adults (Crowinshield, Brand & Johnson, 1978). However, that is just what has been done. Few studies exist that have created normative data for the elderly, and those that do exist have found some significant differences across the age groups in many aspects of normal gait. This has led Murray, Drought and Kory (1964) to suggest the existence of a "pre-senile" pattern that has been reported to exist in men 60 to 65 years of age.

Purpose of the Study

The purpose of this study was to describe the gait patterns in a sample of healthy, elderly women through selected kinematic variables using cinematography and pedigraphic procedures.

Statement of the Problem

This study described selected kinematic and temporal variables associated with normal gait through the use of high speed cinematograph and computer analysis, and through the use of a dynamic pedigraph system. The kinematic and temporal variables analyzed were the following: (a) stride length; (b) step length; (c) step width; (d) foot angle; (e) stride length to body height ratio; (f) velocity; (g) cadence; (h) cycle duration; (i) stance time; (j) swing time; (k) double support time; (l) swing to stance ratio; (m) hip, knee and ankle sagittal excursion patterns; and (n) hip, knee and ankle average angular velocities.

Need for Study

Normative data that characterizes the walking patterns of healthy old men (Murray, Kory & Clarkson, 1969), normal men (Murray et al., 1964; Murray, Kory, Clarkson & Sepic, 1966), men with parkinsonism (Murray, Sepic, Gardner & Downs, 1978), children (Sutherland, et al., 1980), and normal women (Graf, Wong, Gronley & Walker, 1981; Murray, Kory & Sepic, 1970; Zuniga & Leavitt, 1973) abound. In Murray and others (1970), a small group of women (N=6) ages 60 to 70 were studied, whereas the other two studies of the gait patterns of women used much younger subjects. Finely, Cody and Finizie (1969) studied the gait patterns of elderly women, but had many inherent problems in their method of study. It is apparent, therefore, that there is a substantial gap in the existing knowledge of what the normal variables for walking in elderly women are.

There is a need for specific data on the different variables that typify the normal gait of various populations. Just as the pattern of normal gait may vary between men and women, children and adults and those of varying races, body builds or occupations, it is reasonable to assume that there are differences in what normal gait patterns can be expected with aging. Normative data for various populations are necessary for determining realistic goals for rehabilitation from injury or disease, for use in designing architectural structures to be used by specific populations, and for providing a means of comparison between groups. Crowinshield and others (1978) suggested that this information can also be applied to assess the effects of pathological processes or treatment techniques. Most importantly in this author's view is the need for establishing what levels of attainment are possible for the elderly during rehabilitation or when designing and implementing exercise programs specific to this group. Too often the desired goal is lowered for the elderly simply because of the stereotypes associated with aging, either rightly or wrongly attached. It is anticipated that this study will contribute to the establishment of normative data for this population.

The subjects used in this study were selected from what Murray and associates called the "peak of normality" (1969, p. 179). They were all active, healthy women over the age of 65. Although they did not represent what may be considered truly "normal" for women of this age group, they were chosen to describe what levels are possible for the elderly to achieve.

Statement of Question

This study was of a descriptive nature. The question presented was to describe the kinematic and temporal variables of gait in healthy, elderly women. A secondary question that was presented regarded the values obtained in the present study and how these compared with similar variables that describe the gait patterns of other samples as reported by previous studies.

Assumptions

This study was based on the following assumptions:

1. All subjects were healthy, elderly women over the age of 65 years, and did truthfully answer the questions on the personal health history inventory.

2. Normal gait, although there are many variations between individual patterns of walking, is consistent within the individual over several trials.

3. Normal patterns of gait will not be altered significantly by the cinematographic procedures used.

Delimitations

The following delimitations were made:

1. The subjects were healthy, elderly women.

2. The subjects were living in independent home situations.

3. The subjects had no history of total joint replacement, cerebral vascular accident (stroke), any neuromuscular disease,

amputation or other factors that may have influenced that individual's walking pattern in any way, as determined by the personal health history inventory.

4. The subjects were residents of metropolitan La Crosse, Wisconsin.

5. The subjects were volunteers and as such constitute a convenience sample.

Limitations

The following limitations were recognized:

1. The film analysis was limited to two dimensions by the method of filming. Analysis of the film was limited to sagittal plane only.

2. Because of extensive analysis procedures and data collection, only 15 female subjects were used. All of the potential data available were not analyzed.

Definition of Terms

The following terms were defined for use in this study:

Angular Velocity (ω) - The rate of change of angular displacement, expressed in degrees per second (°/sec) (Williams & Lissner, 1977).

Cadence - The number of steps taken per minute.

Cycle - The sequence of events that occur during gait from heel strike to ipsilateral heel strike (see Figure 1). Also referred to as walking cycle or gait cycle.

Cycle Duration - The time required for one complete cycle to occur.

Double Support - The period where both limbs are in contact with the ground at the same time (New York University, 1977) (see Figure 1).

Elderly - Sixty-five years of age or older (Committee on Aging, 1982).

Fast Walking Pace - The fastest walking speed performed by the subject, according to her own perception of fast. As defined by Murray and associates (1970) as "walk(ing) as fast as possible" (p. 637).

Flexion/Extension Patterns - The range of motion that occurs in the sagittal plane about a frontal axis at each joint of the lower extremity (hip, knee, and ankle). Ankle dorsiflexion and flexion and ankle plantar flexion and extension will be used interchangeably.

Foot Angle - The amount of "toe in" or "toe out" present during stance (Boenig, 1977) (see Figure 1).

Free Walking Pace - The walking speed that is perceived by the subject as her normal or comfortable pace (Murray et al., 1970).

Stance Phase - The events that occur in gait from the time of heel strike until the time that same limb breaks contact with the floor. Sub-phases of stance are heel strike (HS), foot flat (FF), mid-stance (MS) and push off, which occurs from heel off (HO) to toe off (TO) (New York University, 1977).

Stance Time - The length of time spent in stance.

Step Length - The distance covered from heel strike to contra-lateral heel strike (see Figure 1).

Step (Stride) Width - The transverse distance between successive steps (see Figure 1).

Stride Length - The distance covered from heel strike to ipsi-lateral heel strike. One complete gait cycle equals one stride (see Figure 1).

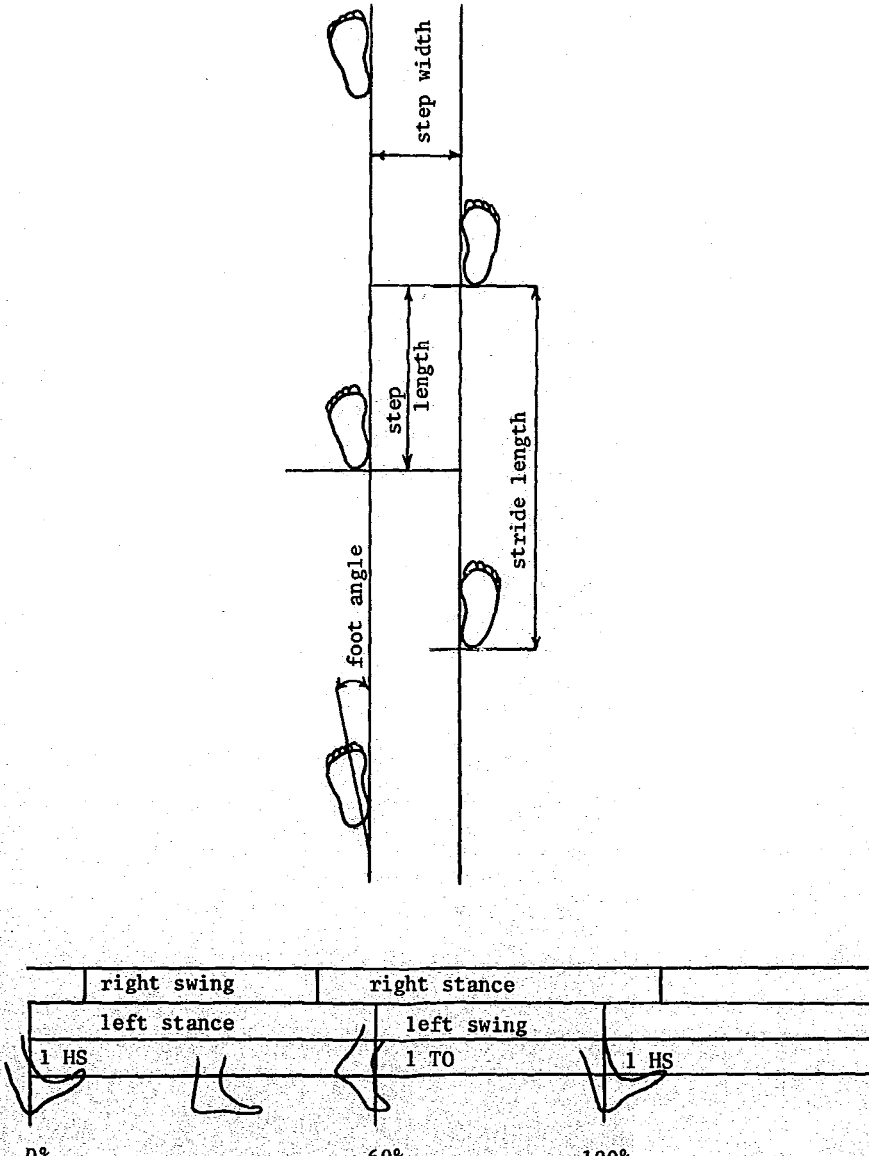
Swing Phase - The events that occur in gait from toe off to immediately prior to heel strike. The sub-phases of swing are accel-eration, mid-swing and deceleration, which describe the relationship of the lower extremity to the body (New York University, 1977).

Swing Time - The period of time spent in swing.

Swing/Stance Ratio - Swing time divided by stance time.

Velocity - The forward displacement of the subject expressed in centimeters per second (cm/sec).

Figure 1
The Gait Cycle and its Components



CHAPTER II

REVIEW OF LITERATURE

The available literature on the study of gait attests to the popularity and the importance of the event. This chapter will give a brief historical overview of gait analysis along with presenting the rationale for gait analysis. Various methods of analysis will also be presented. An introduction to the biomechanics of normal gait will be discussed, followed by reviews of many studies of the specific kinematic variables of gait that will be studied here. Finally, mention will be made of the studies in aging as they relate to gait, and the specific difficulties associated with the study of aging.

Historical Overview

Although it appears that the interest in locomotion has very ancient beginnings, the scientific study of gait is only a rather recent development. Cavanagh (1980) reports that the earliest shoe ever made reaches back 10,000 years. This may allude to our ancestor's interest in walking. More philosophical references to walking were made by Aristotle and by Hippocrates in the third century B.C. (Smidt, 1974). Much later, Galen wrote on the origin and study of muscles as related to locomotion (Greene, 1959). However, the father of the scientific studies in human gait is generally agreed upon to be Borelli (Contini et al., 1963; Greene, 1959; Steindler, 1953).

He introduced the fundamental concept of muscle actions, determined the center of gravity in humans and its relationship to locomotion in the seventeenth century.

Interest in the study of locomotion was resumed in the early 1800's when the Weber Brothers recorded their observations of gait (Brunnstrom, 1972; Corcoran & Peszcznski, 1978; Steindler, 1953). Although their methods of study would be considered crude by today's standards, their results are reported to be extremely accurate (Steindler, 1953). This study served as the ground work for the many photographic studies that occurred later in that century. Marey was the first to use crude cinematography in 1873 and his co-worker Carlet recorded the length and duration of the specific phases of gait (Steindler, 1953). Muybridge in 1882 worked towards perfecting the existing methods of photography which led the way for the study by Braune and Fischer in 1895. Fischer also was the first to do extensive mathematical treatment of gait and contributed to the early kinetic analysis of locomotion (Greene, 1959).

The twentieth century has seen many improvements in the study of locomotion. In the early years of the century, many studies of energy expenditure during walking were initiated, while in the 1920's and 1930's Scherb described the sequence of muscle action in the lower extremity through the use of palpation. The accuracy of this method was supported in 1947 through the use of electromyography (EMG) by Inman and others at the University of California (Corcoran & Peszczyski, 1978). Basmajian (1974) has reviewed the works of many EMG studies in gait analysis.

Schwartz et al. reported in a series of articles on the forces exerted through the foot during walking from the 1920's through 1964 (Schwartz, Heath, Morgan & Towns, 1964) while Elftman (1938) constructed a crude force platform for the calculation of ground reaction forces. More recently, Steindler (1964) has outlined the pathomechanics of gait.

In the 1960's and 1970's, Murray with others wrote a series of papers at the Wood Veterans Administration Hospital in Milwaukee. The method of study was through stroboscopic or light-interrupted photography at a frequency of 20 cycles per second. These studies will be discussed in greater detail later. Other important gait laboratories now performing sophisticated studies of locomotion are at the University of Iowa, Moss Rehabilitation Institute in Philadelphia, Rancho Los Amigos Hospital in Downey, California, and at McMaster University and the University of Waterloo in Canada.

Analysis of Gait

The characteristics of gait can be described in two basic manners, qualitatively and quantitatively (Stanic, Bard, Valencic, Kljajic & Acimovic, 1977). The primary means of qualitatively evaluating gait is through direct observation (Smidt, 1974). This is the most common method of analysis used in the clinical setting to describe normal and pathological gait patterns (Boenig, 1977) but is plagued by the lack of objective measures in which to record the variables of gait. It should be stressed that the author is in no way diminishing the importance of direct observation as a viable means of describing the events of gait, however, the lack of objective data from such a description has long been a complaint of this method (Robinson, 1977; Robinson & Smidt, 1981).

Quantitatively, gait can be described by temporal, kinematic and kinetic variables (Contini et al., 1963). The present study will utilize temporal and kinematic means, while kinetic descriptions are available only through the use of extremely sophisticated equipment. Temporal analysis is provided by the timing of certain events, while kinematic analysis provides for the description of the movement itself without reference to forces. Kinetic measures record the forces that are present in the system. Winter (1979) states that much of the future of biomechanical analysis lies in the research of kinetic variables in movement.

The need for objective measures for analyzing gait is especially important in the rehabilitative setting. Normative data are needed as a base to compare pathological gait (Leavitt, Zuniga, Calvert, Conzoneri & Peterson, 1971; Smidt, 1974; Sutherland et al., 1980). Objective means of describing gait may assist the clinician in noting changes in gait as a result of treatment procedures used and to evaluate the end result for comparison to the initial state of the patient (Leavitt et al., 1971; Little, 1981; Smidt, 1974). Finally, the gait analysis may assist the clinician in diagnosing certain pathological processes (Leavitt et al., 1971; Little, 1981).

There are many ways of gathering objective data for analyzing gait. These methods range from the very simple and inexpensive to some very advanced means technologically. Perhaps the simplest and most frequently used means of assigning objective data to gait is by measuring the temporal and distance variables, i.e., velocity, stride length, step length and cadence. This method has been used by walking over a grid on the floor (Jims, 1974; Robinson, 1977; Robinson & Smidt, 1981). By using a stopwatch, these very simple variables may be calculated. Footprint analysis can also yield this information, and in addition allow for determination of the foot angle, the step width and, in certain cases, a rough idea of the pressure bearing surfaces on the foot. These methods have been explained by Boenig (1977), Chodera (1974), Clarkson (1983), and Shores (1980).

More precise, but also somewhat more expensive and more complicated methods of gaining temporal information can be gained through the use of screened walkways with current conducting material placed on the sole of the foot. Although this type of analysis is somewhat more time consuming to perform, the information is often fed directly into a small computer. This method is particularly well suited for analysis of gait asymmetries that are often association with pathological patterns. Several researchers have used this method to analyze the foot contact periods of gait (Dewar & Judge, 1980; Gardner & Murray, 1974; Larson, Odenrick, Sandlund, Weitz & Oberg, 1980; Leavitt et al., 1971; Smith, McDermid & Shideman, 1960; Zuniga & Leavitt, 1973).

Specific observation tools have been designed to assist the clinician in assessing normal and pathological gait patterns. An excellent example of this system was developed at Rancho Los Amigos Hospital (1978) in Downey, California. With this method, the phases and components of gait are broken down into a checklist. As gait abnormalities occur as perceived visually by the evaluator, they can be quickly noted on the checklist for future reference. An obvious drawback is the skill needed to be developed by the rater before this means of examination can be used accurately.

More advanced means of analyzing gait are used in some rehabilitation centers, but these are mostly confined to research centers due to the cost of such equipment and the time necessary to develop a program to optimize the use of these systems. These different methods are reviewed by Stanic with others (1977) and by Winter (1979, p.23). These systems provide the researcher with various kinematic variables, and are often interfaced with a computer network. These systems include cinematography, television, "Selspot" systems, electrogoniometers, and accelerometers. Some methods, such as the electrogoniometers, have restricted application to gait studies because of the encumbrance to walking due to the application of the system to the subject. Other systems, such as the Selspot, cinematographic and television means of analysis, are limited in use due to the considerable cost involved in purchasing the equipment. The use of cinematography and stroboscopic photography does not allow for use of online computer analysis, therefore, there is a considerable time lag between testing and determination of results. Finally, there is a direct relationship between the cost of such systems and the accuracy of measures involved.

Other methods that have been used to analyze gait have been through the use of force plates, using treadmills in conjunction with other methods, and energy expenditure studies. Extensive mathematical models have also been constructed for kinetic analysis during gait. The use and description of this means of evaluating human gait is beyond the scope of the present study.

Biomechanics of the Lower Extremity in Normal Gait

The following review of the biomechanics of normal gait will make use of many sources. Because of the general agreement between sources on this basic information, they will be referenced here for the reader to refer to if necessary. They are Brunnstrom (1972), Corcoran and Peszczynski (1978), Daniels and Worthingham (1972), Hoppenfeld (1976), New York University (1977), Perry (1967) and Rancho Los Amigos (1978).

The gait cycle is broken down to two separate phases, that of stance and of swing. In normal gait stance occupies approximately 60% of the gait cycle whereas swing assumes the remaining 40%. There is a period of overlapping of stance that is known as double support, and accounts for 22% of the cycle.

The movement of the center of gravity within the individual is of interest to assess the efficiency of walking. The greater the excursion of the center of gravity, the more energy that must be used to walk. Normal center of gravity excursion is approximately two inches vertically and one and three quarters inches horizontally. This movement does not occur in a single plane, but moves in a three-dimensional sinusoidal curve, with the vertical peak occurring in mid-stance and the lowest point occurring at double support. Horizontally, the center of gravity is at its farthest point laterally during mid-stance over that extremity.

Stance phase begins at the moment of heel strike. At this point, the hip is flexed to its maximum amount, usually about 30°, the knee is fully extended and the ankle is in neutral. At foot flat, the hip begins to extend slightly, while the knee flexes to 15° for shock absorption. The ankle plantar flexes to 15° to allow the foot to rest flat on the floor. As the body advances over the stance leg, mid-stance occurs. During this phase, the hip extends to neutral, the knee extends to 0°, and the ankle moves past neutral to slight dorsiflexion. The final phase of stance is termed push off and is further divided into heel off and toe off. At heel off, the hip moves to 10-15° of extension, the knee remains slightly flexed and the ankle dorsiflexes to 15°. At the point where the toes clear the floor, the hip has reached its maximum extension to 20°, the knee flexes to 35° to initiate foot clearance and the ankle plantar flexes to 20° to give push off.

After toe off, the swing phase has begun. The purpose of swing is to advance the leg forward in preparation for stance to occur again. Initially, as the leg accelerates forward the hip flexes to 20°, the knee flexes to its maximum of 60° and the ankle has dorsiflexed to clear the toes. At mid-swing, the hip continues to flex as the leg passes under the body, the knee begins to move toward extension and the ankle is neutral. The leg then begins to decelerate in preparation for heel strike. Here the hip is in its maximum amount of flexion (30°), the knee moves to full extension and the ankle remains at neutral. At heel strike, the swing phase ends, stance begins and a new gait cycle is started.

Kinematic Variables Found in Normal Gait

This section will review the present normative data on each of the variables that are to be described in this study. The wide range of "normal" found in gait should become obvious. The variables reviewed are the following: (a) cadence, (b) velocity, (c) cycle duration, (d) step length, (e) stride length, (f) step width, (g) step angle, (h) stride length to body height ratio, (i) hip, knee and ankle sagittal excursions and (j) the angular velocities that occur at those joints.

Cadence

A very wide range of "normal" or free cadences have been reported. These values generally lie between 107 and 120 steps/minute (Robinson, 1977; Robinson & Smidt, 1981; Shores, 1980; Smidt, 1974). Boenig (1977) reported 90 steps/minute for 30 women between the ages of 20 and 70. Zuniga and Leavitt (1973) found that 89 steps/minute was "average" for men and 106 steps/minute was the value for women. Finely and Cody (1970) observed over 1100 pedestrians in Philadelphia and found similar values of 110.5 and 116.5 steps/minute for men and women, respectively, These differences were significant. The Murray studies of the 1960's and early 70's (Murray et al., 1964; Murray et al., 1966; Murray et al., 1969; Murray et al., 1970) reported cadence values of 113 and 117 for men, 111 for elderly men and 117 steps/minute for women in low heels. Fast speed values reported by Murray were 138 (1966), 132 (1969), and 146 (1970) steps/minute.

Crowinshield and others (1978) reported that older people generally walk at a higher cadence, but this conflicts with what Murray and others described in 1969 with old men. In Finely and co-workers (1969) study of older women, it was found that the aged walked at a frequency of 109.5 steps/minute against 105.4 steps/minute for younger women. No statistical treatment for significance was reported by Finely. Murray reported in 1970 that cadence was related to height, but only at free speed in women. Similar reports were not made in the other Murray studies.

Velocity

As with cadence, there is a wide range of "normal" velocity values present in the literature. The normal value most reported is 112 cm/sec (Robinson, 1977; Robinson & Smidt, 1981; Shores, 1980). However, values of 135 cm/sec have been reported by Smidt (1971) for young men, 151 cm/sec for young men by Murray and others (1966) and 130 cm/sec by Smidt (1974). Finely and others (1969) reported lower walking velocities of 70 and 82 cm/sec for elderly and young women. Fast walking velocities ranged from 188 cm/sec (Smidt, 1971) to 218 cm/sec (Murray et al., 1966).

Changes in velocity have many effects on other variables associated with gait (Andriacchi, Ogle & Galante, 1977). Craik, Cook and D'Orazio (1980) have reported changes in joint motion, footfall patterns and muscle activity with changes in velocity. Crowinshield and co-workers also report changes in hip excursions with changes in velocity (1978). These changes are often exaggerated at higher walking speeds. Changes in velocity occur as a result of changes in cadence, changes in stride length or both (Andriacchi et al., 1977; Brunnstrom, 1972; Murray et al., 1966; Smidt, 1971; Smidt, 1974). Smidt (1974) reported a low correlation of velocity to cadence, but Larson, Odenrick, Sandlund, Weitz and Oberg (1980) reported a linear relationship of cadence to velocity.

Women tend to have a slower free walking velocity than men have (Finely & Cody, 1970; Murray et al., 1970). Murray also reported that velocity is related to body height, and that walking velocity in women is faster on lower heels (1970).

Many researchers have demonstrated that younger people walk significantly faster than elderly (Ayalon & Van Gheluwe, 1975; Crowinshield et al., 1978; Finely et al., 1969; Graf et al., 1981; Imms & Edholm, 1979; Murray et al., 1969). Craik, Inverso, Soucy and Dawkins reported that elderly individuals also have a smaller range of velocities than younger adults (1983). Cunningham, Rechnitzer, Pearce and Donner (1982) maintain, however, that if fitness levels and body size are held constant or young and old are evaluated in matched pairs, there is not a significant difference in walking velocity.

Cycle Duration

The cycle duration can be broken down into time of stance and time of swing. Average values for cycle duration reported are 1.40 seconds at a free pace by Leavitt and others (1971), 1.06 seconds by Murray and others (1966, 1969, 1970), 1.10 seconds by Smith and co-workers (1960), and 1.20 seconds by Smidt (1974). With increases in walking velocity, all components of the gait cycle shorten in duration, but stance decreases porportionally more. Put another way, the swing time to stance time (swing/stance) will increase (Andriacchi et al., 1977; Larson et al., 1980; Murray et al., 1964; Murray et al., 1966; Murray et al., 1969, Murray et al., 1970). Similarly, cadence is inversely related to cycle duration (Murray et al., 1966; Murray et al., 1969; Murray et al., 1970).

Stance and swing (contact and noncontact) times average .70 seconds and .40 seconds respectively (Greene, 1959; Smith et al., 1960) while double support is about .17 seconds (Smith et al., 1960). These values show that stance occupies approximately 60% of the gait cycle, while swing accounts for approximately 40% and double support is about 20%.

Differences in the cycle durations between men and women were reported by Zuniga and Leavitt (1973). They reported that women had shorter swing, stance and total cycle times. Smith and others (1960) reported that only swing time was shorter in women.

There is further difference of opinion regarding age differences for cycle duration. Murray and associates (1964), Ayalon and Van Gheluwe (1975), Smith et al. (1960), Green (1959) and Jansen, Vittas, Heilberg and Hansen (1982) all reported that there was no difference in the duration of the gait cycle or in the components of the cycle. Craik and others (1983) and Finely and associates (1969) reported, however, that older subjects tend to spend less time in swing when compared to younger people. This view was also reported by Murray and others (1970) and by Imms and Edholm (1979).

Step Length

The distance between the heel strike of one foot and the heel strike of the next foot also has a wide range of normal values reported. Sixty-six centimeters has been reported by many authors (Robinson, 1977; Robinson & Smidt, 1981; Shores, 1980), while Murray and others reported mean values of 78 cm (1964) and 76.5 cm (1970). Andriacchi and others (1977) have reported that step length varies linearly with velocity of walking and this is supported by others (Finely & Cody, 1970; Murray et al., 1966).

Men are reported to have a significantly longer step length than women, 74.09 cm to 63.42 cm (Finely & Cody, 1970). Older subjects have also been described as having a shorter step length (Ayalon & Van Gheluwe, 1975; Craik et al., 1983; Finely et al., 1969; Murray et al., 1970).

Stride Length

Values reported for average stride length are 132 cm (Robinson, 1977; Robinson & Smidt, 1981; Shores, 1980), 124 cm (Boenig, 1977) and 133 cm (Murray et al., 1970) for women, 156.6 cm for men (Murray et al., 1964), 156 cm for men (Murray et al., 1966), 146 cm for older men (Murray et al., 1969) and 150 cm (Smidt, 1974). Linear relationships between stride length and velocity have been reported by Larson and others (1980), while Crowinshield and others have reported that relationship to be non-linear (1978). Shorter stride lengths for older subjects have been reported by Murray and others (1964; 1966; 1969; 1970), Cunningham and co-workers (1982), Crowinshield and others (1978), Bassey, Fentem, MacDonald and Seriven (1976), while Jansen and associates (1982) report that there is no change in stride length with aging if it is expressed as a percentage of the person's height.

Stride Width and Foot Angle

The stride width of walking, along with the foot angle, can provide a rough idea of the base of support used by the individual. These two items are probably the most variable within groups, but are remarkably consistent within individuals (Murray et al., 1970). Mean values for stride width range from 5-10 cm (Shores, 1980), with values of 6.0 cm (Chodera, 1974), 6.8 cm (Boenig, 1977), 6.9 cm (Murray et al., 1970), 7.7 cm (Murray et al., 1966), 8.0 cm (Murray et al., 1964), and 9.0 cm (Murray et al., 1969) also found. For fast speeds, the stride width tends to increase, but this difference was statistically significant in only one study (Murray et al., 1966). Older individuals also tend to have a larger stride width, but neither Finely and others (1969) or Murray and associates (1969) found statistically significant differences in stride width changes with age.

The foot angle (in or out toeing) also tends to be highly variable within the group. Boenig (1977) reported values of 9.0^{o} on the left and 8.0^{o} on the right whereas Murray and others (1970) reported 6.4^{o} and 5.1^{o}, left and right respectively for women. The foot angle tends to be greater at slower speeds in men (Murray et al., 1964; Murray et al., 1969) and greater in older men (Murray et al., 1969). Murray and others (1969) concluded that at higher walking speeds lateral base of support was not as important as forward propulsion, which accounts for the decreased foot angle at faster speeds. Similarly, older individuals tend to increase their base of support by out toeing more.

Stride Length to Body Height Ratio

The stride length to body height ratio has been used in many studies to equate the stride length of people of different heights. Jansen and co-workers (1982) have reported that stride length differences were apparent only if the body height of the individuals were not considered. They found this ratio to be 58-59% in their study of young adults and elderly walking at a free speed. This contrasts with Foley and others (1979) figure of 89% found in young children. Murray and others (1964) found similar results with tall, medium, and short stature men, but their value was 89-90% for the three groups, walking at a free speed. In their 1966 study of older men, Murray and associates found that below 65 years of age, the stride length to body height ratio was 89%, but over 65 was only 79%. This difference also held at fast paces, with the under 65 group averaging 107% while the over 65 group was at 90%. Finally, Ayalon and Van Gheluwe (1975) expressed the ratio of 68% for younger adults compared to 44% for 70-80 year old subjects. It is apparent, therefore, that there is some disagreement over the effect of height and aging on the stride length in free walking.

Hip Sagittal Excursions

The pattern of hip flexion and extension during gait has been well established. Maximum hip flexion occurs late in swing or early in stance while hip extension reaches its maximum value during late stance (Smidt, 1971). The range of hip motion increases at faster paces (Andriacchi et al., 1977; Craik et al., 1980) with the majority of the increase occurring from increased hip flexion (Murray et al., 1964; Murray et al., 1966; Murray et al., 1970; Smidt, 1971). At fast walking velocities, the excursion is between 52^o (Murray et al., 1966) and 56^o (Murray et al., 1969). This value drops to 45-48^o in free paced walking (Murray et al., 1964; Murray et al., 1966; Murray et al., 1969; Murray et al., 1970; Smidt, 1974). Finely and others reported excursions of 20^o for young and 24^o for elderly women (1969). Murray and associates (1969) reported a decrease in hip range of motion in older men also.

Of the 48^o of hip excursion, approximately 30^o is flexion and the remaining 18^o is extension (Smidt, 1971).

Knee Sagittal Excursion

The knee undergoes a "double lock mechanism" during normal gait. This was first described by Saunders, Inman and Eberhart (1953) as a mechanism to smooth the direction changes of the center of gravity and to assist in shock absorption. The knee extends at heel strike but then flexes to accommodate the weight of the body. It extends again at mid stance and flexes at heel off.

The range of knee motion during gait is from approximately 0^{o} or 3^{o} to 70^{o} of flexion (Murray et al., 1964; Murray et al., 1966; Murray et al., 1969; Murray et al., 1970). At faster walking speeds, the amount of flexion is reported to increase, and the knee often does not reach full extension (Murray et al., 1966). Other values reported are 52^{o} excursion (Leavitt et al., 1971), 45^{o} excursion (Finely et al., 1969) and $2\text{-}62^{o}$ of motion (Brinkman & Perry, 1982).

Finely with others (1969) reported slightly different flexion patterns in elderly women when compared with younger subjects. There was a decrease in the amount of knee flexion used in swing in older subjects. Murray and associates (1969) found similar findings with older men, but neither of these studies made a statistical inference.

<u>Ankle Sagittal Excursions</u>

The range of ankle motion during normal gait generally is reported to be between 20^{o} ankle plantar flexion (extension) and 10^{o} of dorsiflexion (flexion) (Murray, 1967). At heel strike, there is an initial movement toward plantar flexion, then a reversal toward dorsiflexion as the body moves over the support limb. The ankle then again moves toward plantar flexion at push off, but must quickly dorsiflex to clear the toes at the beginning of swing. Finely and others (1964) again report slightly lower values of 10^{o} plantar flexion to 4^{o} dorsiflexion. They also found a difference of 5^{o} less ankle dorsiflexion in elderly women compared to younger subjects. Murray and others (1964) reported no age differences in men ages 20-65, but did find some decrease in dorsiflexion in men 65-80 years of age (1969). However, the patterns of movement were quite similar.

At fast walking speeds, the increase in step length is due to a combination of increased hip flexion in the swing leg and increased ankle plantar flexion in the stance leg at push off (Murray et al., 1966).

Angular Velocities of the Lower Extremity Joints

There has been very little research done determining the mean angular velocity that occurs at the joints of the lower extremity in walking. No related literature has been found on the angular velocity that occurs at the hip and ankle, and only two studies have been located on the angular velocity at the knee during walking.

Wyatt and Edwards (1981) have reported that the knee extends at 233^{o}/second during swing phase. This number was interpolated from a range of motion graph against time by using the slope of the curve in the last .12 seconds of swing. Brinkman and Perry (1982) reported a value of 344^{o}/second knee extension and flexion. This was obtained through electrogoniometer measurements of range of motion at the knee. Furthermore, pre-operation state rheumatoid arthritic patients averaged 82^{o}/second of flexion and 83^{o}/second of extension, while post operatively those values increased to 154^{o}/second and 277^{o}/second, flexion and extension, respectively. These are the only values that have been found on knee angular velocity in normal walking.

Gait in Aging

There have been few studies that have tried to describe the normal characteristics of gait in the elderly. These will be reviewed and critiqued in this section. Of these, only two have dealt specifically with female subjects.

Finely, Cody and Finizie (1969) compared the walking patterns of elderly women to those of younger women. They used 23 elderly subjects with a mean age of 74.4 years and compared those findings to 12 adult women with a mean age of 29.9 years. Extensive electrogoniometry was used, along with a six lead electromyography (EMG) system. Their results indicated that the elderly women had a decreased step length, an increase in cadence, a decrease in walking velocity and an increase in time of support. The kinematic data of joint angles was quite similar between groups, as was the EMG data. They concluded that aging did not affect gait per se, and that although the study did not describe a new phenomenon, it did quantitatively describe elderly gait in women. It is interesting to note that many of the variables described in this study are remarkably smaller in value than other studies have reported, even for the younger subjects. For example, they reported an average step length of 18.48 inches (46.94 cm) for their younger subjects, compared to the normally accepted value of 66 cm (Robinson, 1977; Robinson & Smidt, 1981; Shores, 1980). It is this author's opinion that the restrictive nature of the method of data collection significantly altered the gait patterns of the subjects, and that the data presented must be interpreted as such. Furthermore, the sample of elderly was noted to have a large percentage of arthritic symptoms, which would also significantly alter the gait patterns recorded.

Murray, Kory and Sepic (1970) looked at the walking patterns of women from the ages of 20 to 70 years. Walking changes associated with aging, height and low or high heeled shoes were described. However, they used only six subjects in each decade divided age group, with each sub-group divided into short, medium and tall subjects with two participants of each. The data was collected through the use of stroboscopic photography at 20 cycles per second. Although this method did not have the extensive instrumentation of the study by Finely and associates (1969), it did require that each subject walk in a darkened hallway. The sampling rate of 20 cycles per second is also considered to be lower than desirable. They reported some evidence of pre-senile gait changes, mostly in the 60-70 age range, with some changes that were apparent at 50 plus years. This was especially apparent in the amount of time spent in stance. Also reported were decreases in step length and velocity with aging.

Murray, Kory and Clarkson (1969) used similar methods to describe the walking patterns of elderly men and compared those to values obtained for younger men. There were eight subjects in each age group ranging from 20 to 87 years of age. All of the subjects were considered to be healthy, with all participants 65 and older receiving a neurological exam. Again, as with the other studies, a senile gait pattern was suggested by the results, with the impression of the study described as guarded and restrained gait appearing in the elderly. It was again noted that there was an increase in stance time in elderly subjects.

In contrast, Greene (1959) reported on the remarkable consistency in gait, particularly the temporal aspects, with aging using an electrobasometer and 150 subjects between the ages of 12 and 70. It was also reported that the variations in gait were slight and statistically insignificant on a day to day basis. This conclusion contrasts with a recent study by Graf and others (1981) which reported a statistically significant difference in free walking velocity over three trials with 10 subjects. They described no significant difference in temporal variables at a fast pace over three trials. Bassey and associates (1976) also reported similar findings of the variability of slower walking paces regardless of age.

In an attempt to control for differences in gait as a result of height and velocity, Jansen, Vittas, Hellberg and Hansen (1982) used a treadmill to evaluate the walking patterns of 20 subjects 60-69 years of age and 20 subjects 20-29 years. Although they reported an apparent statistically significant difference in stride length with aging, they pointed out that if the stride length was reported as a percentage of the height, that value was fairly constant at 58 to 59%. They concluded that there is a "constant pattern of gait regardless of age or sex of normal persons" (p. 196). However, the use of a treadmill to control walking is an extremely artificial situation, and the results derived from this study must be interpreted accordingly. The control for differences in velocity is a valid point, however, and has also been expressed as a need for further study by other researchers (Andriacchi et al., 1977; Craik et al., 1980; Craik et al., 1983; Crowinshield et al., 1978; Smidt, 1971).

Finally, Ayalon and Van Gheluwe (1975), did a biomechanical descriptive study on the activities of daily living in older and younger subjects, including that of gait. They found considerable subjective differences in many activities, but made few statistical comparisons. They generalized their findings as being a result of the more flexed posture associated with aging.

Problems in Aging Research

The study of aging itself creates many methodological problems that are unique to this population. Although the purpose of this study is not to determine the physiological effects of aging on walking, a brief word on the difficulty in studying the aging process is in order. Especially pertinent to this paper is the separation of disease processes and changes of normal aging.

The differentiation between aging and disease is the primary obstacle in the study of aging. Wiesfeldt (1980) stated that some diseases may be a direct result of aging itself, while others are often found to increase in incidence and severity in the aged. Or, the changes may be non-pathological and simply a product of aging. Furthermore, the "use it or lose it" syndrome has complicated the differentiation between aging, disease and disuse (Holloszy, 1983; Shepard, 1978). Many authors have suggested that regular physical activity may retard the effects of aging, although scientific evidence to support this premise is inconclusive at this time (Holloszy, 1983; Kent, 1982; Payton & Pollard, 1983; Shepard, 1978). Wiesfeldt (1980) suggested that if changes that are not due to pathological states can be demonstrated in multiple species, those effects can be interpreted as being a result of aging.

The design of aging studies often creates many methodological problems (Shepard, 1978; Wiesfeldt, 1980). Longitudinal studies are good for separating disease from normal aging, and noting the effects of aging, however, consistency of measures and study becomes a problem over time. This is especially difficult to control in human studies where the information may be gathered over a 30 to 40 year span. In animal studies, the object of study can not be harmed or sacrificed in longitudinal designs (Wiesfeldt, 1980). In humans, strict experimental conditions can not be maintained for long periods (Shepard, 1978). Cross sectional studies are easier to handle but suffer from the inability to distinguish disease from normal aging and from the study of a select population (Wiesfeldt, 1980).

Finally, aging processes must be separated from maturational changes (Wiesfeldt, 1980). This necessitates that the portion of the life span studied must be clearly identified, especially when comparing different species.

CHAPTER III

METHODS

The purpose of this study was to describe the gait patterns in a sample of healthy, elderly women through selected kinematic variables using cinematography and pedigraphic means. The methods outlined in this chapter are divided into the following sections: (a) Subject Selection; (b) Development of Instrumentation; (c) Experimental Procedures; and (d) Data Analysis.

Subject Selection

The subjects used in this study were healthy, elderly women, ages 65 to 78 (mean age 70.3 ± 4.4 years s.d.) from metropolitan La Crosse, Wisconsin. Fifteen females were recruited from the La Crosse Young Women's Christian Association (YWCA) senior citizen fitness programs which assured active participants. All women were volunteers that had the experimental procedures outlined to them twice before they individually signed the informed consent (see Appendix A). The subjects were considered healthy after a review of the personal health inventory form that each was asked to complete (see Appendix B). It was stressed to all women that participation in this study was entirely voluntary and that they could withdraw their support from the project at any time and for any reason.

Development of Instrumentation

The instruments used in this study are described as follows: (a) Cinematography; (b) Dynamic Pedigraph System; and (c) Measurement of Body Height.

Cinematography

The filming performed in this study utilized the University of Wisconsin - La Crosse Cine 8 super 8 high speed motion picture camera (Model SP-1 with R-10 reflex view finder) manufactured by the Meckel Engineering Corporation. A 12-120 mm Angenieux zoom lens was used. The distance from the camera to the walking path measured 40 feet perpendicularly to the center of the walkway. The camera was placed on a tripod and leveled with the center of the lens 36 inches from the floor. Placed in the camera field of view was a trial marker to reference the subject and trial, and a timing clock with .01 second time demarcations. Two small distance markers were placed three meters apart and centered within the field of view. A timing light generator (TLG) was also used to verify proper camera speed by placing timing marks on the edge of the film at a rate of 10 cycles per second.

The filming was performed in two separate sessions in the Mitchell Hall Fieldhouse at the University of Wisconsin - La Crosse. No specific backdrop was used other than the wall of the Fieldhouse. The subjects walked from left to right to allow for film analysis of the right side.

Adequate lighting was achieved through the use of 12 high intensity 1000 watt Lowel Tota-light tungsten lamps directed at 45° to to supply uniform lighting throughout the field of view. For the first filming session, seven lamps were placed on the left side with five on the right side of the field of view, while for the second session the lighting was evenly split with six lamps on each side. Kodak 4-X black and white film (ASA 400/320) was used. The lens aperture was set at f/2.8 for the first session and at f/4.0 for the second. This was determined by the use of the Sekonic Incident Light Meter.

The camera speed was set at 100 frames per second (fps). This was considerably higher than the 24 to 32 fps suggested by Winter (1982) for the filming of normal and pathological gait. This camera speed was chosen over Winter's suggestion primarily for reasons of accuracy in determining the temporal factors related to this study, allowing the analysis to be accurate within .01 seconds. Winter stated that filming at this rate does not violate the Sampling Theorem, that the sampling of any signal must occur at least twice that of the highest frequency present in the signal itself. Normally, most signals in gait are sampled at four to five times the highest signal frequency, which is generally six cycles per second. This frequency is also that given by Sutherland and associates (1980) as the normal frequency of gait. Winter (1982) does concede that faster camera speeds are more accurate for determining temporal factors.

The shutter factor on the camera was set at 160°, allowing for a film exposure time of 1/225 seconds.

All subjects wore swimsuits or shorts that properly exposed the right lower extremity. No clothing restrictions were placed on the upper body. Shoes were not worn by any of the participants. Segmental end-point markers were placed over the right greater trochanter, the center of the right mid-joint line of the knee, the functional axis of the right ankle, and the base of the fifth metatarsal on the right foot. The end-points were marked by a 1.91 by 1.91 centimeter square of black tape with a white circle within the square. The segmental end-point markers were used to improve the rater reliability during the digitizing procedures. (See Figure 2 for the camera and equipment set-up and Figure 3 for the segmental end-point locations.)

Measurement of Body Height

Each subject's height was measured prior to the filming itself using a standard tape measure with 1 millimeter divisions that was taped to the wall. This was used to determine each subject's stride length to body height ratio.

Dynamic Pedigraph System

Shutrak pedigraph paper (Healthcare Products & Systems) was used to determine many of the gait variables associated with foot placement. This system provided a simple permanent record of each footprint to be used later for analysis. A 279.4 by 40.64 cm section of Shutrak was secured to the floor in the middle of the camera field of view, perpendicular to the camera. The paper was used as the bounds for the walkway. One to two full strides were available for analysis.

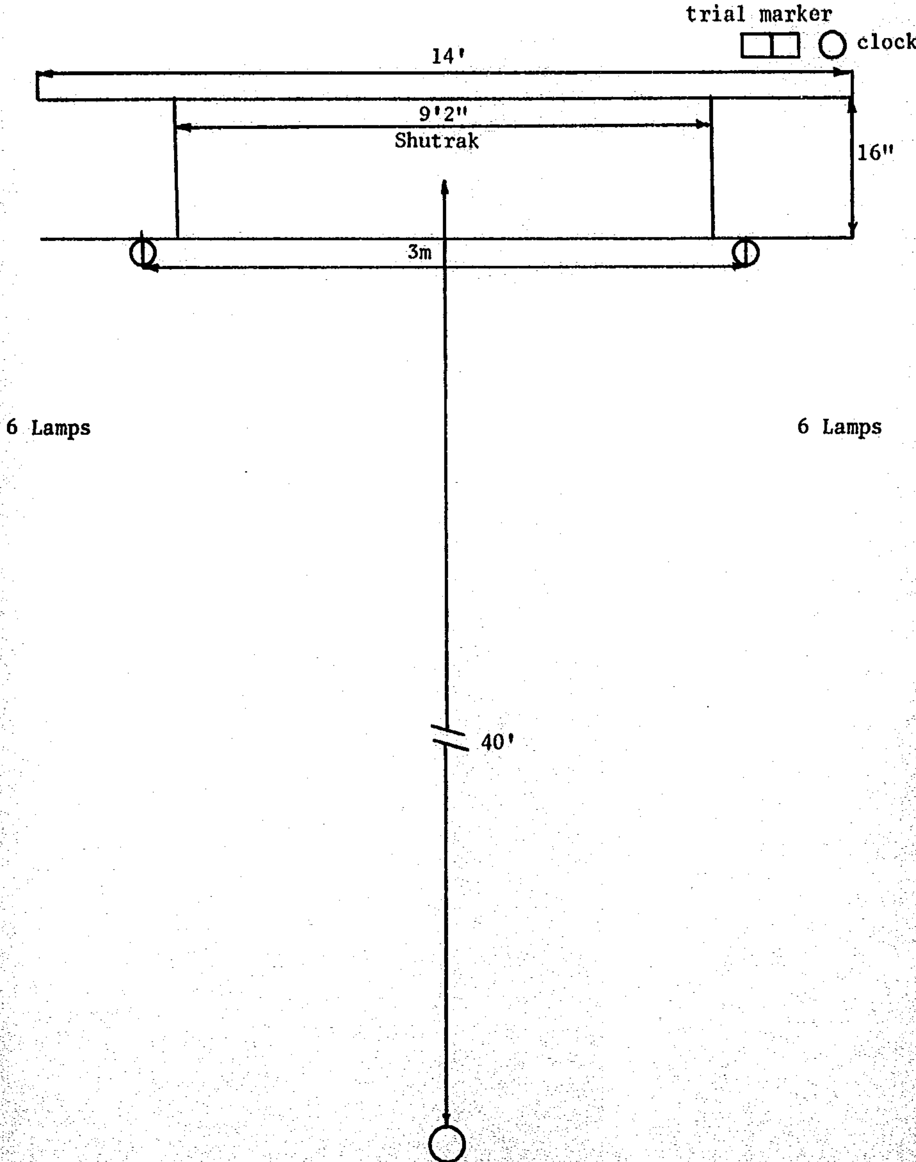


Figure 2. Camera and equipment set up for filming.

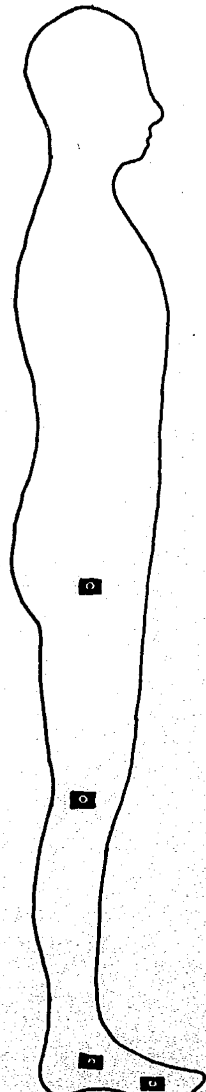


Figure 3. Segmental end-point locations for the right lower extremity.

Experimental Procedures

The following experimental procedures were performed as discussed below. This section is divided into the following subsections: (a) Range of Motion and Strength Tests; (b) Instructional Information; (c) Filming Procedures; and (d) Dynamic Pedigraph Procedures.

Range of Motion and Strength Tests

To insure that each subject had normal or within normal limits of strength and range of motion in the lower extremities, quick tests were used to evaluate each participant. Specific criteria for age-matched strength and range of motion norms do not exist at this time, therefore these tests were based on the present normal values available. Lower extremity range of motion was judged to be within normal limits if the lower ends of range could be obtained as outlined by the American Academy of Orthopaedic Surgeons (AAOS, 1965) for the following motions: hip flexion (100^{o}), extension (20^{o}), abduction (40^{o}), adduction (20^{o}), knee flexion (125^{o}), extension (neutral or 0^{o}), ankle plantar flexion (40^{o}) and dorsiflexion (15^{o}). It is reasonable to expect some age related decreases in flexibility, therefore the lower limits of normal range were used. Also, bilateral comparisons were made to insure symmetry in lower extremity range of motion.

The assessment of lower extremity strength was somewhat more subjective. Manual muscle tests (MMT) were performed on all subjects prior to filming in a fashion similar to that mentioned by Daniels and Worthingham (1972). Normal ratings were given if the subject performed with "good plus" or better strength. Good plus is defined as "movement against gravity with a great deal of resistance..." (p. 3). Again, bilateral comparisons were made to assess for lower extremity strength symmetry.

All strength and range of motion tests were performed by the same person for both testing sessions.

Instructional Information

The subjects were each instructed to walk on the designated walkway at two speeds, to be referred to as free (normal) and fast, as outlined by Murray and associates (1970). The free pace was described as "a comfortable speed" while the fast pace was explained as "to walk as fast as possible" (p. 637). Further instructions given were to "walk at your normal pace" and to "walk as fast as you comfortably can." Neither pace was controlled by any external means, nor was any practice session deemed to be necessary.

Filming Procedures

All filming was done from the sagittal plane, and one trial at each speed was filmed. A single trial was used because although there is much inter-subject variability in walking, most intra-subject variables of gait are quite consistent (Grieve, 1969; Murray et al., 1964; Murray et al., 1970). Graf, Wong, Gronley, and Walker (1981) reported that there was little variability in the fast-speed walking on a day to day basis. These premises are used to support a single trial at each walking speed. There is some discussion also that an average of trials at any speed does not represent the true gait, but rather an average of gait, which in itself represents nothing.

At the initiation of each new role of film, a reference measure of one meter was filmed vertically and horizontally to the ground. The camera was started before each subject entered the field of view to allow sufficient "catch up" time for the camera, and filming was stopped after the subject left the field of view.

Dynamic Pedigraph Procedures

Prior to each trial, a 279.4 by 40.64 cm path of Shutrak pedigraph paper was secured to the floor with self adhesive for the purpose of recording footprint information and various spatial variables. This information was recorded simultaneously with the filming.

Data Analysis

Eighteen separate components of gait were analyzed from the raw data. These were the following: (a) velocity; (b) cadence: (c) cycle duration; (d) stance time; (e) swing time; (f) double support time; (g) swing to stance ratio; (h) step length; (i) step width; (j) stride length; (k) foot angle; (l) stride length to body height ratio; (m) hip, knee and ankle sagittal excursion patterns; and (n) the angular velocities that occurred at each of those joints. Three separate methods were used to analyze these data. The first data obtained were from the spatial factors provided by the Shutrak pedigraph paper. The second analysis was from the temporal factors that were determined from the number of frames elapsed during the specific events being timed and checked by the timing light generator. More specialized film analysis procedures utilizing the IBM Personal Computer (PC) were used to determine the remaining kinematic variables of this study.

Spatial Analysis

Four distance factors were easily discernible from the raw data provided by the Shutrak system. These were step length, step width, stride length and foot angle. The step length was calculated as the distance from one heel strike to the next contralateral heel strike along a line parallel to the line of forward progression. The stride length was measured in a similar manner from heel strike to ipsilateral heel strike. Foot angle was determined as described by Boenig (1977). A line drawn from the second metatarsal and bisecting the heel and a line parallel to the line of forward progression and intersecting the first line at the heel formed the adjacent sides used to determine the foot angle. Both the left and right foot angles of one stride were measured and recorded. Step width was also measured as suggested by Boenig. The perpendicular distances from successive left and right medial borders of the heel footprints to the left border of the paper were measured. The stride width was equal to the distance from the right footprint to the border minus that distance of the left footprint. For a diagrammatic representation of these measures, see Figure 1.

The stride length to body height ratio was determined by dividing the stride length as recorded above by the height of each individual which was measured with a standard tape measure. This measure was expressed as a percentage.

Temporal Analysis

The timing patterns of stance, swing, double limb support and cycle duration were directly calculated by counting the number of frames elapsed for each event. At a frame rate of 100 fps, .01 seconds elapsed between each successive frame. This rate was confirmed by the timing clock within the camera field of view and also by the timing light generator. Single readings for each variable were taken for one representative stride beginning with right heel strike and one with left heel strike. Double support time was calculated from the overlapping strides.

Forward velocity was calculated by determining the time elapsed from the moment the right hip passed the first distance marker on the left to the point where the hip passed the marker on the right; a distance of 300 centimeters. This variable was expressed in centimeters per second (cm/sec). Finally, cadence was found by recording the elapsed time of one stride and multiplying by the appropriate factor to give steps per minute.

Film Analysis

Five segmental end-points that marked the joint centers of the lower extremity were digitized on every third frame for one complete representative gait cycle, beginning with right heel strike. Digitizing was performed on the Numonics 1224 Digitizer. In addition to the digitizing of every third frame, the same five points were digitized at the following events of the gait cycle if the event did not occur at one of the sampled three frame intervals; left toe off, left heel strike and right toe off. This sampling pattern allowed for the sampling rate to be at least 33 fps, which is still in accordance with the Sampling Theorem as reported by Winter (1982).

The five points digitized were, in order, the right base of the fifth metatarsal, the functional axis of the right ankle, the right knee mid-joint line, the right greater trochanter and the right mid-axillary line just distal to the shoulder. These points were entered directly on a Memorex Mini-Flexible Disc through the IBM PC and stored.

The data stored on the disc were analyzed using the JFILM computer program (Richards, 1979) for angular displacements. The displacements calculated by this program provided angular information for the absolute angle of each segment against a right horizontal (see Figure 4). The original JFILM program was altered to present the relative angles at each joint between the adjacent segments of the lower extremity (see Figure 5). This allowed for the determination of the range of motion used during gait of the hip, knee and ankle on the right side of the body. The time elapsed between each sampled frame was also entered and the angular velocity at each joint was computed. This was averaged and reported as the mean angular velocity at each joint for each phase of the gait cycle.

Statistical Treatment

The purpose of this study was entirely descriptive in nature, therefore means and standard deviations for each of the variables analyzed at each walking speed were calculated and presented as the normative data of this sample of healthy, elderly women.

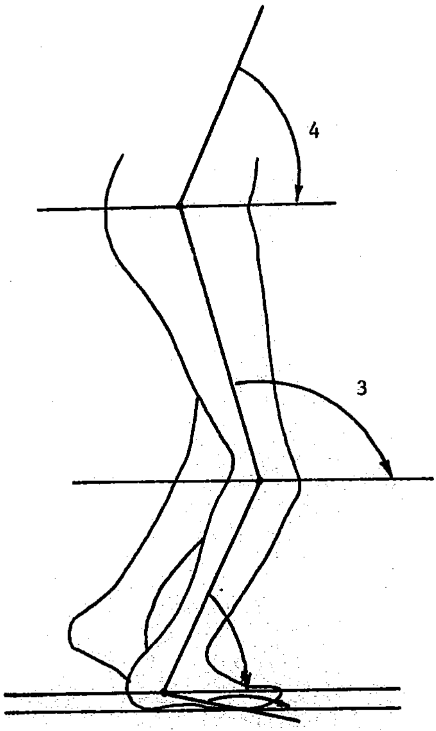


Figure 4. Absolute angles of the hip, knee, ankle and foot as given by JFILM (Richards, 1979).

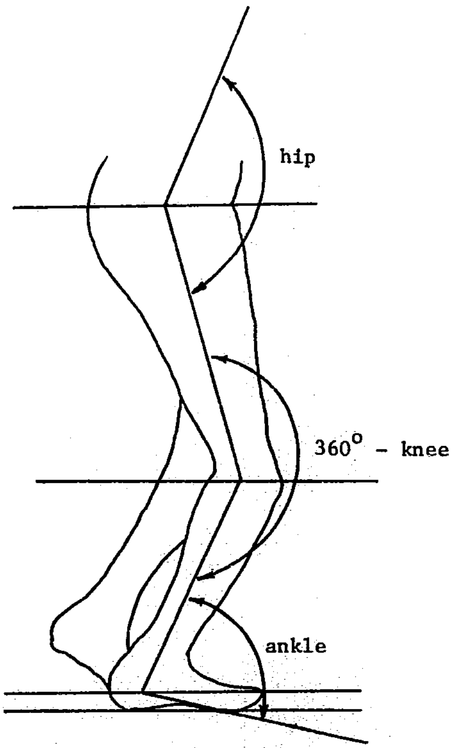


Figure 5. Relative angles of the hip, knee, and ankle.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to describe the gait patterns in a sample of healthy, elderly women through selected kinematic variables. High speed cinematographic and dynamic pedigraph procedures were used to secure the following information: (a) velocity; (b) cadence; (c) cycle duration; (d) stance time; (e) swing time; (f) double support time; (g) swing to stance ratio; (h) step length; (i) step width; (j) stride length; (k) foot angle; (l) stride length to body height ratio; (m) hip, knee and ankle sagittal excursion patterns; and (n) the angular velocity at the hip, knee and ankle. The results of these variables from free and fast walking trials are presented in the first section of this chapter. Selected gait variables and how they relate to locomotion in the elderly are discussed in the latter part of this chapter.

Results

Subject Description

Fifteen elderly females with a mean age of 70.3 [± 4.4 s.d.] years participated in this study. The mean height of the participants was 159.87 [± 6.0 cm s.d.] All subjects were considered healthy after reviewing the personal health inventory that each completed (see Appendix B). Subject 1 reported having a bone spur on her left heel, but added that this was not an acute problem and was resolved at the time of testing. Subject 10 reported that she may have had a slight cerebral vascular accident, but this was not diagnosed with certainty by her physician. Review of her film trials and kinematic results revealed no gait abnormalities. Finally, Subject 11 reported intermittent claudication but only with longer distance walking. No other problems were reported. The strength and range of motion tests were considered to be normal or within normal limits and symmetrical for all subjects.

Velocity

Table 1 shows the mean velocity and standard deviation for the 15 subjects at the normal and fast walking pace. It should be noted that there is much variability at each of the two walking speeds.

Table 1

Mean Velocity and Cadence at Normal and Fast Paces for Healthy, Elderly Women

Variable	Normal[a]	Fast[a]
Velocity (cm/sec)	97.05 (15.66)	137.63 (13.01)
range	74.07 - 121.95	110.7 - 157.89
Cadence (steps/min)	108.83 (9.39)	134.13 (10.57)
range	93.02 - 121.21	122.45 - 164.38

[a]Numbers in parentheses indicate one standard deviation.

Cadence

The calculated cadence in steps per minute is given in Table 1 for the normal and fast walking speeds. As with the velocity of walking, there is a wide range of cadences for each walking speed.

Temporal Components of Gait

The temporal components of gait in this sample of women are listed in Table 2. The values for normal and fast walking speeds are presented.

Table 2

Mean Temporal Values of Gait in Healthy, Elderly Women at Normal and Fast Walking Velocities, in Seconds

Variable	Normal[a]	Fast[a]
Cycle Duration	1.11(0.10)	0.90(0.06)
Stance Time	0.72(0.07)	0.56(0.05)
Swing Time	0.39(0.04)	0.34(0.02)
Double Support Time	0.32(0.06)	0.22(0.05)

[a]Numbers in parentheses indicate one standard deviation.

As expected, the cycle duration, time spent in stance and time spent in swing decreased at the faster walking speed. The swing to stance ratio at the normal pace expressed as a percentage was 55.12 [± 4.11% s.d.], while at the faster pace it was 61.04 [± 5.04% s.d.]. This agrees with many observations that as the velocity of walking increases, the amount of time spent in stance will proportionally decrease more than the time spent in swing (Andriacchi et al., 1977; Larson et al., 1980; Murray et al., 1964; Murray et al., 1966; Murray et al., 1969; Murray et al., 1970). These values of 55% and 61% compare favorably with other values presented.

Spatial Characteristics

The mean values for the spatial variables of step length, step width, stride length and foot angle are presented in Table 3 for normal and fast walking speeds.

Table 3

Mean Spatial Characteristics of Gait in Healthy, Elderly Women at Normal and Fast Walking Velocities, in Centimenters

Variable	Normal[a]	Fast[a]
Step Length	56.76(7.14)	64.86(6.89)
Step Width	2.99(2.83)	1.80(3.39)
Stride Length	111.89(13.34)	128.65(11.52)
Foot Angle		
Right	9.53(5.73)	8.52(3.72)
Left	6.62(5.90)	8.70(5.54)

[a]Numbers in parentheses indicate one standard deviation.

As expected, the stride length and step length increases with increased walking speed. There is a high degree of variability in the values obtained for the foot angle and the step width at both speeds.

Murray and co-workers (1970) also reported much variability in these two measures. The range of values found in the present study for foot angle was from -4.8° to 18.7° for the right foot and -5.4° to 14.8° for the left foot at normal walking speeds; at faster speeds the values ranged from 3.2° to 14.7° on the right and 0° to 21.6° on the left. Similarly, the values for step width ranged from -1.4 cm to 8.0 cm at the normal pace and from -4.1 cm to 9.2 cm at the faster pace.

The stride length to body height ratio has been used to equate the stride length of people of different heights. In this study, this ratio expressed as a percentage was 69.99 [± 7.7% s.d.] at the normal pace and 80.51 [± 7.0% s.d.] for the faster speed.

Hip, Knee and Ankle Sagittal Excursion Patterns

The patterns of sagittal excursion for the hip, knee and ankle are plotted against specific events of the gait cycle in Figures 6, 7, and 8, respectively. Joint position and standard deviations for each event at normal walking speed is listed in Table 4, and for fast speed in Table 5. Total hip range of motion used in gait at normal speeds was 45.19° [± 6.9° s.d.] with 26.44° [± 6.5° s.d.] flexion and 18.94° [± 6.5° s.d.] of extension. At the faster speed, there was 46.94° [± 8.0° s.d.] of total motion with 27.68° [± 4.67° s.d.] and 19.27° [± 5.07° s.d.] of flexion and extension respectively. The patterns of movement represented by Figure 6 are very similar at the different speeds, with slightly more hip flexion occurring early in the gait cycle and just prior to heel strike at the fast speed.

Table 4

Mean Ankle, Knee and Hip Positions at Selected Events in

Gait for Healthy, Elderly Women at Normal Speed

Event	Ankle[a,b] $\bar{x}$	Knee[a,c] $\bar{x}$	Hip[a,d] $\bar{x}$
Right Heel Strike	112.77(4.15)	174.87(4.88)	159.15(5.03)
Left Toe Off	108.21(4.03)	168.67(5.36)	168.46(6.64)
	90.45(3.9)	178.52(4.87)	
Left Heel Strike	94.19(5.77	171.64(4.93)	196.48(6.99)
			199.30(5.98)
Right Toe Off	116.93(5.18)	133.04(7.91)	185.25(8.33)
	96.30(4.61)	117.81(6.17)	154.38(6.87)
Right Heel Strike	112.92(3.39)	176.36(5.11)	163.1(6.97)

[a]Numbers in parentheses indicate one standard deviation.

[b]Neutral position is 90°.

[c]Neutral position is 180°.

[d]Neutral position is 180°.

Table 5

Mean Ankle, Knee and Hip Positions at Selected Events in

Gait for Healthy, Elderly Women at Fast Speed

Event	Ankle[a,b] $\bar{x}$	Knee[a,c] $\bar{x}$	Hip[a,d] $\bar{x}$
Right Heel Strike	113.15(4.86)	173.50(5.94)	156.60(7.00)
Left Toe Off	109.37(4.9)	163.08(6.34)	162.04(7.45)
	92.03(3.48)	178.51(3.77)	
Left Heel Strike	99.98(7.57)	170.04(5.35)	198.51(6.60)
			198.34(6.27)
Right Toe Off	121.18(5.18)	132.58(8.29)	186.58(5.66)
	96.45(4.89)	115.25(5.61)	153.34(4.67)
Right Heel Strike	112.17(4.05)	174.40(3.42)	160.09(5.88)

[a]Numbers in parentheses indicate one standard deviation.

[b]Neutral position is 90°

[c]Neutral position is 180°

[d]Neutral position is 180°

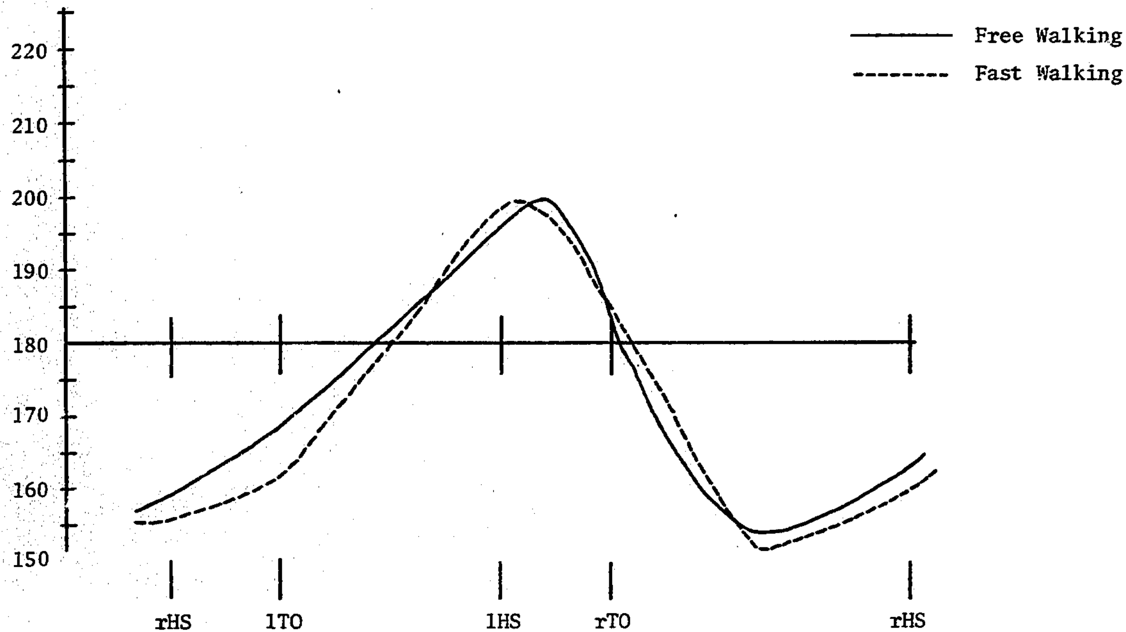


Figure 6. Mean patterns of sagittal excursion for the right hip, beginning at right heel strike (rHS). Neutral position for the hip is 180. (l = left)

Total knee range of motion found in gait was also similar at both speeds. At the normal pace, the mean total range of motion was 61.09^{o} [± 6.5^{o} s.d.], with 61.54^{o} [± 6.1^{o} s.d.] of flexion used. At periods of maximal knee extension, 0.7^{o} [± 2.8^{o} s.d.] of flexion existed, indicating that some subjects hyperextended at the knee while others never reached full knee extension. Total knee range of motion at the fast speed was 63.52^{o} [± 6.1^{o} s.d.] with 64.68^{o} [± 5.64^{o} s.d.] of flexion occurring and the knee lacking 1.1^{o} [± 2.2^{o} s.d.] of full extension. Again, this indicated that some subjects were hyperextended at the knee at periods of maximal extension, while others remained slightly flexed. Patterns of knee range of motion are shown in Figure 7. At both speeds, the characteristic "double-lock mechanism" (Saunders et al., 1953) is evident, with slightly more knee flexion occurring after heel strike and after toe off at the faster speed.

Total ankle range of motion varied slightly between normal and fast paces, although the patterns of movement between the trials were quite similar. Total movement at the ankle at the normal speed was 34.09^{o} [± 4.7^{o} s.d.], with 33.63^{o} [± 3.4^{o} s.d.] of plantar flexion and only 0.44^{o} [± 3.4^{o} s.d.] of dorsiflexion used. At the fast speed, less total motion occurred. There was 31.98^{o} [± 5.56^{o} s.d.] of total excursion with 33.67^{o} [± 4.9^{o} s.d.] of plantar flexion occurring. In contrast, the ankle did not move past neutral in many subjects, lacking a mean value of 1.31^{o} [± 3.11^{o} s.d.] of dorsiflexion. The pattern of ankle motion between trials is shown in Figure 8. At the fast speed, there was more ankle plantar flexion at right toe off than at normal speed. In contrast, less ankle dorsiflexion was found to occur between left toe off and left heel strike, and after right toe off.

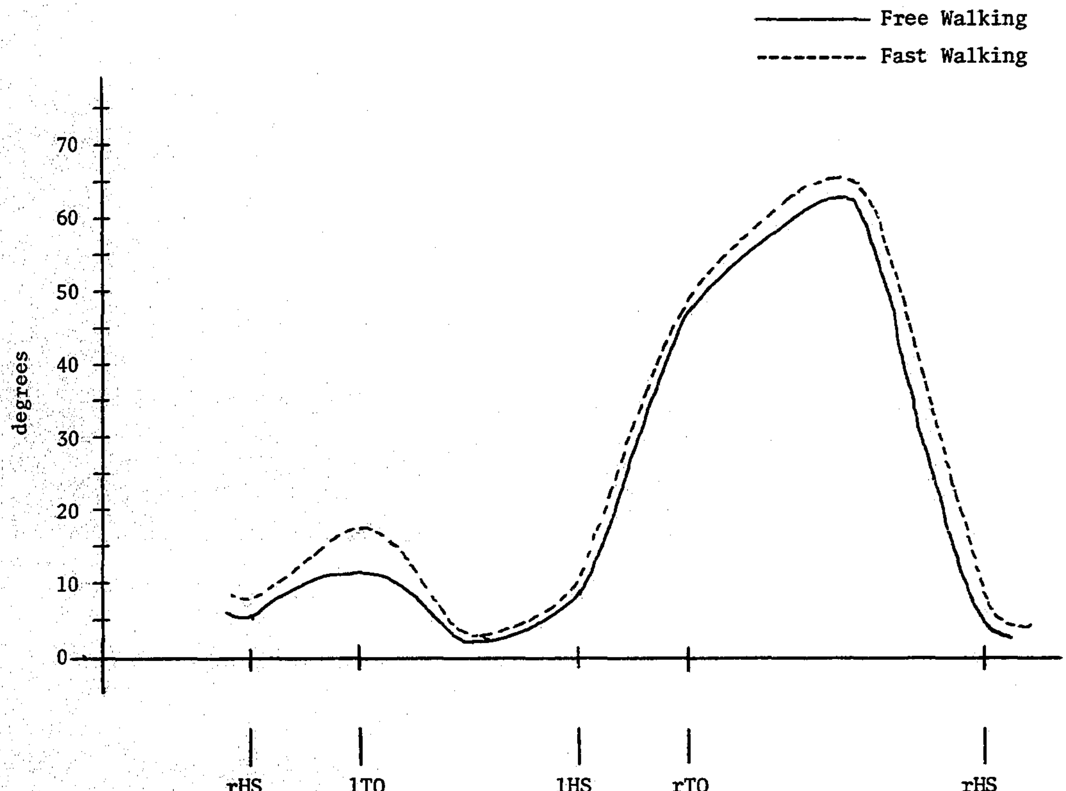


Figure 7. Mean patterns of sagittal excursion for the right knee, beginning at right heel strike (rHS). Neutral position (full extension) for the knee is 0. (1= left)

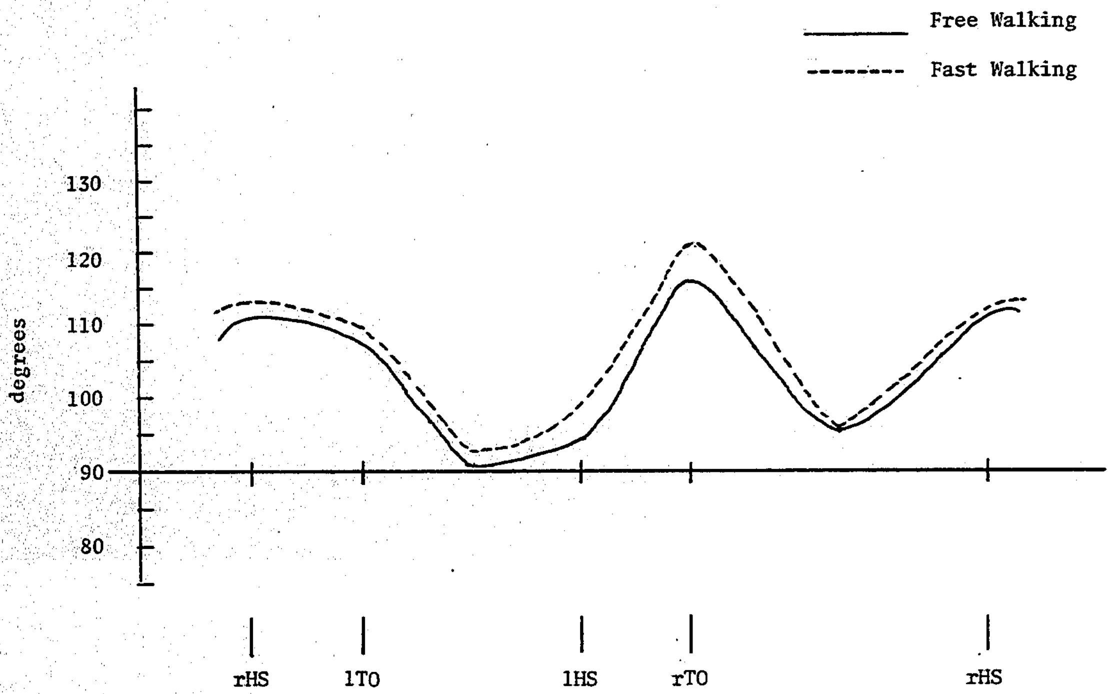


Figure 8. Mean pattern of sagittal excursion for the right ankle at free and fast walking speeds, beginning at right heel strike (rHS). Neutral position for the ankle is 90. (l = left)

Angular Velocity at the Hip, Knee and Ankle

The rate of change in position between two adjacent limb segments about a joint is the angular velocity that occurs at a joint. The values reported in this section are average values determined by dividing the total movement occurring at the joint by the elapsed time of the movement.

The average angular velocity that occurred during the flexion and extension phases at the hip are presented in Figure 9 for both the normal and fast walking speeds. The flexion angular velocity was calculated from the point of maximum extension at the hip that occurred near the end of the stance phase to the point of maximum flexion that occurred late in swing. This movement corresponds roughly with the swing phase of gait. Similarly, the extension angular velocity corresponds with stance. As expected, the angular velocity at the hip for the fast walking speed was quite higher than for the normal pace. The velocity of extension was slower than that for flexion, but higher for the faster walking speed when compared to the normal speed.

As demonstrated by Figure 7, there are four changes in direction (flexion to extension to flexion to extension) occurring at the knee during gait. The angular velocities associated with these changes at the knee are presented in Figure 10. Within each phase of gait, there was a flexion and extension component. As with the angular velocity at the hip, higher velocities were reached at the faster walking speeds, and higher velocities were reached during swing as opposed to stance.

Finally, the angular velocities occurring at the ankle for normal and fast walking paces are presented in Figure 11. Like the knee, there

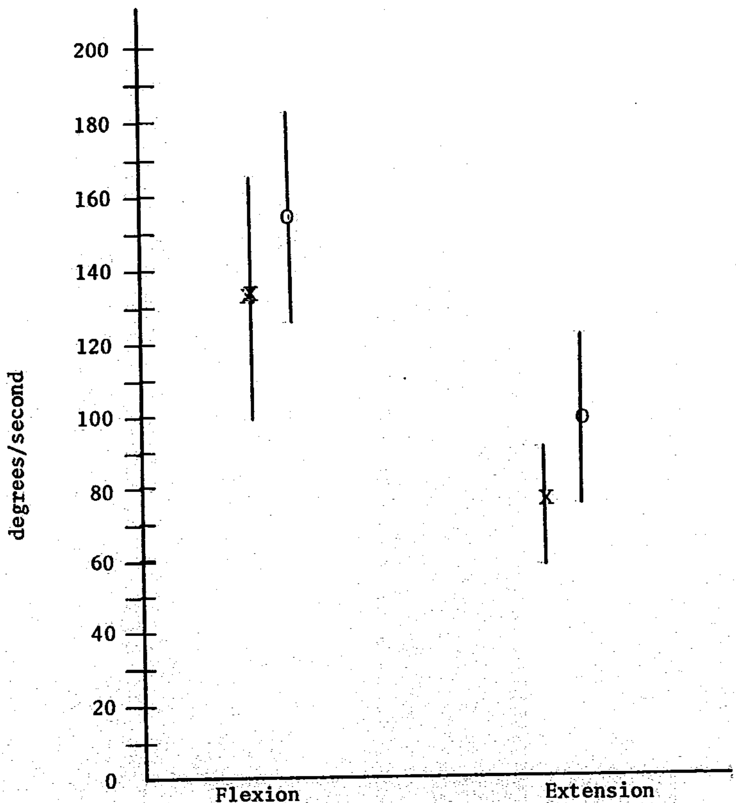


Figure 9. Mean angular velocities of the right hip at free (X) and fast (O) walking speeds. Solid line represents one standard deviation on each side of the mean.

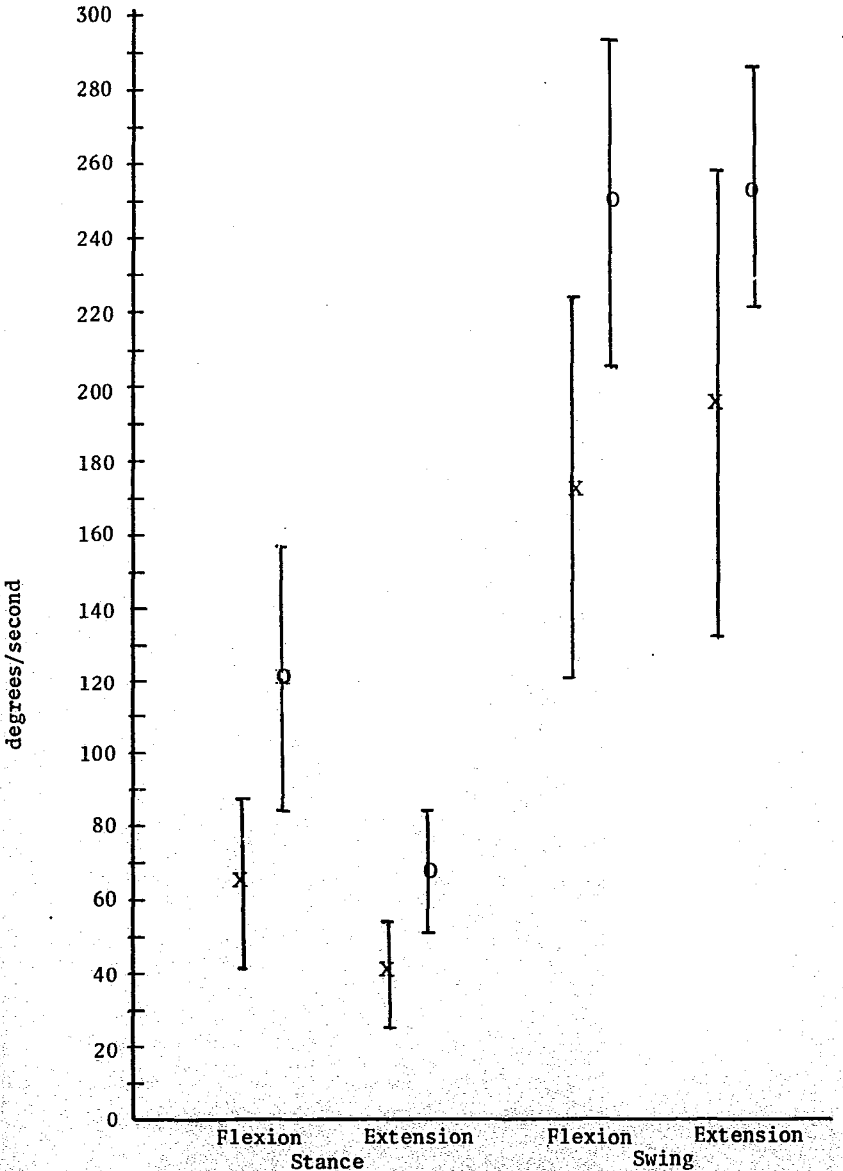


Figure 10. Mean angular velocities of the right knee at free (X) and fast (O) walking speeds. Solid line represents one standard deviation on each side of the mean.

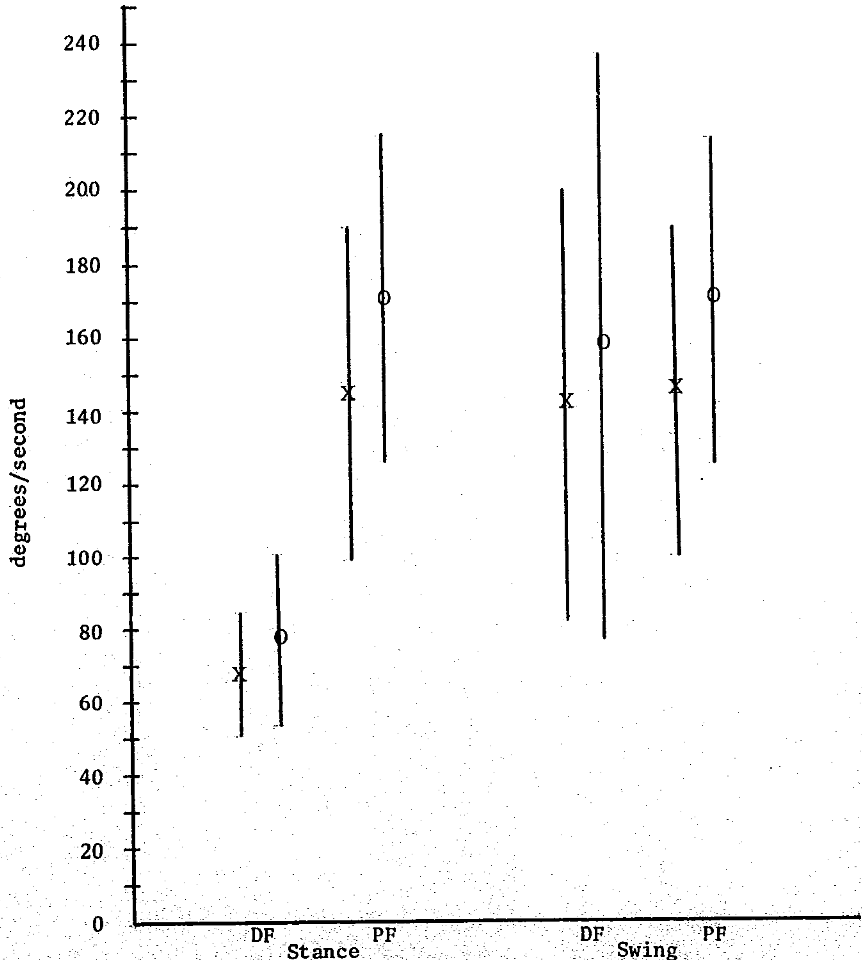


Figure 11. Mean angular velocities at the right ankle for free (X) and fast (O) walking speeds. Solid line represents one standard deviation on each side of the mean. (DF = dorsiflexion, PF = plantar flexion)

were two direction changes during stance and swing. There was little difference between the angular velocities that occurred at the ankle at each walking speed, except for the plantar flexion that occurred during stance and is associated with push off. The angular velocity of plantar flexion at the fast walking speed was higher than that at the normal pace for the same phase of gait.

The angular velocities obtained in this study are quite variable, but they do appear to be related to the speed of walking as Craik et al. (1980) have suggested.

Discussion

As discussed earlier in this thesis, there is a noticeable lack of a kinematic description of the walking patterns of elderly women. In the previous section of this chapter, many kinematic characteristics of a sample of healthy, elderly women were presented. In this section, these reported values are compared with other samples and the implications of rehabilitation and aging changes as related to gait will be considered. This section will be divided into the following discussions: (a) Velocity and Cadence; (b) Spatial Characteristics; (c) Temporal Characteristics; (d) Patterns of Lower Extremity Movement; and (e) Angular Velocity at the Hip, Knee and Ankle.

Velocity and Cadence

It has been well demonstrated that walking velocity decreases with aging (Ayalon & Van Gheluwe, 1975; Crowinshield et al., 1978; Finely et al., 1969; Graf et al., 1981; Imms & Edholm, 1979; Murray et al., 1969). The free walking speed of 97.0 cm/sec reported in the present study supports that conclusion when compared to the other normal values of 112 cm/sec (Robinson, 1977; Robinson & Smidt, 1981; Shores, 1980). It is interesting to note, however, that at the fast walking speed, the mean velocity reported here was 137.6 cm/sec, which compares favorably with Murray and associates reported value of 130 cm/sec for a sample of 30 women with an age range of 20 to 70 years (1970). It has also been reported that women tend to have a slower free walking speed than men (Finely & Cody, 1970; Murray et al., 1970). The normal value for a similar age range group of men as reported by Murray and co-workers (1969) was 118 cm/sec which tends to support the contention that these velocity differences at a free speed continue with aging.

The cadence value of 108.8 steps/minute for free walking falls within the range of reported "normal" cadences. Likewise, the fast speed cadence reported here of 134.1 steps/min is similar to the fast walking speed values reported by Murray and others of 138 steps/minute for men (1966), 132 steps/minute for older men (1969) and 146 steps/minute for women (1970).

Comparisons of velocity and cadence, as well as other temporal and spatial characteristics between this study and other studies of young and elderly women (Finely et al., 1969), women (Murray et al., 1970) and old men (Murray et al., 1969) can be found in Table 6.

Spatial Characteristics

The step length reported in this study is slightly shorter than that reported as a normal value, 56.75 cm. to 66 cm. (Robinson, 1977; Robinson & Smidt, 1981; Shores, 1980), or to the value of 78 cm for women as reported by Murray et al. (1970). Others have reported that the step length of the elderly tends to decrease (Ayalon & Van Gheluwe, 1975; Craik et al., 1983: Finely et al., 1969; Murray et al., 1970). The stride length (reported here) of 111.89 cm is similarly shorter than the range of average values and is as expected from an older sample. As with the values reported here for velocity and cadence, the fast speed values for stride length and step length begin to approach those values reported for normal walking speeds (see Table 6).

Many authors have reported that increased walking velocity is a result of increases in stride length or cadence (Andriacchi et al., 1977; Brunnstrom, 1972; Murray et al., 1966; Smidt, 1971; Smidt, 1974). The present study supports this contention, but it appears that much of the increase in speed is a result of increased cadence, as suggested by Crowinshield and co-workers (1978).

The stride length to body height ratio has been suggested by Jansen and associates (1982) as a method for controlling for the generally shorter stature of the elderly and of women. They reported a percentage value of 58-59% for both young and elderly male and female subjects walking at free speeds. The present study reported a value of 69.99% at free speeds for elderly women. Murray et al. (1969) reported values of 89% for men under 65, but only 79% for men over 65, while Foley and others (1979) reported that children had stride length to body height ratios of 89%. The wide disparity in values reported do not support Jansen et al. contention that there are not age related changes in stride length when compared to body height. It is suggested by the author that this expression for controlling for height differences

Table 6

Comparison Between Wiegand, 1983 and Finely et al., 1969: Murray et al., 1970; and Murray et al., 1969 of Selected Mean Kinematic Variables

Study	Finely et al. 1969		Murray et al. 1970		Murray et al. 1969		Wiegand 1983	
Variable	Women		Women		Men		Women	
	young adult	elderly	normal	fast	normal	fast	normal	fast
age	29.9	74.4	(range 20-70 yrs)		55.6		70.3	
height	166.1	155.7			171.0		159.9	
N	12	23	30		64		15	
step length (cm)	46.94	38.1					56.76	64.86
step width (cm)			6.90	6.90	9.0	10.0	2.99	1.8
stride length (cm)			133.0	152	146.0	172.0	111.89	123.65
foot angle (R/L)			5.1/6.4	4.4/5.8	8	6	95/6.6	8.5/8.7
velocity (cm/sec)	82	70	130	188	139.0	195.0	97.0	137.6
cadence (steps/min)	105.4	109.4	117	146			108.8	134.1
cycle duration (sec)			1.03	.82	1.08	.91	1.11	.90
stance time (sec)			.64	.47			.72	.56
swing time (sec)			.39	.35			.39	.34
double support (sec)							.32	.22
swing/stance (%)	55.6	49.5	63.0	74.0	62.0	73.0	55.1	61.0

may be reliable for comparisons within age and sex groups, and at similar velocities.

Murray et al. (1969) characterized the gait of elderly men as having "shorter and broader stride dimensions" (p. 176). The purpose of this stereotyped gait pattern was explained as increasing the base of support to aid in balance. At fast walking paces, the foot angle tends to decrease (Murray et al., 1966) to assist in altering the lateral stability to that of forward stability needed for fast walking. In the present study, there was little change in the stride dimensions between fast and normal walking speeds, and both were highly variable as suggested by Murray and co-workers (1970). In addition, the step widths expressed in this study are considerably smaller than those expressed by Murray and others (1970) for women and for old men (1969) (see Table 6). Other factors, however, tend to indicate the need for greater stability in the elderly during gait. These will be addressed in the next section.

Temporal Characteristics

The temporal characteristics of the gait of the elderly women in this study tend to support Murray and others' (1969) description of elderly gait as "guarded or restrained walking" (p. 176). The cycle duration time for normal walking in this study was 1.11 seconds which compares favorably with the duration times of 1.03 seconds for women (Murray et al., 1970), 1.08 seconds for elderly men (Murray et al., 1969), and 1.12 seconds for adult women (mean age, 27 years; Zuniga & Leavitt, 1973). In the present study, the time spent in swing was proportionally less than found in these other studies. This can be easily seen when the swing to stance ratios are compared. The present study found the swing to stance ratio expressed as a percentage to be 55.1%, while the other studies reported higher ratios: 63% for women (Murray et al., 1970), 62% for older men (Murray et al., 1969) and 64.7% for young adult women (Zuniga & Leavitt, 1973). Greene (1959) reported the mean time of swing and stance to be .40 seconds and .72 seconds respectively, a swing to stance ratio of 55.6% which compares more favorably to the present study. These values were determined from a large sample of subjects between the ages of 12 and 70 years, and no report was made for individual age groups.

In one single stride, there are two overlapping periods of double support. As stance time increases, or the swing to stance ratio decreases, the period of double support increases. During this period of double support, the center of gravity in the individual is at its lowest point (Brunnstrom, 1972) over the widest anteroposterior and lateral base of support possible, providing the most stable position during stance. Lateral stability is obtained through widened stride dimensions. Although the value for step width in this study is smaller than in similar studies (see above section), the "out toeing" of the foot widens the base of support laterally. By spending more time in double support during each stride, the amount of time in swing is decreased. During swing, the center of gravity is at its highest point and is over a narrow base of support, one foot. With less time spent in swing, and more spent in double support, the body spends less time in a precarious stability position.

Patterns of Hip, Knee and Ankle Motion

The patterns of hip, knee and ankle sagittal excursions as shown in Figures 9, 10 and 11, respectively, demonstrate the relative consistency in these variables over one's lifetime. At the hip, the total excursion of 45.2^{o} at normal speeds compares well with the values of 45 to 48^{o} by Murray and others for men, old men and women (Murray et al., 1964; Murray et al., 1966; Murray et al., 1969; Murray et al., 1970) and by Smidt (1971) for men. Somewhat surprising was the amount of hip extension found in the present study which was 18.9^{o}. This will be discussed along with the ankle motion.

The similar patterns of hip excursion at free and fast walking speeds is in agreement with other studies, with slightly more hip flexion found at the faster speed (Murray et al., 1964; Murray et al., 1966; Murray et al., 1969; Murray et al., 1970; Smidt, 1971). The total excursion of 46.9^{o} found here for fast walking is slightly lower than the 52^{o} (Murray et al., 1966) to 56^{o} (Murray et al., 1969) described. It was at the faster speed that Murray and others' statement of decreased hip motion in aging was supported by this study (1969).

In this study, the motion occurring at the knee in the sagittal plane during gait was remarkably consistent with previous studies, and again demonstrates consistency in knee motion with aging. The total motion at the knee at free speeds was from 0.7^{o} to 61.5^{o} of flexion and from 1.0^{o} to 64.7^{o} of flexion at faster speeds.

The pattern of motion at the ankle must be noted for its lack of dorsiflexion throughout the gait cycle, more so at the faster walking speed and for the larger than expected amount of ankle plantar flexion.

The pattern of motion at both speeds is again similar, and is consistent with previous reports (Finely et al., 1969; Murray et al., 1964; Murray et al., 1966, Murray 1967, Murray et al., 1969; Murray et al., 1970). Murray and others (1969) have reported less dorsiflexion in men 65 to 80 years of age, and it is this author's experience that the average amount of dorsiflexion available is much less in elderly women.

The increase in ankle plantar flexion at toe off corresponds with the higher than expected amount of hip extension found at the same time. There was not a corresponding increase in knee flexion which would absorb any of the transfer of extension at the ankle to the hip. At this point in the gait cycle, there is an extension moment about the hip which creates maximal hip extension, and an extension moment about the knee which supports the knee at or near complete extension (New York University, 1977). There is also a dorsiflexion moment about the ankle that is resisted by an intense contraction of the triceps surae to actively plantar flex the ankle to create the push off. At faster walking speeds, there is an increase in the plantar flexion at toe off, which also aids in increasing the step length (Murray et al., 1966).

Angular Velocity at the Hip, Knee and Ankle

Although the values reported for the angular velocity occurring at the hip, knee and ankle during gait appear to be highly variable, their importance lies in the establishment of "ball park" figures of such kinematic information. There have been few studies that have reported angular velocities for the lower extremities during sprinting and running (Bates, 1973; Elliot & Blanskby, 1979 a & b; Tolsma, 1979), however, these studies have expressed the angular velocity of a segment rotating about a fixed axis using absolute angular data (see Figure 4). The present study was unique in its presentation of the angular velocity that occurs at the joint between two adjacent body segments (see Figure 5).

At the hip, there was a single wave of flexion and a single wave of extension that occur roughly during swing and stance, respectively. The point of maximum hip extension occurs late in stance, and the point of maximal hip flexion occurs late in swing or immediately prior to heel strike (Smidt, 1971). With faster walking speeds, the range of motion from extension to flexion increased, while the time spent in swing and stance decreased. Therefore, it is not surprising that the angular velocity at the hip is faster at faster walking speeds, for both the flexion and extension phases. Likewise, because time spent in swing is always less than time in stance, the angular velocity of flexion was greater than that of extension.

At the knee, extension and flexion angular velocities occur which correspond with the "double lock mechanism" of the knee. At heel strike, the knee flexes to absorb the impact of the transfer of weight on to that limb. At slow paces that flexion occurred at 64.6^{o}/second and was controlled by the eccentrically contracting quadriceps. The knee then extended at a rate of 40.2^{o}/second. At the fast walking speed, the knee flexed at a much higher rate of 120.5^{o}/second. At this faster rate of eccentric quadriceps contraction, the muscle group is able to produce more force to absorb the tranfer of weight on to the lead limb. This is because of the characteristics of the force-velocity curve as described by Astrand and Rodahl (1977; see Figure 12). A rapid eccentric contraction of a muscle can generate more force than a slow eccentric contraction or any isometric or concentric muscle contraction. Likewise during swing, the motions of flexion and extension at the knee are concentrically controlled by the hamstrings and quadriceps groups respectively (Basmajian, 1974). Because those muscle groups are under minimal load at this time in the gait cycle, and through the transfer of momentum from the hip and ankle to the knee, the knee flexes and extends at a much higher velocity. The value reported here for knee extension during swing at the fast walking pace (137.6 cm/second) of 252.4^{o}/second compares favorably with the calculated value given by Wyatt and Edwards (1981) of 233^{o}/second at a velocity of 133 cm/second. These speeds have been presented as argument for "functionally rehabilitating" the knee at a speed that is similar to that used during the activity of walking (Parker, 1981; Wyatt & Edwards, 1981).

Finally, at the ankle two cycles of dorsiflexion and plantar flexion occurred. The trend here is also for increased angular velocities at the faster walking speed. During swing, the concentrically contracting pretibials dorsiflex the ankle to clear the toes (Basmajian, 1974) at rates of 141.8 and 158.1^{o}/second at the normal and fast walking speeds. During plantar flexion in preparation for heel strike and foot flat, the pretibials eccentrically contract to allow rates of 110.7 and 130.2^{o}/second at the ankle. Because the pretibials are under minimal load, faster eccentric angular velocities are not required to control the movement of plantar flexion during swing. During stance the triceps surae muscle group controls the dorsiflexion of the ankle eccentrically

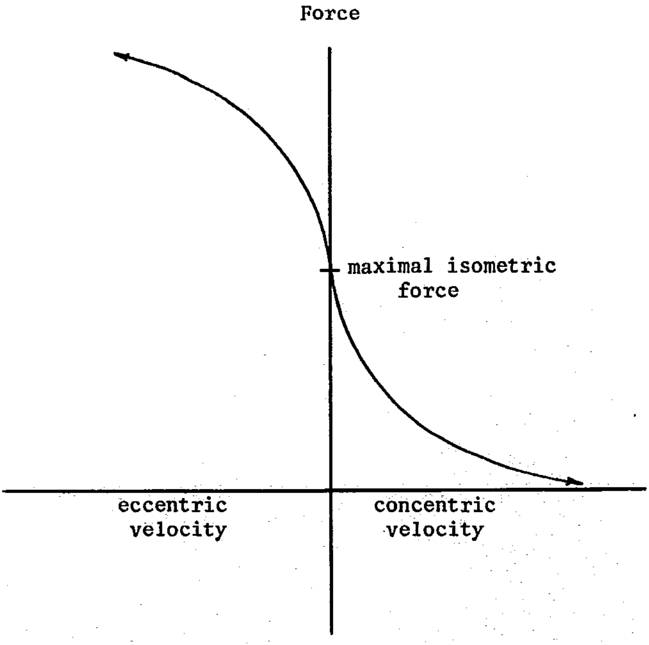


Figure 12. The force-velocity curve (Astrand & Rodahl, 1977, p. 104)

as the body passes over the stance limb at 68.4°/second and at 78.7°/second. At push off, the ankle plantar flexes through concentric contraction of the triceps surae at a rate of 145.3 and 170.5°/second to assist the hip flexors in actively advancing the limb through swing in preparation for another gait cycle.

CHAPTER V

SUMMARY

This study was designed to describe selected kinematic and temporal characteristics of gait in a sample of healthy, elderly women. This chapter is divided into the following sections: (a) Summary; (b) Impressions; (c) Implications; and (d) Recommendations for Further Study.

Summary

The walking patterns of fifteen healthy, elderly women were analyzed using cinematographic and pedigraphic means. The following temporal and kinematic variables of gait were analyzed at normal and fast walking speeds in effort to describe the gait patterns of this sample: (a) velocity; (b) cadence; (c) cycle duration; (d) stance time; (3) swing time; (f) double support time; (g) swing to stance ratio; (h) step length; (i) step width; (j) stride length; (k) foot angle; (l) stride length to body height ratio; (m) patterns of hip, knee and ankle sagittal excursion; and (n) hip, knee and ankle mean angular velocities. Mean values and standard deviations of these variables were presented for the free and fast speeds.

The observations of this study tend to support previous findings that report slower walking speed, decreased step and stride lengths, and increased temporal variables in the gait patterns of the elderly.

Patterns of lower extremity motion were found to be similar to those reported in younger samples and to those found in samples of elderly men. This study was unique in its presentation of relative mean angular velocities that occur throughout the gait cycle at the hip, knee and ankle.

Impressions

Within the constraints of this descriptive study, the following impressions of the gait patterns of healthy, elderly women were reached:

1. Many of the temporal and kinematic variables of gait in healthy, elderly women are substantially different from those of younger samples of men and women.

2. At fast walking speeds, many kinematic and temporal variables of gait approach similar values that describe the gait of younger samples.

3. The patterns of movement occurring at the hip, knee and ankle are similar in healthy, elderly women and other age and sex samples.

Implications

The characteristics of the gait patterns of healthy, elderly women as described in this study can be used for comparisons with other populations, or can be used as guidelines for rehabilitation of elderly women following injury, surgery or disease. The presentation of angular velocities that occur at the hip, knee and ankle can be used as guidelines for "functionally rehabilitating" those joints following musculoskeletal insult or injury.

Recommendations for Further Study

The following recommendations for further study are suggested:

1. A study enlarging the present sample of healthy, elderly women in attempt to be more representative of the population.

2. A series of studies to describe similar gait characteristics of other populations of men and women in the following living situations: (a) nursing home; (b) minimal care elderly apartment residences; and (c) mental health facilities.

3. A series of studies to describe the characteristics of gait in populations of men and women who are afflicted with Alzheimer's Disease, or following total joint replacement of the hip or knee.

4. Continued study on the angular kinematics of the joints of the lower extremity, including angular velocity and angular acceleration of these joints.

5. A study that provides normative values of joint motion and strength in elderly men and women.

6. A correlation study that relates the velocity of gait to the other variables of gait, especially to the angular velocity that occurs at the hip, knee and ankle.

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APPENDIX A

Informed Consent

INFORMED CONSENT

I understand that the purpose of this study is to learn more about the walking patterns of older, healthy women.

I confirm that my participation as a subject is entirely voluntary. No coercion of any kind has been used to obtain my cooperation.

I understand that I may withdraw my consent and terminate my participation at any time during the investigation.

I have been informed of the procedures that will be used in the study and understand what will be required of me as a subject.

I understand that all of my responses, written or oral, will remain completely anonymous.

I wish to give my cooperation as a subject.

Signed ______________________

Date ______________________

From:
Locke, LF & Spirduso, WW. Proposals that work. A guide for planning research. New York: Teachers College PRESS, 1976.

APPENDIX B

Personal Health History

Personal Health History Inventory

The purpose of this health history inventory is to screen potential participants in this study for any possible medical condition that may influence the walking pattern of each participant. This information will be held in the strictest confidence, and none of the responses given will be used in any form in the text of this study except to state that the participants were free from any medical influences on walking. As explained in the informed consent, participants may withdraw from this study at any time.

I have read the above statement and understand its meaning.
_____ (Please check)

1. Have you ever had a stroke? _____yes _____no

2. Have you ever had surgery for joint replacement? _____yes _____no
   If yes, which joint(s)? ____

   ____

3. Have you had any amputations of toes? _____yes _____no

4. Have you had any recent fractures? _____yes _____no
   If yes, of which bone(s)? ______________________________________

   ____

5. Do you have any numbness, tingling, burning, weakness, or any abnormal feelings in your legs? _____yes _____no
   If yes, explain ____

   ____

   ____

6. Are there any medical problems that you have had that you think may affect your walking? _____yes _____no
   If yes, what? ____

   ____

   ____

(Signed) ____________________________

(Date) ____________________________